The Canada Country Study:

Climate Impacts and Adaptation

NATIONAL CROSS-CUTTING

ISSUES VOLUME

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Environment
Canada

Canada

This is a component report of the Canada Country Study: Climate Impacts and Adaptation. In addition to a number of summary documents, the first phase of the Canada Country Study will produce six regional volumes, one volume comprising twelve national sectoral reports, and one volume comprising eight cross-cutting issues papers. This is The Canada Country Study – Volume VIII : National Cross-Cutting Issues Volume

Ce rapport est une partie composante de L'Étude pan-canadienne sur les impacts et l'adaptation à la variabilité et au changement climatique. En plus de quelques documents sommaires, la première phase de L'Étude pan-canadienne produiront six tomes régionaux, un tome comprenant douze rapports nationaux au sujet des secteurs sociaux et économique, et un tome comprenant huit papiers concernant les questions intersectorielles. Ce rapport est L'Étude pan-canadienne – Tome VIII: Questions Intersectorielles.

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Climate change is one of Canada's biggest challenges as we head toward the millennium. If we meet that challenge, it will ensure the continued health of our planet. Otherwise future generations may suffer.

We know that the science on climate change is sound. Scientists from around the world agree that our climate is warming at an increasingly rapid rate because of higher volumes of greenhouse gases entering the atmosphere.

The Canada Country Study provides another important piece of knowledge on how climate change could impact our communities across the country. Not only does it alert Canadians to what scientists expect will happen, it suggests ways in which Canadians can adapt to changes in climate. The Study also provides a critical perspective for charting Canada's future.

The Canada Country Study helps us understand how to capitalize on economic opportunities and enhance our social well-being as we face this challenge. In some cases, we have the answers. In others, further study and consultation is required to forge the best strategies. Much work remains to be done.

Overcoming the problem of climate change will require a concerted effort. It is imperative that Canadians are well-informed when preparing to respond to the potential impacts of this phenomenon. Once Canadians understand the implications, I am confident that they will take action to safeguard our environment, health and economy for the benefit of our children and grandchildren.

I would like to thank the many individuals who have contributed to the Canada Country Study. Through your efforts, Canadians are better informed about how they can take greater responsibility in ensuring our continued prosperity.

Christine S. Stewart

Executive Summary

INTRODUCTION

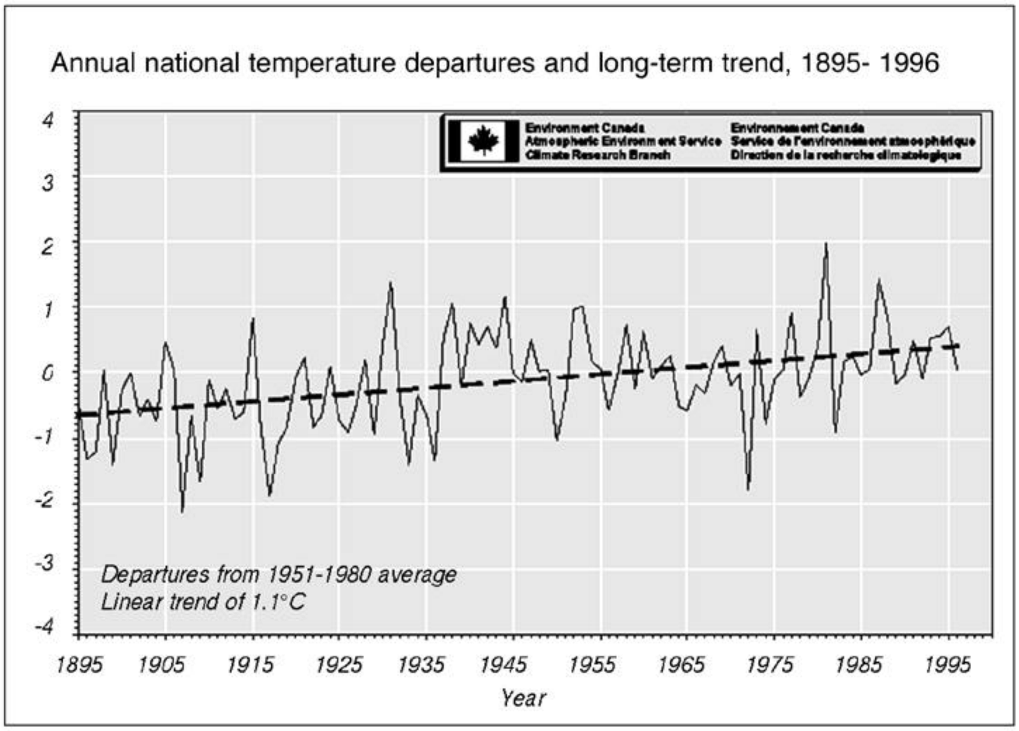
The scientific and technical results of the assessment phase of the Canada Country Study (CCS) are published in eight volumes - six regional volumes (Arctic, Atlantic, Ontario, Pacific and Yukon, Prairies, and Québec), a national sectoral volume consisting of twelve papers and a cross-cutting issues volume consisting of eight papers. The current document - the Executive Summary of the cross-cutting issues volume - provides a digest of the material in the eight cross-cutting papers (costs of adaptations and residual impacts of climate change, extreme events, integrated air issues, extra-territorial issues, domestic trade and commerce, changing landscapes, sustainable development and northern subsistence and land-based economies).

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.

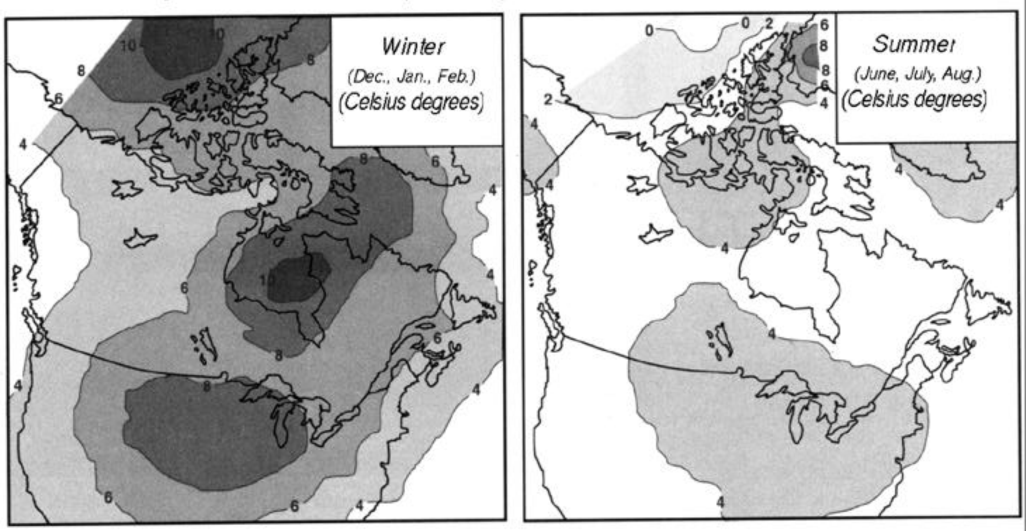
In order to understand how the world's climate may respond, sophisticated computer models called general circulation models (GCMs) are used to simulate the type of climate that might exist when global concentrations of greenhouse gases are doubled from pre-industrial levels. As an initial focus has been 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 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.

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".



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

CROSS-CUTTING ISSUES LINK TO CLIMATE CHANGE

Introduction

The studies comprising the Canada Country Study indicate the possibility of significant implications for Canada as a consequence of projected changes in climate. Our climate is variable and Canadians and the economy react to it on different temporal and spatial scales. In addition to regional and sectoral impacts, there are a number of concerns related to climate change that are multidisciplinary in nature and broad in scope. These are called cross-cutting issues and highlights of the key findings are identified in this executive summary.

Costing the Adaptations and Residual Impacts of Climate Change

The issue of identifying the costs of impacts and adaptations to climate change was highlighted as an important aspect of the CCS. Very few studies exist which definitively quantify the costs of adaptation to, and residual impacts from, the projected climate change for Canada. There are methodological issues regarding attempts to assess the various impacts of climate change and account for them in monetary terms. Values cited by the IPCC of some percentage of GDP (i.e. 1-2% of GDP assuming a doubling of atmospheric carbon dioxide by 2050 and a mean global warming of 2.5^{o}C) reflect predominately estimates for the U.S. and extrapolations thereof. There are other methodological issues regarding aggregation of costs across individuals, sectors and regions, as well as across time, and the disregard for the cost of adapting to a changing climate and for the social value of most non-market goods and services. Finally, there are many uncertainties in the timing and magnitude of climate change that affect the results.

Extreme Weather Events

Small changes in the mean climate or climate variability can produce relatively large changes in the frequency of extreme events with a small change in variability having a stronger effect than a similar change in the mean. At this time, there remains considerable uncertainty regarding projections of changes in flooding and other extreme events, the implications, should these changes occur, warrants consideration of the possible impacts.

Storms: It is not clear at this time whether extra-tropical storms will become stronger or weaker under climate change. Intuitively, however, one would expect more frequent and more intense convective activity in a warmer world. In addition, climate models suggest an increase in the probability of intense precipitation with increased greenhouse gas concentrations. Changes in the number or geographic distribution of convective storms (severe thunderstorms producing hail, lightning, tornadoes, heavy rain and strong winds), however, remain a difficult issue for GCMs due to their small scale.

Extreme temperature events: In a warmer climate, it is expected that heat waves would become more frequent, while cold spells would become rarer. 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.

Floods and droughts: New results reinforce the view that variability associated with the enhanced hydrological cycle translates into prospects for more severe droughts and/or floods in some places and less severe droughts and/or floods in other places. In those areas where the length of dry spells and the severity of droughts are projected to increase, concerns are heightened regarding potential impacts on water availability and vegetative growth. Conversely, where precipitation intensity increases or other climate factors increase the potential for flooding, 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 precipitation, and spring ice jams on rivers is a major concern.

Integrated Air Issues

Ecosystems, agriculture, human health and other sectors and regions will not be impacted by climate change acting in isolation, but also by other atmospheric conditions such as stratospheric ozone depletion, acidic deposition, smog (mainly ground-level ozone), suspended particulate matter and hazardous air pollutants. However, atmospheric scientists and decision makers in Canada have largely addressed these issues individually resulting in single-issue policies such as the Montreal Protocol to ban stratospheric ozone-depleting substances.

It is now recognized that climate change has the potential to exacerbate the other air issues. Excess greenhouse gases and projected higher temperatures can be expected to alter atmospheric chemistry, especially through interactions between the key greenhouse gases (carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), chlorofluorocarbons (CFCs) and ozone (O_3), as well as the most important oxidants (hydroxyl radical (OH) and hydrogen peroxide (H_2O_2)), and other trace gases/particles that are involved in one or more of the other five air issues.

Examples of effects of climate change on the other air issues:

Stratospheric ozone: Carbon dioxide contributes to modification of the temperature structure of the atmosphere, including a projected cooling of the higher atmosphere (i.e. the stratosphere). Normally, less ozone is destroyed if the stratosphere is cooler, so the effect of increased atmospheric CO_2 is to decrease ozone depletion. However, increasing atmospheric CO_2 concentrations are expected to cause further cooling of the lower stratosphere and this could enhance the formation of polar stratospheric clouds (PSCs) in some regions, convert potential ozone-depleting species to their active forms and, thereby, potentially intensifying ozone depletion.

Acidic deposition: Climate warming would increase the physical and chemical transformation rates of primary and secondary acidifying materials. The general circulation of the atmosphere and precipitation patterns are expected to change, and the overall tropospheric reactions and instability would change affecting the acid rain issue. These changes are expected to alter the transport trajectories of acidifying gases and the subsequent deposition patterns and regional concentrations. Summertime emissions of sulphur and nitrogen compounds from power plants could increase because of increased demand for air conditioning of buildings and automobiles. Hydrogen peroxide (H_2O_2) is also produced, which is a strong oxidant and catalyst in the production of sulphuric acid, thereby increasing the acidic deposition.

Smog: Natural and anthropogenic emissions of several pollutants (e.g. NOx and VOCs) and particulate matter are sensitive to weather conditions. For example, VOCs released from fuel tanks, solvent use and chemical plants are more volatile at high temperatures. Also, nitrogen compounds emitted by soil microbes and VOCs from vegetation are temperature dependent. Climate change is also expected to increase the potential for smog episodes as a result of increased frequency of hot summer days.

Conversely, other air issues also have effects on climate change:

Stratospheric ozone: Decreased ozone in the stratosphere results in reduced flux of ozone to the upper troposphere where it acts as a greenhouse gas. A thinner ozone layer allows more UV-B radiation to penetrate into the lower atmosphere, where it increases the production of OH radical (a primary sink for methane, a greenhouse gas about 20 times more powerful than CO_2). Thus, destruction of stratospheric ozone could lead to a decrease in the rate of climate warming.

Acidic deposition: Precursors of acidic precipitation (SO_2 and NOx) oxidize in the atmosphere and form sulphate and nitrate aerosols. These particles reflect some solar radiation back to space, causing negative radiative forcing (climate cooling).

Suspended particulate matter: Some aerosols such as soot are efficient light absorbers and cause slight warming, the net (direct and indirect) global mean radiative forcing of anthropogenic aerosols is negative and the magnitude is significant. Some studies suggest that, on a global average, anthropogenic sulphate particles mask about 25% of the warming caused by CO_2 and other GHGs.

Extra-Territorial Influences

Most of the studies highlighted earlier and in the other volumes focused on the potential climate change impacts in Canada. Canada, however, is a member of a family of nations and Canadians have interests and connections to people and places across the globe. Therefore, the effects of climate change beyond Canada's borders also needs to be considered. Issues of international trade, security (both food security and military security) and international migrations are highlighted.

International Trade: The effects of climate change on international prices and supply and demand could have as much effect on Canada as the first and second order impacts of climate change in Canada itself. Although climate change will affect all sectors of the economy, almost all of the research on climate and international trade has focused on the agricultural trade. A number of models predict that Canada's position on the world market as a leading agricultural exporter will be improved. This is both because climate changes are projected to improve overall yields in Canada and because Canadian producers will fare better than their competitors in places such as the American Great Plains. All of these model outcomes, however, are sensitive to assumptions about levels of adaptation, costs for which are not generally accounted for in these projections, and assumptions about the effect of CO_2 fertilization.

The possible effects of climate change on other sectors of international trade such as forestry, fisheries and energy are poorly known. However, since Canada relies heavily on exports from these production sectors, Canada's trade balance is vulnerable to the projected changes in climate.

International Relations: Future climate change is projected to affect Canada's foreign relations in a number of ways. If, as most people project, it is the developing nation's that are most severely affected by anthropogenic climate change, there will likely be an increase in tensions between developed and developing countries.

Climate change could also create new sources of tension within the international community. Warmer temperatures are projected to exacerbate problems of international air pollution. Transboundary water management will also be affected. For example, in the event of long-term drought in the central

American states, a scenario predicted by many GCMs, Canada can expect to face increasing pressure from the US for southern diversions of water. The melting of sea ice in the Northwest Passage may makes this waterway navigable. Although Canada has long claimed the Northwest Passage as an internal waterway, this has never been recognized by all members of the international community.

The management of international common property resources is also climate sensitive and thus potentially affected by climate change. For instance, the productivity of Pacific salmon is strongly tied to the pattern of climate and ocean circulation in the North Pacific. In the past, changes in this climatic regime have produced both dramatic declines and increases in catches. When pressures have been placed on the resource, there have been conflicts among fisheries stakeholders, complicating international efforts to manage this resource sustainably.

Food and Military Security: Canada's geopolitical position buffers it from most military offenses, and its abundant agricultural sector and peaceful border with the United States insulates it from the vagaries of climate change-induced variations in food production. Although there is considerable uncertainty as to the nature of changes in extreme events as a result of climate changes, projected changes in the frequency or severity of these events could lead to an increase in the demand for domestic security forces to assist civilian authorities in the face of natural disasters.

Also chronic, intra-national and ethnic conflicts such as in Bosnia and Rwanda affect Canada and Canadians a number of ways: by making the world a more dangerous place; by spilling over the boundaries through acts of international terrorism; by escalating into wider conflicts; by increasing demands for Canadian participation in peace-keeping and diplomatic missions; and by contributing to internal and international refugee problems.

Environmental Migrations: The effect of climate change on environmental migrants coming to Canada is unknown. Estimates of the number of refugees generated by projected changes in climate range as high as 150 million, though only the most mobile of those could be expected to make their way to Canada. This enhancement of the number of international refugees would put an unprecedented strain on Canada's refugee assimilation mechanisms, though the exact cost would be impossible to quantify at this time.

Domestic Trade and Commerce

Research of the impacts of Canadian domestic trade under climate change is quite meager and statistics about interprovincial trade are generally of poor quality. As a result, potential impacts in this area are quite speculative in nature.

Domestic trade and commerce is likely to intensify with northern regions of Canada possibly becoming the new frontier. Large population centres in the south (i.e. markets and service centers) are not likely to change location as manufacturing activities are less dependent on natural resource location than on manpower cost and availability of services. Projected impacts on natural resources could result in shifts or movements of centres of activity (e.g., agricultural opportunities, and harvesting and processing centres in the forestry and fisheries industries). These changes could lead to shifts in people and commerce within and across regions as opportunities arise and production potentials change. Concerns are being raised regarding the sustainability of vulnerable communities and industries due to projected changes in the availability of water as a result of projected changes in climate.

Changing Landscapes

Broad landscape-scale effects of climate change should be anticipated for Canada. These impacts are expected to be driven by the resulting forces of: altered and more variable hydrology, melting of permafrost; rising sea levels, and the shifting and altering of ecozones. Such broad-scale landscape alterations have serious implications for hydrology, wildlife, biodiversity, infrastructure and transportation, economic activities, cultural values and lifestyles, and the well-being of Canadians.

Sustainable Development and Climate Change

At first glance it might seem odd to suggest that climate change and sustainable development represent very different ways to think about global environmental problems. This has led to difficulties in establishing strong working linkages between the research and policy communities, both here in Canada and at the international level. Within the climate change and sustainable development research communities, different visions of future development are being generated. This has led to problems in several key areas such as: differences in scenarios of emissions, economic patterns, etc.; unequal treatment of mitigation (abatement) and adaptation (vulnerability) aspects of climate change; ethical concerns raised by developing countries, and; questions about the relevance of science to policy making on climate change and sustainable development. These visions have very different dimensions, and as long as they remain separate, there is a risk of significant errors in the assessments of costs and benefits of responding to climate change.

Northern Subsistence and Land-Based Economies

Northern indigenous peoples, already one of the more vulnerable segments of Canadian society, would be affected by ecosystem shifts caused by climate change. Very little is known about the possible impacts climate change might have on the northern economy which is comprised of three sectors: the wage sector, transfer payments, and subsistence harvesting. The types of changes anticipated to accompany climate change as described, however, are likely to challenge severely the capacity to adapt of many subsistence societies. The effects are likely to be wide-spread, with regional variations, and attempts to modify or prevent events/effects for vast northern regions are not likely to be viable once the impacts begin to be felt.

Climate change may affect the distribution of animals and other resources on which subsistence and land-based economies are based. Under conditions of projected climate warming, multi-year ice and large areas of discontinuous permafrost are expected to disappear, precipitation is expected to increase on average by 20 to 30% and the length of the annual frost-free period would increase. Terrestrial, aquatic and marine mammals in the Arctic and subarctic live in a marginally supportive physical environment and small changes in conditions could have major impacts on their health and survival. The transition in the north to settlement life over the last forty years has reduced, though not eliminated, northern peoples' options for traveling to new areas in response to animal migrations. Loss of waterfowl and fish populations would have serious implications for the subsistence economy because these resources are not likely be replaced by other wild food sources.

Thermal expansion of the ocean coupled with melting glaciers and ice sheets are projected to raise mean sea levels about 50 cm from the present to the end of the 21st century. Such changes in sea level are expected to have effects on the Arctic's coastal settlements, and costly measures may be needed to protect them from flood damage, if indeed they can even be protected.

Climate change may affect the validity of traditional knowledge and local adaptations. For example, hunters, fishers and trappers depend on detailed local knowledge of animal distributions and behaviour, snowfall patterns, and timing of freeze-up and break-up. Climate change can play havoc with the use of such knowledge by making locational knowledge unreliable.

Climate change may interfere with wildlife harvests, thus resulting in diet-related problems and medical costs through elevated levels of cardiovascular disorders, diabetes and vitamin-deficiency disorders. As the consumption of fresh meat in the diet has declined, the nutrients formerly provided by this diet are not been replaced by the new food choices. This is thought to be the major mechanism behind the virtual epidemic of obesity, cardiovascular disorders, and diabetes mellitus among northern populations. The pursuit of subsistence harvesting demands a high level of physical fitness. As members of subsistence societies fall prey to modern diseases they are less able to hunt for wildlife and so contribute to their family's welfare.

A warmer climate would result in melting permafrost, the thawing of wastes and greatly increasing the possibility of contaminating water resources. The increase of ultraviolet-B radiation caused by thinning of the ozone layer in the Arctic stratosphere is a real threat to human and animal health as well as to productivity of terrestrial and marine vegetation.

SCIENCE GAPS AND RECOMMENDATIONS FOR FURTHER RESEARCH

On a national basis, we need to fill science gaps. We need to predict with higher confidence the impacts of climate change on Canada's landscapes, on physical and biological processes, and on our socio-economic sectors so that we can develop adaptation strategies to deal where possible with such impacts. To put this into a societal context, we must turn such physical and biological changes into socio-economic values (costs and benefits).

Costing Research: Develop a true benchmark estimate of the costs over time of adaptation to, and residual impacts from, climate change for Canada (e.g., estimating a time profile of marginal costs of CO_2 emissions).

Extreme weather events: Develop and maintain databases related to the costs of and adaptations to natural hazards; develop climate change scenarios based upon real case studies of extreme events, as well for assumed reductions in the return periods of these events; assess how Canadians perceive their risks related to natural hazards and climate change in order to better understand how adaptive decisions are made.

Climate Change and Other Air Issues: Conduct an integrated assessment of the climatic effects of all gaseous and particulate emissions, the physical and chemical processes involved, the effects on socioeconomic systems and ecosystems, and the various control strategies on all of the air issues; assess the most cost effective and socially acceptable control measures for each air issue; assess the possible effects of other air issues on the frequencies and intensities of extreme weather events.

Climate Change and Other Non-Climatic Factors: Use an integrated approach to study the impacts of multiple stresses on human health, socio-economic sectors, and ecosystems. Studies should consider climate change as one of many factors which determine the overall response. For example, projected population changes and associated changing land-use and air and water quality will continue to influence the health and existence of natural and human systems. Impacts and adaptation studies should include consideration of competing interests, current policies and boundary demands.

Indirect, extraterritorial effects: Assess the indirect links between climate change and international trade regimes and policies on specific economic sectors in Canada such as agriculture, forestry, fisheries and energy; conduct further work on the effects on Canada of environmental refugees displaced by climate change.

Domestic trade and commerce: Assess how patterns of human settlement in Canada would be affected by changes in domestic flows of trade and commerce under climate change; improve input-output analysis capabilities with availability of better quality provincial economic statistics.

Changing landscapes: Develop and maintain databases on critical variables to improve prediction of climate change impacts on regional ecosystems. Variables required include seasonal averages and the degree of between-year variability in: temperature, precipitation, wind and radiation; the intensity and probability of extreme events including drought, storms and floods; snow cover distribution, depth, extent and duration; precipitation at varying elevations; the probability of short-term anomalies such as late spring/summer frosts, mid-winter temperature or rain events, and intense spring storms; surface heat fluxes and UV-B irradiation; sea-level pressures.

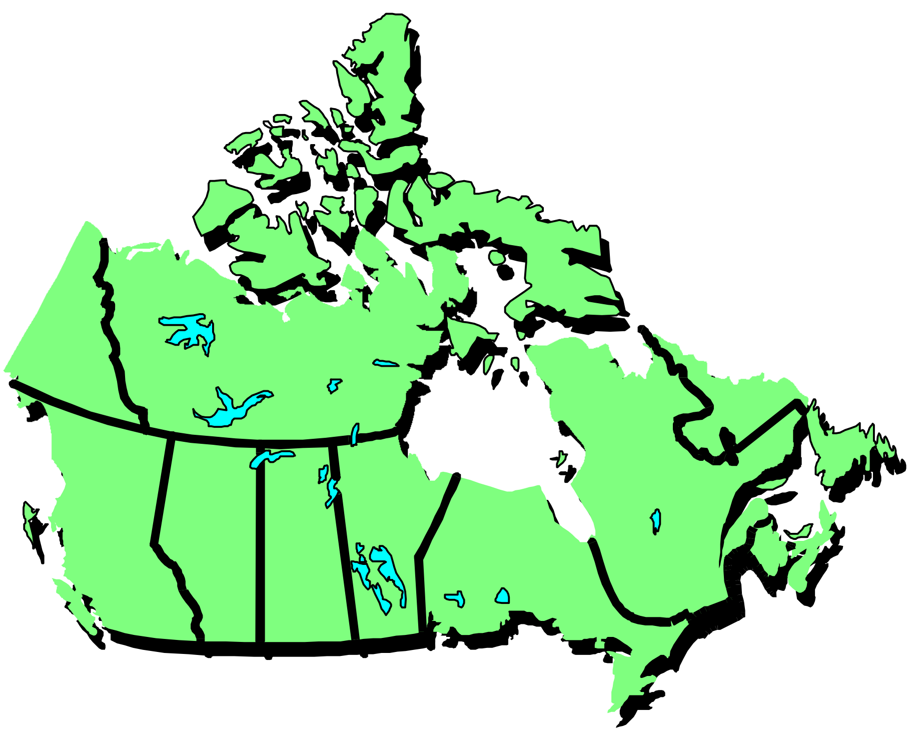
Sustainable development and climate change: Ensure that climate change and sustainable development is explicitly included in their respective research agendas; conduct integrated assessments of climate change that incorporate alternative methodologies that complement global scale integrated assessment models.

Northern subsistence and land based economies: Conduct research to link available biological/ecological information on the impacts of climate change to local resource use and the northern economy; determine the effects of non-linear, sudden changes in climate on northern regions; differentiate between the potential effects of climate change in the north from the cumulative impacts of large-scale development projects; determine the limits to adaptability in northern subsistence economies; conduct research to develop adaptive management strategies with emphasis on the resilience of social and ecological systems, and on flexibility to respond to uncertainty and largely unpredictable climate change; conduct research to study the issue of the health of northern populations relative to the implications climate change has for the long-term availability of country foods; improve knowledge on the epidemiology of climate change for the north; develop methodologies to estimate costs of increasing dependence on financial government support, and the costs of facilitating adaptation options to encourage self-reliance.

CHAPTER ONE

COSTING CLIMATE CHANGE: THE ECONOMICS OF ADAPTATIONS AND RESIDUAL IMPACTS FOR CANADA

Dale S. Rothman[1], David Demeritt[2], Quentin Chiotti[3] and Ian Burton[3]



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EXECUTIVE SUMMARY

Climate change is likely to have a wide range of impacts for Canada. A number of these will be amenable to adaptation, which can reduce negative impacts; others may present beneficial opportunities. Previous estimates indicate that Canadians spend on the order of 1.5-2.0% of GDP on adapting to current climate. The IPCC has presented a tentative estimate that, if the equilibrium atmospheric concentration of CO_2 were double that of pre-industrial levels, with an expected temperature increase of 2.5^{o} C, the GDP of present-day economies would be lower by 1-1.5% in developed countries and 2-9% in developing countries. Almost no consideration of specific impacts on Canada were used in developing these estimates. Furthermore, there are a number of concerns related to the estimates, particularly the lack of consideration of the transient costs as societies adapt to a changing climate.

No new monetary estimates for the costs of adaptations to and residual impacts from climate change for Canada are presented in this chapter. Several issues involved in developing monetary estimates and the appropriateness of traditional economic methods for evaluating a long-term social and environmental concern, such as climate change, are discussed, as are the requirements for further work in this area.

INTRODUCTION: PURPOSE OF THIS REPORT

There are three main categories of costs generally associated with climate change. These are the costs of stopping or slowing the rate of change, commonly referred to as mitigation; the costs of adapting to those climate changes that are not avoided by mitigation; and the costs of the residual impacts after adaptation.[1] Although these are usually referred to as costs, it must be remembered that, in each case, the net effect may actually be beneficial, in which case we may speak of benefits. Policies for responding to climate change should be based, in part, upon the best available understanding of the extent and distribution of these costs and benefits.[2]

The purpose of this report is to provide a synthesis of the current knowledge on the latter two categories; the former is being dealt with in separate reports. We will explore these costs assuming that no mitigation is undertaken. This has been referred to as the costs of inaction, but this is misleading as on-going adaptation also constitutes action. Therefore, we prefer to be more explicit and refer to the costs of adaptation to, and residual impacts of, climate change.

The difficulties of pursuing this exercise are well recognized. These were perhaps best stated by William Nordhaus (1991), one of the first persons to undertake a similar effort – “We now move from the *terra infirma* of climate change to the *terra incognita* of the social and economic impacts of climate change.” The need to do so are also recognized, however. In a recent article

[1] One other cost has been mentioned. This is the cost to Canada of walking away from the table in the international negotiations as part of the Framework Convention on Climate Change. Although these are likely to be significant, they are not the focus of this paper.

[2] A Canadian action program for the reduction of greenhouse gas emissions (mitigation) based on voluntary efforts is already in place. International negotiations towards a global agreement on targets and schedules for mitigation are also continuing, which may have a significant impact on Canada.

in the magazine *Nature* on valuing ecosystem services that speaks to many of the same issues we will be dealing with here, Costanza, *et al.* (1997) express it this way:

> although ecosystem valuation is certainly difficult and fraught with uncertainties, one choice we do not have is whether or not to do it. Rather, the decisions we make as a society about ecosystems imply valuations (although not necessarily expressed in monetary terms). We can choose to make these valuations explicit or not; we can do them with an explicit acknowledgment of the huge uncertainties involved or not; but as long as we are forced to make choices, we are going through the process of valuation.

Thus, it should not surprise the reader that we spend a significant amount of time discussing topics related to the measurement of the costs presented in this report and elsewhere. This is also, in part, because very little empirical work has been done on estimating the costs of adaptation to, and residual impacts from, climate change. Furthermore, the bulk of this work has been done solely for the United States and has not been comprehensive in its consideration of all aspects of human and natural systems.

We also wish to caution the reader to be very careful in how they interpret and use the numbers presented here and those they might find elsewhere. This is particularly important for those who might wish to compare these to the costs of mitigation. David Pearce (1997), lead author of the IPCC Working Group III (IPCC WGIII) chapter on the costs of climate change impacts, notes that the estimates of the costs of impacts and the costs of mitigation and emission control presented in IPCC WGIII "were never comparable," because the "cost of control figures relate to emissions stabilization, not to avoiding (the impacts and adaptation costs of) $2xCO_2$." Thus, it would be inappropriate simply to compare the estimates we provide in this report with most, if not all, of the estimates of the costs of control. They are like apples and oranges, based on different measures, assumptions, and methods.

Finally, as Munasinghe, *et al.* (1996) note, “application of cost-benefit analysis (CBA) to climate change is difficult because of the global and intergenerational nature of the problem. It is further complicated by the difficulties of valuing some categories of ecological, cultural, and human health impacts. . . . the most important benefit of applying CBA may be the *process itself* rather than the predicted outcome.” We agree with the sentiment that what is most important is process whereby due consideration is given to both the potential effects of a changing climate and the potential costs of avoiding a changed climate, but would argue that this process needs to be much broader than has been employed in traditional CBA.

The next section of this report provides a more complete discussion of what we mean by adaptations to, and residual impacts from, climate change. This is followed by a summary of some of the major issues that must be considered in any attempt to estimate the costs of adaptation and residual impacts. We then present a summary of existing estimates, both for Canada and other regions of the world. This is followed by a discussion of how Canada may be affected by adaptations and residual impacts outside of its boundaries. Finally, we present our conclusions and discuss possible next steps.

ADAPTATIONS TO, AND RESIDUAL IMPACTS OF, CLIMATE CHANGE

The focus of this section is to broadly define the costs of the impacts from climate change, the costs of adapting to climate change, and the residual costs that occur despite adaptive actions. Before doing so, however, it is important to recognize that there are many aspects of climate change and variability that affect human and natural systems.

Because the science of climate change has emphasized the increase of global mean temperature, it is often assumed that the main impacts will also be related to mean temperature change. This is far from the truth, as the relationships between climate change upon human and natural systems is much more complex. There are different aspects of temperature that go beyond changes in means. These include spatial and seasonal distribution, inter-annual variability, and extremes. Furthermore, there are many other elements of climate that can be just as important for environment and economic activity as temperature. These include changes in precipitation, length of seasons, sea level rise, increased iceberg activity, and the frequency, severity and duration of extreme events. Of particular concern is that the risk from extreme events is increasing. While recent extreme events have yet to be conclusively linked to climate change, damage has been extensive, both on a global basis and across Canada (Brun 1997).

What is Meant by the 'Impacts of Climate Change'?

The impacts of climate change are generally defined as the adverse consequences of not reducing greenhouse gas emissions. It should be noted, however, that there are also potential benefits from climate change. The impacts are generally thought of in terms of a chain of consequences. The first order impacts include the direct consequences for other environmental processes closely linked to the atmosphere. This includes run-off, stream flow, lake levels, groundwater, soil moisture, sea level, and, in fact, all stages of the hydrological cycle. Other first order impacts include the distribution of the permafrost, of natural ecosystems including wildlife, forest species, and so forth. First order impacts are pervasive. They include numerous natural environmental processes and conditions.

Second order impacts include the further or next step consequences, especially on those economic sectors that are most closely linked to the environment such as agriculture, forestry, recreation and tourism, waterborne transport, hunting and fishing, hydroelectric power production, and human settlements on lakeshores and coasts. These second order impacts may take many different forms. Take for example the case of the forest and the forest-products industry. In a changed climate some forest species will no longer be able to survive in their present range or location, because of changed conditions of temperature, seasonality, and rainfall. Other first order impacts may have second order consequences for forests. Changes in the distribution of insect pest and disease vectors may result in the loss of forest resources. Drier conditions may result in more forest fires. Thus, the major concern about the possible loss of the boreal forests in Canada is due to a combination of first order and second order impacts. This combination of impacts applies to all other sectors as well.

Third order impacts include the consequences of the second order impacts. To continue the example of forests, this means the loss of forest wildlife and the recreational benefits associated with such resources. It also includes the loss of employment in the forest industry and the loss of value of forest industry production. Beyond this, there are further impacts such as loss of income in related businesses, e.g. the forest machinery supply industry. Furthermore each sector that is impacted can adversely affect others including the entire finance, banking, commerce and insurance sector. Thus, the impacts of climate change are both far-reaching and widespread.

The task of assessing these various impacts and the feedbacks between them is enormously complex and requires a number of simplifying assumptions. Although there are complex macro-economic models to assess the costs and macroeconomic consequences of various mitigation policies, the state of the art in impacts work at present does not permit this kind of 'top-down' modeling. Instead, the dominant approach has been 'bottom-up,' aggregating first, second, and third order impacts into a single overall estimate without much attention to the feedbacks between various sectors.

What is Meant by 'Adaptations to Climate Change'?

Many of the impacts of climate change can be reduced by adaptation measures, strategies and policies. We use adaptation to refer to all actions that can be taken to offset or reduce the impacts of climate change. These may occur through the autonomous actions of individuals or enterprises, or they may be policy driven by those concerned with planning and infrastructure development. As the adaptive capacity of a country or region decreases, the vulnerability to climate change increases, leading to greater costs associated with impacts. Successful adaptation will reduce the impacts associated with climate change, and will depend upon, among other factors, a country's or region's technological capability, institutional arrangements, availability of financing, and information exchange (Watson, *et al.* 1996). It is generally accepted that developed countries will be impacted less severely than developing countries, due in part to their greater adaptive capacity.

There are various ways of categorizing adaptive measures, ranging from organizing them according to different social, economic, temporal, and spatial scales (Smit 1993), or differentiating them according to their 'software', i.e. programs, behavioral modification and 'hardware', i.e. machines, structures, status (National Academy of Sciences Committee on Science 1991). Burton *et al.* (1993) provide a particularly useful typology of responses to natural hazards, which can be applied to climate change. They identify six categories of adaptation: bearing capacity, modifying capacity, preventative capacity, research capacity, education capacity, and avoidance capacity.

Bearing Capacity refers to the ability of a system to absorb impacts without taking any action to prevent or avoid the potential negative effects. For example, insurance is a popular adaptive strategy that enables people to absorb impacts through a risk sharing process. It is possible, however, the long term the cost of 'bearing the loss' via insurance could become more expensive than the cost of alternative adjustments. Furthermore, this response may actually promote maladaptative decision-making, as persons overestimate the extent of the buffer against the full effects from climate change and variability (Smit, *et al.* 1996).

Modifying Capacity consists of actions directed at minimizing losses by modifying events at the outset. These include actions such as cloud seeding to prevent hail, but they also include those directed towards limiting the causes of the problem. Thus, this category in effect includes all actions that have been discussed under the rubric of mitigation. This points out the artificial nature of the distinction drawn between mitigation and adaptation in the climate change literature. For the purposes of this report, however, we will continue to maintain this distinction.

Preventative Capacity refers to mechanisms that promote actions that reduce vulnerabilities to climate change, and subsequently reduce the impacts. Preventative action is wide ranging and can be broken down into further sub-categories, varying from the construction of physical structures that minimize impacts to institutional interventions that regulate human actions.

Research and Education Capacity include activities that enhance or promote societal understanding of adaptation and the actions that can be taken.

Avoidance Capacity refers to mechanisms, such as changing use or changing location, which are adopted when drastic changes are required to avoid unacceptable losses. This may be considered an efficient means of adapting to climate change, since it can include developing new opportunities. However, when it takes the form of large-scale migration of environmental refugees, the economic, social, and political costs can be unfathomable. The issue is further discussed in a later section of this report that considers the implications for Canada of changing climate in other regions of the world.

The present day organization of society in all its socio-economic activities and technostructures includes many examples of adaptation to climate. In fact, like many developed countries, it is clear that Canada as a whole is relatively well adapted to its present climate. Canadian agriculture is extremely successful, as are Canadian forestry and other sectors that depend to some degree on climate. Generally speaking, roofs do not get blown away, power and transmission lines do not get blown over, bridges do not collapse, and structures built on lakeshores, the sea coast, and the permafrost are safe and stable. That this is not universally the case, and the fact that storms and other extreme weather events cause damage and an occasional disaster demonstrates that improper attention to adaptation can have major and serious consequences. Adaptation to the extremes and the harshness of climate is not without cost and, while the cost cannot be specified with great accuracy, there is no doubt that it is considerable. Some estimates of these costs are summarized later in this report.

The difficulty with adaptation to climate change is that the choices and decisions, both public and private, will have to be reviewed and in many cases changed. This will have to be done under conditions in which the climate is changing at an unprecedented rate, and in ways that are not fully understood. Each of these changes will require different sorts of adaptation. There is no doubt that a wealthy society like Canada, with a high availability of technical and organizational skills, will be able to offset at least some of the impacts of climate change. This confident prediction, however, is subject to three important caveats:

- successful adaptation can only be achieved at a cost, and these costs can only be very broadly 'guesstimated' at the present time. It is clear, however, that they could be, and are perhaps likely to be, very large compared with the present costs of adaptation. Moreover, the capacity to adapt is not the same amongst different sectors of the economy, different regions of the country, and different social groups (children, the aged infirm or handicapped, the poor and otherwise disadvantaged).
- no matter how successful Canada's efforts to adapt to climate change there will remain significant residual costs resulting from changes in means, variability, and extreme events. The costs of forest fires, floods, droughts and storms, and other less predictable elements of climate will remain significant and are likely to increase over present levels. The trends are already sharply upwards in some areas.
- there will be some irreversible losses. There is likely to be some species loss, and the disappearance of landscapes and parts of the natural heritage of Canada that it will not be possible to conserve.

Finally, adaptation is important not only to reduce the impacts of a changing climate on Canada, but also to take advantage of opportunities that may present themselves. In some places, the growing season will be longer, winter temperatures may be a little less severe, there may be a longer ice free period in the St. Lawrence Seaway, and some desirable new species of plants and animals not now found in Canada may appear. None of these will actually produce economic benefits unless Canadians set out to make use of them. Taking advantage of the opportunities of climate change requires effort, initiative, and investment, the costs of which must also be considered in examining the effects of climate change on Canada.

ISSUES IN MEASURING THE COSTS OF ADAPTATION TO, AND RESIDUAL IMPACTS OF, CLIMATE CHANGE

The policy context in which global climate change is being debated demands monetary estimates of the costs of future climate change impacts. The inherent object is to determine what the effects will be on human welfare and utility. There are large uncertainties surrounding the rate, magnitude, and regional variation of projected climate changes, their impacts on human and natural systems, and the effectiveness of future adaptations. Perhaps as important as these uncertainties are the difficulties in translating these into costs and the fact that value-judgments are necessarily built into any damage assessment measure. As Banuri *et al*. (1996) emphasize, "it needs to be recognized that attempts to quantify the costs associated with climate change involve inherently difficult and contentious value judgments, and different assumptions may greatly alter the resulting conclusions." And as Grubb (1995) warns, "(t)here is the danger that economic evaluations . . . enshrine in apparent objectivity the current value system of the practitioner."

Although other methods do exist and monetary valuation is highly contentious, even within economics (Vatn and Bromley 1995), it is a standard way used to represent changes in welfare. To perform such a valuation exercise is a daunting task. Climate change will affect a dizzying array of physical, geochemical, biological, and socio-economic processes. Assessing these various impacts and accounting for them in monetary terms will "push economic valuation techniques to their limit, and quite possibly beyond (Fankhauser 1995)." In this section we review a number of key issues that need to be considered when undertaking such an exercise or reviewing the work of others.

Valuation in General

Monetary Value versus Social Value

It is important to acknowledge up front the difference between monetary value and a more general sense of social value. Monetary valuation represents a particular, and somewhat narrow, representation of value that is closely linked to the price that would be paid for a specific good or service. This depends on a number of factors that are not necessarily linked to what many would consider a true measure of value. A common example used to describe this difference is the diamond-water paradox - the price of diamonds is much greater than that of water, but no one has been known to die from a lack of diamonds, whereas it is impossible to live for more than a few days without water.

The Implicit Assumptions about Substitutability in the Use of a Common Metric

Valuation generally implies the reduction of values to a common metric. In monetary valuation, this metric is dollars or some other form of currency. The use of a common metric contains within it the very significant assumption about the substitutability of very different items. If a dollar value can be placed on both a barrel of oil and a human life, does this mean that a sufficiently large number of barrels of oil can substitute for a human life? Can the extinction of a species be compensated for by placing the assets earned from their extinction in a bank and accruing interest on these assets? (Clark 1973)

Differences of opinion about substitutability underlie many of the debates about long-term development and environmental degradation. This issue has been extensively discussed in the sustainable development literature and was briefly raised in the IPCC's Second Assessment Report (Pearce, *et al.* 1996). Does "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" imply that future generations should inherit a world with as much of every resource as the present one? (World Commission on Environment and Development 1987) Or does it allow for greater quantities of one good to offset the irreversible loss of another?

Pearce *et al.* (1994) distinguish two broad approaches: weak sustainability and strong sustainability. Weak sustainability allows for the depletion of natural resources to be offset by future increases in human-produced capital or by the substitution of other goods. Advocates of weak sustainability presume the possibility for infinite substitution among goods. Thus, they are less concerned about the possibility of irreversible impacts and extinction, because they believe that future generations can be adequately compensated for any declines in the stocks of a natural resource by increases in the stock of other kinds of capital. This approach is inherent in any monetary-based valuation of climate change damage, which converts all of the various impacts to a single, monetary metric.

Proponents of strong sustainability insist that some environmental and social goods and services are irreplaceable and thus must be preserved. Strictly speaking, strong sustainability would preclude consuming any non-renewable natural resource, so in practice most advocates of strong sustainability allow for some limited trade-offs and substitutions among goods to be made. Their injunction against inflicting environmental damage stems both from a moral compunction against treating "probable improvements in the well-being of future generations ... as 'compensation' for harm knowingly inflicted upon them by present generations (Pearce, *et al.* 1996)" and from a belief that there are no adequate substitutes for many irreversible environmental impacts. Within this strong sustainability perspective, Pearce, *et al*. (1996) distinguish two broad standards for evaluating with the costs of climate change:

- The absolute standards approach insists that since the obligation to avoid harm is absolute, the costs of climate change impacts, like the costs of mitigation, are irrelevant.
- The safe minimum standards approach maintains that since many potential impacts are irreversible and the risks uncertain, harm should be avoided, subject to the constraint that avoiding harm (the cost of mitigation) does not impose unacceptable costs.

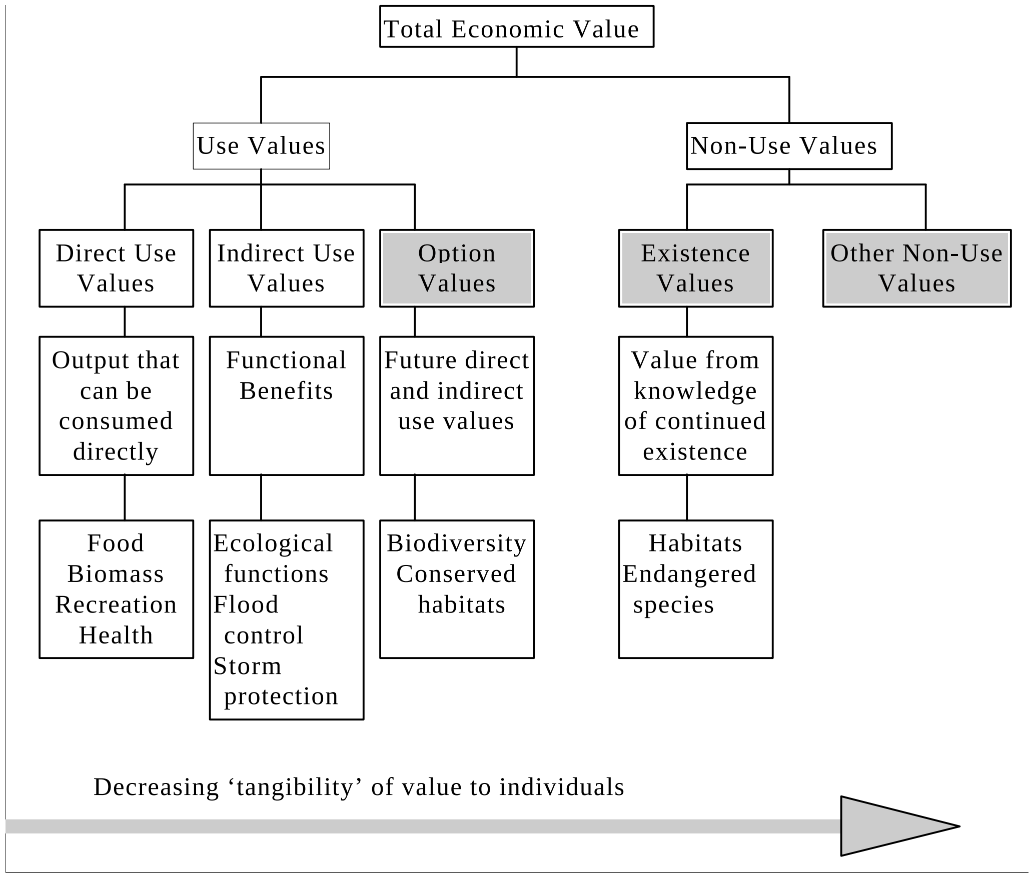
Valuation Methods

Market and Non-Market Evaluation

In considering monetary valuation, five different kinds of value have been identified: direct use values, indirect use values, option values, existence values, and other non-use values (see Figure 1.1). Ideally, all of these values would be represented in the price of a good or service sold in an open, competitive market, in which the external impacts of the production and use of the item have been taken into consideration. Under these conditions, the price of a good would provide an accurate estimate of its economic value. In reality, these conditions are not met more often than they are - many items are not bought and sold, many markets are neither open nor competitive, and many externalities are not considered in the pricing of goods and services.

Economists have developed a variety of techniques for assigning economic values to goods and services for which there are no price-fixing markets. Economic value can be estimated through the price of proxy goods or services; oftentimes this is the cost of replacing the specific good or service of interest. Techniques exist to assess value via indirect markets, such as the travel cost method, which derives monetary estimates from data on costs of traveling to visit a particular recreational site or engage in a particular activity, and hedonic pricing methods, which attempt to decompose property and wage differentials into components that capture the use value of non-market goods such as air quality or mortality risk. Direct methods, such as contingent valuation, have also been developed in which artificial markets are created by directly asking people what they would pay for normally unpriced goods or be willing to accept as compensation for their removal (Freeman III 1993).

Figure 1.1: Categories of Economic Values Attributed to Environmental Assets (from Munasinghe, *et al.*, 1996)



Though accepted by many within economics and other disciplines, these valuation techniques remain problematic in many situations. As noted above, many, if not most, existing markets are not free and do not consider many externalities. For price to accurately represent economic value requires that other, fairly strict requirements also be met. These include the existence of a world of rational agents, who are perfectly knowledgeable about the consequences of their actions and able, therefore, to act consistently in a way that maximizes their individual utility. Critics complain that human behavior hardly ever lives up to this assumption of economic rationality. People do not always understand the systematic effects of their behavior or the costs associated with various trade-offs. Other, non-economic values, such as family, community, and religion, are important as well, but economic valuation, as opposed to other, more qualitative forms of valuation elicitation, is not well suited to representing them. These other, non-economic considerations often make economic valuation very difficult, if not down right offensive to many.

This difficulty is reflected in the work that has been done to date on estimating the effects of climate change. Of the five types of economic value mentioned above and shown in Figure 1.1, the farther one moves away from direct use values, the less effort has been put into including these values in estimates of the costs of climate change. Some are even categorically excluded, such as by the expert cited by Nordhaus (1994a) in a survey on the potential effects of climate change - "the existence value of species is irrelevant -- I don't care about ants except for drugs." In another example, the forthcoming study by Mendelsohn and Neuman, which in many ways represents the state of the art, omits "non-market impacts, such as health effects, aesthetics, and some ecosystem impacts" (forthcoming). These non-market impacts will likely include some of the most severe effects of future climate changes. An economic valuation that omits them will systematically underestimate the true costs of climate change, providing an incomplete and distorted basis for policy makers to address the threat of climate change.

Ability to Pay and the Income Bias

A fundamental concern with economic valuation is that most of the techniques used are biased against persons with low income. The price of market goods are functions of effective demand, i.e. the ability of a person to make their demand felt within the market. For non-market commodities, although both willingness to pay and willingness to accept compensation are theoretically valid measures, it is generally the former that is used in valuation.

Since effective demand and willingness to pay are constrained by the ability to pay, i.e. wealth or income, monetary valuation "in effect yields the result that the impact {of climate change} is less if it is poor people, or people in poorer countries, who suffer" (Banuri, *et al*. 1996). This income bias was central to the controversy over the IPCC and its treatment of the value of a statistical life, which, whether measured by willingness to pay or income forgone is much higher in developed countries than it is in developing countries (Pearce 1996; Pearce, *et al*. 1996).

Aggregation Across Individuals, Sectors, and Regions

Geographic Specificity of Estimates

Because economic valuation of climate change impacts is so difficult, it has only been attempted for a limited set of goods and services and a limited set of values in a limited number of areas. In particular, most of the work has focused on the United States. Many of the estimates for other regions are based upon transferring U.S. based estimates to these very different locales. However, biological, societal, and economic structures, as well as cultures and values, differ widely within and between countries. Also, for a number of countries, the temperature and precipitation values may be outside the range over which the original estimates were made, making extrapolations tenuous.

Bias Against Poorer Individuals and Regions

As noted in the previous section, economic valuation has an inherent bias against poorer persons and persons in poorer regions. A number of persons have suggested addressing this bias by the manner in which effects on individuals are aggregated. Deriving an estimate of the aggregate effects of climate change runs into the same ethical problems as estimating a measure of societal welfare, in that choices have to be made how to weight individual welfare measures. Fankhauser, Tol, and Pearce (1996) show that different equity weighting schemes can result in widely divergent aggregation estimates of climate change impacts. In all cases where the welfare of all persons are considered, the standard, uniform equity weighting yields the lowest aggregate estimates, by as much as a factor of 5.

Missing Interactions

Finally, by estimating economic values at a small scale and then aggregating these, important interactions and inter-dependencies are lost. In examining the higher-order effects of climate change, Tol (1996a) notes that the "cost of impacts together is larger than the sum of the individual impacts." A prime example of this is seen in how agriculture has generally been dealt with in studies evaluating the effect of climate change. Since agriculture comprises only 1-2% of GDP in developed countries, such as Canada, a complete destruction of Canadian agriculture would only result in a 1-2% GDP loss in standard measures of the effects of climate change. This ignores, however, the extreme dependence of other sectors of Canadian society on agriculture. (Howarth and Monahan (1992) illustrate the difference that considering these dependencies can have on estimating values.)

Aggregation Across Time

Changing Values

Estimates of the costs of future climate change are sensitive to assumptions about the kind of future society that will be the recipients of the future climate. How vulnerable will these societies be? How much and how successfully will they be able to adapt? Perhaps more importantly, how will their values and preferences differ from those of members of the present society.

Most studies use present monetary values to calculate the costs of future climate change impacts and adaptations. These express present-day cultural practices and preferences, not future ones. Because of the trans-generational nature of climate change, this introduces a critical uncertainty in estimating the costs of climate change. Tol (1994) shows, by considering the increased willingness to pay for environmental goods that is assumed to come with projected future increases in income, the costs of climate change may be significantly higher than common estimates.

Some adjustments can account for the rising relative preference of future generations for greater quantities of presently valued environmental goods and services, but they do not take into account the possibility that future generations may value the environment differently than we do. Take the example of coastal salt marshes, which are now threatened by rising sea-level. Largely ignored today, except for their amenity value and the provision of wetland habitat, a century ago, diked salt marshes were among of the most valuable agricultural lands in Canada, providing the hay that fueled horse-drawn society. An 1897 estimate of the economic costs of inundating Canada's salt marshes would have put a much higher price on these impacts than a similar estimate today. Similarly, eastern hardwoods, which were regarded by the professional foresters a century ago as weeds, are now valuable commodities harvested for biomass (Irland 1996).

Bias Against the Future - Discounting

Based upon the assumptions that people are impatient and would rather receive a dollar today than tomorrow (the pure rate of time preference) and that an extra dollar is worth less to a richer person, which we are all assumed to be in the future, than a poorer person (the declining marginal utility of income), economists often apply a discount rate to future values in order to aggregate these across time. This is based on the idea of a single long-lived agent able to make rational trade-offs between present and future benefits. This assumption does not hold for the long time involved in climate change, which involves decisions about the inter-generation allocation of costs and benefits, however. On this basis a number of authors (Broome 1992; Howarth and Norgaard 1995; Arrow, *et al.* 1996; Khanna and Chapman 1996) have argued that discounting is inappropriate to the evaluation of climate change damage.

The debate about discounting is important because calculations of the costs of climate change (and thus the policy recommendation that flow from them) are extremely sensitive to the choice of discount rate. For example, at a 7% discount rate (as is commonly used in short-horizon project analysis), damages of $1 Billion 50 years hence have a present value of only $33.9 million; the same damages 200 years hence have a present value of only $1300.

Evaluating a Changing versus a Changed Climate

To minimize the effect of the compounding uncertainties that would be introduced by trying to project economic and social changes, most estimates of the costs of climate change are based upon a present day benchmark. That is, they ask what the difference in GDP would be between the present economy under the present climate versus the present economy under a scenario of a different climate. By holding constant all social and economic variables, these estimates attempt to tease out the specific differences that a changed climate would make.

By simply imposing a changed climate onto the present economy, these estimates effectively ignore the costs of a changing climate, particularly the transaction costs that would be required to adapt to the new changed climate. The costs of many adaptations, therefore, are not counted, and in many cases the ability to adapt, which has been shown to significantly reduce climate change impacts (Fankhauser and Tol 1996), may be greatly exaggerated. For certain sectors, particularly agriculture, these costs, which are very dependent upon the rate of change, can swamp the equilibrium costs of the changed climate. Tol (1996a) posits a more complete theoretical model and empirically shows that assumptions about rates of climate change and the speed of damage restoration and adaptation have a significant effect on estimates of the effects of climate change.

Uncertainty

Uncertainties in How Climate Will Change

To deal with many of the uncertainties in estimating the effects of climate change, a number of simplifying assumptions are commonly made. As noted previously, estimates are often made of the impact of a changed climate on present-day society. Secondly, although climate change is a continuous process, with no real equilibrium state, most studies consider the impacts of a changed climate that has reached a state of equilibrium. Thirdly, even though the absence of efforts to reduce the emissions of greenhouse gases is likely to lead to atmospheric concentrations of CO_2 exceeding pre-industrial levels several times over, almost all studies of climate change impacts and adaptation to date have based their estimates assuming only a doubling. This is, in many respects, due to the early General Circulation Model (GCM) experiments, which have focused on an equivalent doubling of atmospheric CO_2 concentrations. Finally, although the possibility for surprise and catastrophic impacts is widely acknowledged, most studies have not considered these explicitly; rather they have assumed a smooth transition to a new climate.

Each of these assumptions is likely to have a downward bias on estimates of the effects of a changing climate. We have already noted that focusing on a changed climate ignores many of the transient costs associated with a changing climate. This bias is likely to be more significant if the changes do not occur smoothly. By limiting the analysis to the case of a doubling of CO_2, the effects of larger changes in climate are neglected. Cline (1992), among others, has noted that these effects are likely to increase more than proportionally with changes in climate. Of course, the importance of these changes, since they are not likely to happen for some, depends critically on how researchers deal with the issue of discounting as noted above.

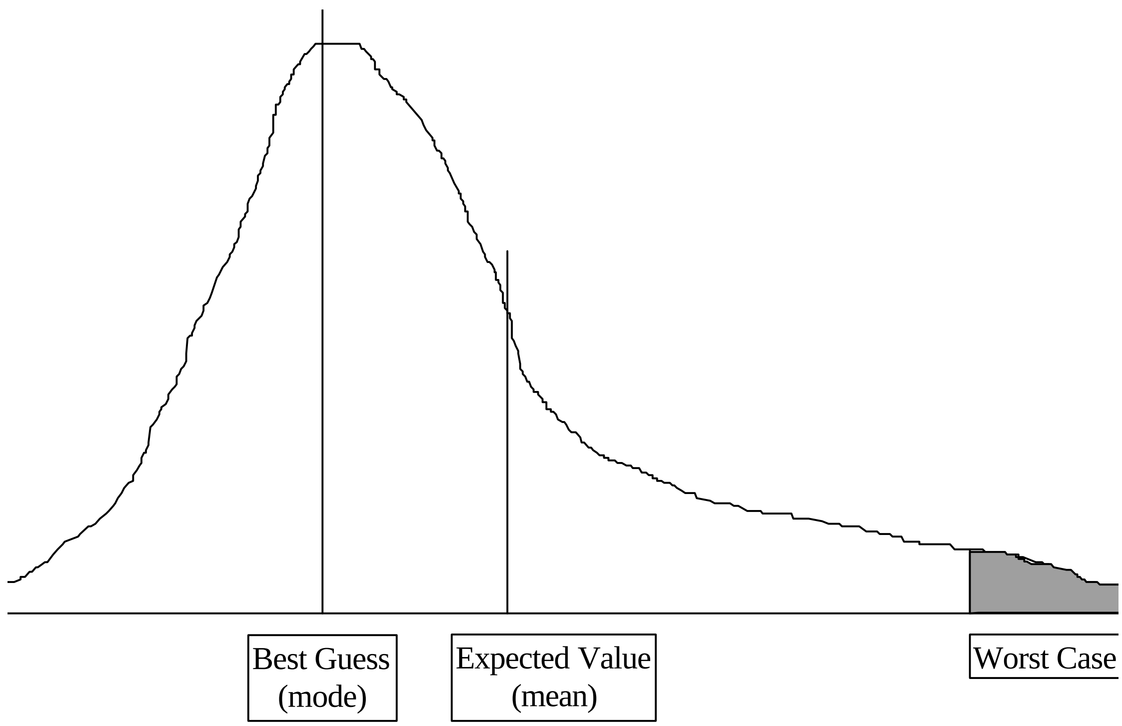
Presentation of Uncertainty

It has been noted earlier that most of the work done on impacts and adaptation have used global mean temperature change as a proxy for climate change and they assume a gradual change to a new equilibrium climate. Although the possibility for surprises and catastrophic impacts is widely acknowledged and some studies have considered issues of uncertainty related to climate changes and human responses, the presentation of the costs has focused on ‘best guesses’ of the most likely scenario.

Figure 1.2 illustrates the problem with this approach. Many of the uncertainties related to climate change have large right hand tails, i.e. the range of uncertainty is not symmetric, but rather there are relatively more possibilities for low probability-high impact occurrences. In such a situation, the impacts associated with the best guess, i.e. the occurrence with the highest probability, can be significantly lower than a weighted average of impacts, each weighted by their probability of occurrence. In effect, the best guess downplays the risk of very costly scenarios. Furthermore, a policy decision based upon the best guess would imply a society that likes to take risks, because the risk premium, i.e. the difference between the best guess and the expected value, is negative. This runs counter to most public policy choices, where a positive risk premium is paid, reflecting the risk adverse nature of society.

Another way in which the presentation of uncertainty is problematic is that when different studies are compared only the totals are usually considered. Because many of these studies consist of aggregations of sectoral estimates, each of which are independent, it would be more appropriate to consider the range of estimates for each sector prior to calculating the aggregate. Doing so will broaden the range of uncertainty and more clearly point out the possibility of much higher damages (Demeritt and Rothman forthcoming).

Figure 1.2: Damage Distribution, Catastrophic Events, and Best Guess Estimates [from Fankhauser (1995)]



EXISTING ESTIMATES OF THE COSTS OF ADAPTATION AND RESIDUAL IMPACTS TO CLIMATE CHANGE IN CANADA

A number of studies have attempted to compile aggregate estimates of the costs of adaptation to, and impacts of, climate change in terms of dollar values and/or shares of GDP (Smith and Tirpak 1989; Ayres and Walter 1991; Nordhaus 1991; Cline 1992; Titus 1992; Fankhauser 1994a; Nordhaus 1994b; Fankhauser 1995; Tol 1995; Tol 1996b; Mendelsohn and Neumann forthcoming; Mendelsohn, *et al.* in preparation). For historic and data reasons, most of these have focused on the United States, but a few have directly considered (Fankhauser 1994a; Tol 1995), or made an effort to extend their findings to, other regions of the world (Ayres and Walter 1991; Nordhaus 1994a; Mendelsohn, *et al*. in preparation). Similarly, most have also considered the impacts of an equilibrium benchmark doubling of CO_2 concentrations in the atmosphere on present-day society. (Cline (1992) considers the impacts of a long-term warming due to an eight-fold increase of concentrations; Mendelsohn, *et al.* (forthcoming) have postulated impacts for the United States in 2060 based upon assumptions on population and economic growth)

The principal areas considered for monetization in these studies have been related to sea level rise, agriculture, and changing energy demand. Other factors - forest loss, species loss, human amenity, human morbidity, human mortality, migration, hurricane damage, leisure activity, water quantity and quality, urban infrastructure, and air quality - have been included in one or more studies. Of these, protection against sea level rise, changes in energy demand, and changes to urban infrastructure are clearly adaptive measures, with the remainder representing mixes of adaptation and residual impacts. Examining this list, it is clear that, even if all of the above mentioned areas were fully accounted for, there remain large parts of natural and human systems that have not been considered. The partial list of these noted by IPCC Working Group III (Pearce, *et al.* 1996) contains: impacts on the insurance, construction, transport, and energy supply sectors; damage from nontropical storms, river floods, hot/cold spells, and other catastrophes; other ecosystem losses; and human impacts including morbidity, physical comfort, political stability, and human hardship. Also, Costanza, *et al*. (1997) list 17 key services provided by natural ecosystems, few of which have been considered in most monetary valuations of the effects of changing climate.

International Estimates

Pearce, *et al*. (1996), Fankhauser and Tol (1996), and Smith (1996) summarize a number of the studies mentioned above. The general conclusion of these is that an equilibrium atmospheric concentration of CO_2 double that of pre-industrial levels, with an expected temperature increase of 2.5°C, would entail a reduction of present day GDP of 1-1.5% in developed countries and 2-9% in developing countries (1.5-2.0% overall). These are, of course, subject to all of the caveats discussed earlier in this paper. Specifically, these ranges represent only the uncertainty presented by comparing totals; a sector-by sector comparison would result in much larger uncertainties (Demeritt and Rothman forthcoming). Perhaps reflecting some of this larger uncertainty, these ranges are contrasted against 'expert judgments' ranging from 0-21% of global GDP. The distribution of these estimates reflects nicely the problem discussed earlier about expected values versus best guesses. The average, or mean value is 3.6%, which is significantly higher that the 'best guess' value of 1.9% (Nordhaus 1994a).[3]

Several studies have attempted to translate the benchmark estimates to damage values per ton of emissions (Nordhaus 1991; Fankhauser 1994b; Nordhaus 1994b; Bein and Rintoul 1996; Tol 1996a). These estimates are even more problematic than the benchmark estimates. A number of reasons for this were discussed in section 3, particularly those related to aggregating estimates across time. Bein and Rintoul (1996) show that, depending upon various assumptions, estimates can range from under $10 to over $4000 per ton of CO_2 emissions, depending on assumptions made on benchmark damages, the discount rate, and the time horizon. In its summary, IPCC WGIII (Pearce, *et al*. 1996) places the present marginal social costs of CO_2 emissions in the range $18-458 per ton of CO_2, with these values rising over time assuming economic growth and increased concentrations.

Estimates for Canada

Determining the costs of adaptation and residual impacts to climate change in Canada is a difficult exercise, given the lack of available information. A review of the literature tends to conirm a concern frequently cited in a recent workshop on the Canada Country Study - there is no sound basis on which

[3] In this case the best guess refers to the median value, i.e. the value at which half of the estimates lie below and half lie above.

to estimate impacts and adaptation costs. As the IPCC Working Group II report clearly illustrates, significant progress has been made in identifying adaptation options in response to climate change, but there is little information on the actual costs of adaptation, or the residual costs which occur despite adaptive measures. The adaptive strategies discussed are drawn from examples across the globe, and while they are extensive - rangeland and pasture management, integrated coastal zone management, population migration policies, efficient energy use, landslides, air and waste management, transportation, water supply, human health, behavioural patterns, agriculture, water resources, forestry, and fisheries - not all of the examples cited apply to the Canadian situation. Moreover, a vast majority (80%) of the adaptation strategies addressed by the IPCC Working Group II tend to be in the preventative category (Watson, *et al*. 1996), suggesting that many other adaptive strategies are not accounted for in their assessment (Andrey, *et al.* 1996).

Smit (1993) provides a wide range of adaptations to climate variability and change that are available in Canada. These examples are drawn from different types of adaptations in response to past, present, and possible future climate conditions. An inventory based on a thorough literature review is also provided, although the authors note that even this list "is not necessarily exhaustive of adaptive possibilities" (Smit 1993). Not surprisingly, costs associated with these adaptation options are not included, and the task of estimating these across many sectors and issues, e.g. agriculture, the Arctic, coastal areas, ecosystems and land use, energy supply, fisheries, forestry, urban infrastructure, and water resources, is a daunting procedure. This suggests that other methods must be sought in order to develop reasonable estimates of adaptation and residual costs. Before doing so, however, it is important to note that there is considerable agreement in the literature on at least three important issues. First, the costs of adaptations will range from region to region, and from sector to sector. Further research on a country and regional basis is needed to improve our understanding of these costs. Second, many measures promoted for adapting to climate change are only minor variations of measures or technologies that are currently in use or are already available. This would suggest that associated costs could be small, especially if initiated early. Lastly, decision-makers may have a good, albeit imperfect, understanding of the broad range of adaptation options available in Canada, which address current climate. There is much more uncertainty, however, if this knowledge is sufficient to enable successful adaptation to climate change.

Three studies that have attempted to estimate the costs of adaptation to current climate in Canada and/or the possible costs of adaptation to, and residual impacts of, climate change. The latter two are based upon modifying estimates originally made for the United States, so these need to be taken with a grain of salt.

Herbert and Burton - Estimates of Current Adaptation Costs

Herbert and Burton (1994) have undertaken a preliminary survey of the current costs of adaptation to climate. It is important to note that this is not the same as the costs of adaptation to climate change. Still is a useful starting point as it provides a benchmark from which to estimate future costs. Although Canada has one of the widest ranges and extremes of climate in the world, adapting to current climate is often taken for granted. Adaptation to present day climate represents the outcome of a slow accumulation of policies and practices that are intended to protect people and property, while allowing economic and social activities to continue with a minimum of loss or disruption. Adaptation costs tend to be incorporated into routine expenditures and budgets. With climate change, it is expected that this 'built-in' cost will change, as the level of adaptation itself changes depending upon the magnitude and speed of 'global warming'.

The cost of adapting to current climate is estimated to be over $11.6 Billion (see Table 1.1). This amount was calculated by surveying current expenditures at the national level, drawn from a combination of published material and expert opinion. Most of these figures were calculated on material compiled during the early 1990s, and in some cases may grossly underestimate 1997 costs. The cost of flood control, for example, is based on expenditures during the 1992-1993 fiscal year, predating many 'floods of the century' across Canada (e.g. southern Alberta in June 1995, Saguenay in July 1996, Red River in May 1997). The results from this survey are shown in Table 1.1, and include figures for 9 major sectors/activity, total expenditures, the percentage attributable to climate adaptation, estimates of the cost of climate adaptation, and the possible trend under climate change. The costs of energy are subsumed under the appropriate sectors, while some adaptive costs were ignored (e.g. health care adaptations). These values need to be treated with caution. The authors expect that the aggregate adaptation costs will actually be higher than those presented. It is difficult to provide an aggregate measure how adaptation costs to current climate will change under future climate conditions, but estimates of trends for specific sectors can be made with a moderate degree of confidence. Adaptation costs associated with agriculture, forestry, water, emergency planning and weather information are expected to increase, while those associated with transportation and most notably household expenditure are expected to decrease.

Table 1.1: Estimates of the Cost of Adaptation to Current Climate in Canada and Possible Trends Under Climate Change

Sector/Activity	Total Cost ($ million)	% Attributable to Climate Adaptation	Cost of Climate Adaptation ($ million)	Possible Trend under Climate Change
Transport:	7,367.5		1,657.3	decrease
Air	83.5	100	83.5	decrease
Marine	258.8	55	143.8	decrease
Rail	702.0	29	203.2	uncertain
Roads	6,323.1	19	1,226.5	decrease
Construction	2,000.0	100	2,000.0	uncertain
Agriculture	1,887.3	70	1,329.6	increase
Forestry	556.3	72	402.6	increase
Water:	1,058.0	73	767.3	increase
Flood Control	4.7	80	3.8	
Household Expenditure	6,023.0	88	5,296.4	decrease
Emergency Planning	14.4	75	10.8	increase
Weather Information	189.4	100	189.4	increase
TOTAL	19,095.9	61	11,653.0.4	

Source: Adapted from Herbert and Burton (1994)

The figures below provide useful insights into the costs of adaptation. There remains an incomplete economic account of the residual costs, both in terms of current damages and those occurring under climate change. Despite the best intentions involving bearing capacity and preventative capacity mechanisms, residual costs can be extensive, particular in terms of climate variability and extreme events. From 1984-1994, the Canadian insurance industry paid more than $1 Billion to compensate for losses sustained by major natural disasters (weather related claims arising from thunderstorms, tornadoes, hail, windstorms and flooding) for damage to homes, businesses and vehicles, and this figure appears to be on the rise (Brun 1997). The total costs to Canada, including the uninsured costs and damage to public property, is estimated at more than double the insurance costs. Furthermore, this figure does not include the costs of smaller events, suggesting that the true costs are actually much higher.

During this decade, prior to the Red River Flood of 1997 and the ice storm of 1998, the costliest single Canadian weather event was the Calgary hailstorm of 1991 which totaled $450 million in economic losses, with $360 million sustained by the insurance industry. Subsequently, in July 1996, there was $295 million insured costs for severe hailstorm damage in Calgary and Winnipeg. At the same time, excessive precipitation also caused extensive damage in the Saguenay region, with the cost of the July 1996 flood estimated between $1-1.5 Billion, of which only $350-400 million was insured costs. At the other extreme, lack of precipitation has also resulted in large negative costs. Extensive drought throughout the Prairies in 1988 resulted in $1.4 Billion in insurance payments and government subsidies. These are only a few, albeit severe, examples of the residual costs associated with extreme events, and it is quite possible that such costs will increase under climate change.

While these figures may suggest that Canadians are not adequately prepared to deal with extreme events resulting in major disasters, the recent Red River flood offers both encouraging and disturbing insights. Although the costs of the flood have yet to be determined, and are expected to be extensive, the costs could have been much higher if adaptive actions were not taken. Adaptations included a combination of historical and reactive actions, most notably a floodway around Winnipeg constructed between 1963-1967, and the rapid construction of the 40 km Brunkild Dike. The $50 million invested in the floodway has no doubt paid itself off many times over, protecting the City of Winnipeg from no less than 3 major floods since its completion. On the other hand, despite the heroic efforts of many volunteers and the extensive building of protective infrastructure, the costs associated with the flood are still expected to be staggering. This may leave little option but to take more drastic preventative measures, if not seriously consider changing land use or location. Such extreme measures may be necessary in other regions vulnerable to climate change and rising sea level in particular. For example, it is expected that an upgrading of existing dykes to protect the residents of Richmond, British Columbia, most of which lies below sea level, may cost hundreds of millions of dollars.

Of course not all expenditures for adaptation will be as costly as those associated with extreme events. Careful and proactive planning, especially in infrastructure that has a relatively long lifespan (e.g. 100 years), is both cost effective and sensible. Planners in the Town of Milton have recommended the spending of an additional $7-10 million to enlarge a proposed water pipeline to accommodate expected water shortages under climate change. This amount represents an extra

10 to 15 percent of the base cost, yet is much cheaper than would occur if changes were required at a later date. Similarly, with the recently completed Northumberland Strait Bridge Project, a one metre sea level rise was incorporated into the design due to the potential effect of global warming over the life of the project (100 years) (Northumberland Strait Crossing Project, nd). The added cost of increasing the height of the bridge by one metre (raising the height of the main channel span from 46 to 47 metres) is a small amount relative to both the total cost of the bridge, and the future costs that may be associated with countering the effects of a one metre sea level rise through alternative measures.

Richard Tol - Estimates of the Costs of a Changed Climate on the Canadian Climate: Base Year 1988

Of the studies discussed in the previous section looking at the costs of a changed climate under a doubling of the atmospheric concentration of CO_2, only Tol (1995) has considered Canada specifically and he combines it with the US. In most cases he simply used Canadian statistics to scale up estimates for the US to get an OECD-American total (Tol 1997). He estimates that an equilibrium atmospheric concentration of CO_2 double that of pre-industrial levels, implying a 2.5° C warming and a 50 cm. rise in sea level, would entail a reduction of GDP in 1988 of 1.5% for the US and Canada.

A reduction of Canadian GDP of 1.5% in 1988 translates into a loss of $8.3 Billion in $1986 Canadian (see Table 1.2). These vary across category, with human mortality and morbidity making up nearly half of the total damages.[4] Of the categories considered by Tol, only coastal protection - representing $0.167 Billion - is clearly an adaptive measure.

Robert Mendelsohn, et al. - Estimates of the Market Impacts of a Changed Climate on the Canadian Economy: Base Year 1990

Mendelsohn, *et al*. (in preparation) have developed two sets of equations, based on studies in the US (except for the tourism sector), that relate market value to average temperature and precipitation levels in addition to other factors, such as atmospheric concentrations of CO_2, length of coastline, and land area. The sectors considered are: agriculture, forestry, coastal resources, energy, water, and tourism. By varying the climatic parameters, the impacts of a changed climate can be calculated for each sector. The equations are based upon a series of underlying studies presented in Mendelsohn and Neumann (forthcoming).

A closer examination of the studies raises a number of troubling questions about the optimistic conclusions at which they arrive. These include optimistic assumptions about the benefits to agriculture and forestry from CO_2 fertilization, the lack of consideration of many of the costs of adaptation, and the fact that only those impacts that could be measured in the market for a subset of economic sectors were considered. Aside from these concerns, it is important to question the ability of estimating the costs of adaptations on, and residual impacts of, climate change impacts using single, country-wide, annual average values for temperature and precipitation. There are

[4] Tol (1995) uses a value for a statistical life of $250,000 US plus 175 times average income, yielding a value for a Canadian life of about $3.5 million US.

also problems with applying these results to other countries. Specifically, biological, societal, and economic structures differ widely between countries and for a number of countries the temperature and precipitation values may be outside the range over which the equations were estimated. In Canada's case, this is compounded by the fact that data points above 65° latitude were omitted as it is assumed that economic activities there are limited.

Table 1.2: Estimates of the Cost of Doubled CO_2 for Canadian Society in 1988 (2.5°C, 50 cm sea level rise)

	Raw Data for US + Canada (From Tol (Tol 1995))			Data for Canada assuming Equal Share of Damages between Sectors in Two Countries (Total GDP from CANSIM)
Category	**Billion $US**	**Percentage of Total Damages**		**Billion 1986 Can$**
Coastal Defense	1.5	2.0%		0.167
Dryland Loss	2.0	2.7%		0.223
Wetland Loss	5.0	6.7%		0.557
Species Loss	5.0	6.7%		0.557
Agriculture	10.0	13.4%		1.113
Human Amenity	12.0	16.1%		1.336
Human Life	37.7	50.6%		4.197
Migration	1.0	1.3%		0.111
Natural Hazards	0.3	0.4%		0.033
Impacts on the Insurance, Construction, Transport, and Energy Supply Sectors				neglected
Damage from Nontropical Storms, River Floods, Hot/Cold Spells, and Other Catastrophes				neglected
Other Ecosystem Losses				neglected
Other Human Impacts, including Morbidity, Physical Comfort, Political Stability, and Human Hardship				neglected
TOTAL	74.5	100%		8.294
% of GDP	1.5			

Several categories, e.g. coastal defense, dryland and wetland loss, and agriculture, reflect costs of adaptation plus residual damages.

Categories considered in other studies not considered by Tol - forestry, energy, water, other sectors, air pollution, water pollution.

A statistical life, the "personal willingness to pay for risk reductions" (Pearce 1997, p.3),is assessed at $250,000 plus 175 times per capita income. (Tol 1996a)

Migration costs reflect the costs of incorporating immigrants into the social welfare infrastructure (Pearce, *et al*. 1996).

Even with the above caveats, it is still useful to look at the estimates that these equations provide for Canada, as the totals, if not the specific sectoral estimates, have been discussed elsewhere (Kloeppel 1997; Mendelsohn, *et al*. in preparation). For Canada, a warming of 2.5°C in 2060 is estimated to provide significant overall positive benefits, largely dominated by gains in agriculture and forestry.

THE EFFECT OF EXTRA-TERRITORIAL CLIMATE CHANGE IMPACTS ON CANADA

Thus far, this report has focused on the costs of potential climate change impacts and adaptation in Canada. Since Canada is a member of the family of nations and Canadians have interests and connections to people and places across the globe, the effects of climate change beyond Canada's borders also need to be considered. This sections considers a number of these.

International Relations

Future climate change will affect Canada's foreign relations in a number of ways. If, as most people predict, it is the developing nations that are most severely affected by anthropogenic climate change, caused principally by historical CO_2 and other greenhouse gas emissions from developed countries, there will likely be an increase in tensions between developed and developing countries.

Climate change will also create new sources of tension in Canadian-American relations. Warmer temperatures will exacerbate problems of international air pollution, particularly in southern Ontario, which already suffers as the tailpipe of the American midwest. Transboundary water management will also be affected. In the event of long-term drought in the central American states, a scenario predicted by many GCMs, Canada can expect to face increasing pressure from the US for southern diversions of water, whose precise status under the North American Free Trade Agreement remains unclear. The melting of sea ice in the Northwest Passage may make this waterway navigable. Although Canada has long claimed the Northwest Passage as an internal waterway, this has never been recognized by the United States.

The management of international common property resources is also climate sensitive and thus potentially affected by climate change. For instance, the productivity of Pacific salmon is strongly tied to the pattern of climate and ocean circulation in the North Pacific (Mantua, *et al*. 1997). In the past, changes in this climatic regime have produced dramatic declines in catches, precipitating conflicts among fisheries stakeholders and exacerbating international efforts to manage this resource sustainably. Furthermore, because migration routes are highly sensitive to ocean temperature, climate change and variability have played a strategic role in Canadian-American negotiations over the salmon. When ocean temperatures are such that salmon return to their spawning ground by way of the Juan de Fuca Strait, American negotiators have the upper hand because American fishing fleets have the first crack at the fish and are able to hold them hostage to secure Canadian concessions. By contrast, when the climate is such that the salmon return to their spawning grounds by way of the Straits of Georgia, salmon bound for Canadian waters are less vulnerable to over-fishing from American vessels.

Environmental Security

As noted above, climate change may exacerbate regional conflicts over scarce natural resources. If the past is anything to go by, these conflicts may be intra-national and ethnic, such as in Bosnia and Rwanda, rather than international clashes of the organized armies of nation-states, such as in the Gulf War. These chronic, low level conflicts affect Canada and Canadians a number of ways: first by making the world a more dangerous place; second, by spilling over the boundaries through acts of international terrorism; third, by escalating into wider conflicts; fourth, by increasing demands for Canadian participation in peace-keeping and diplomatic missions; and fifth, by contributing to internal and international refugee problems (Homer-Dixon 1991; 1994).

Environmental Refugees

As IPCC WG II (Aguilar, *et al*. 1996) notes, some of the most dramatic human impacts of climate change are likely to the migrations that ensue as people, particularly in developing countries, are displaced by shoreline erosion, coastal flooding, and agricultural disruption. Most migration, environmentally induced or otherwise, is internal, although with the globalization of the world economy, displaced persons increasingly resort to international destinations (Hugo 1996). As a result, environmental refugees may become an increasing source of international as well as domestic tension. There is already a nativist backlash against immigration in many host countries in both developed and less developed countries. This will likely be true for Canada as well. Many of the areas that will be most severely impacted, such as the small island states of the Caribbean and the delta area of Guandong province, China, are nations with whom the government and the citizens of Canada have historic ties. Canada can expect pressure for immigration from these areas to increase. In the case of Mexico, another country that is projected to hard hit by most future climate change scenarios (Liverman 1992), illegal immigration will likely become a sore point of relations between NAFTA signatories.

The potential number of environmental refugees to Canada and the costs associated with these migrations is a significant knowledge gap. Myers (1993) estimates that as many of 150 million people might be displaced in the next century by climate change. Although it is possible to quibble with this particular estimate, there is no doubt that the problem will be a significant one, particularly as the international community is already struggling to cope with the present quantity of displaced persons. Although some of the direct costs of government outlays for immigration services have been included in the figures presented above, these estimates are extremely conservative. They discount the cost of human misery and dislocation in source countries as well as the secondary effects of immigration on domestic labor markets, where unemployment is running at over 10% and real wages have been stagnant or in decline for 20 years or more.

International Trade Position.

The effects of climate change on international prices and supply and demand will have as much effect on Canadians as the first and second order impacts of climate change in Canada. Almost all of the work on climate and international trade has focused on the agricultural trade. A number of models predict that Canada's position on the world market as a leading agricultural exporter will be improved (Reilly, *et al*. 1994; Rosenzweig and Parry 1994). This is both because climate changes are projected to improve overall yields in Canada and because Canadian producers will fare better than their competitors in places such as the American Great Plains. All of these model outcomes, however, are very sensitive to assumptions about levels of adaptation, whose costs are not generally accounted for, and the effect of CO_2 fertilization. The possible effects of climate change on other sectors of international trade are poorly known.

CONCLUSIONS AND NEXT STEPS

At this point in time, very little can be definitively stated about the costs of adaptation to, and residual impacts from, climate change for Canada. Estimates based upon studies principally in the United States place the impact of an equilibrium climate change associated with a doubling of atmospheric concentrations of CO_2 imposed on the present economy and population to be on the order of 1-2% of GDP or $8 - $16 Billion.[5] More recent studies indicate that the costs may be lower and that Canada may actually benefit overall from a changing climate. However, equally valid considerations suggest that the costs could be significantly larger than previously estimated.

One next step would be to develop a true benchmark estimate of the costs of adaptation to, and residual impacts from, climate change for Canada. This could be an important component of the next phase of the Canada Country Study and could build upon previous work represented by the Mackenzie Basin Impact Study and the Great Lakes-St. Lawrence Basin Study. What we are really interested in is probably not simply an improved benchmark, however, especially for a present-day Canada, but rather some sense of the costs of adaptation and residual impacts over time. This essentially means estimating a time profile of marginal costs of CO_2 emissions. Developing such a profile is not a straightforward exercise, but several authors have begun working towards this (Fankhauser and Tol 1996; Tol 1996a).

We should not underestimate the difficulties in pursuing any of these options. Nor should we underestimate the costs of doing so. In discussing with Robert Mendelsohn the effort undertaken to produce the study for the US cited earlier (Mendelsohn and Neumann forthcoming), he provided a ballpark figure of $500,000-$1,000,000 to do a similar study properly for Canada. And recall that this study considered only the market impacts for a limited number of sectors in the economy.

[5] Canadian GDP in 1995 was $776 Billion in current dollars according to CANSIM.

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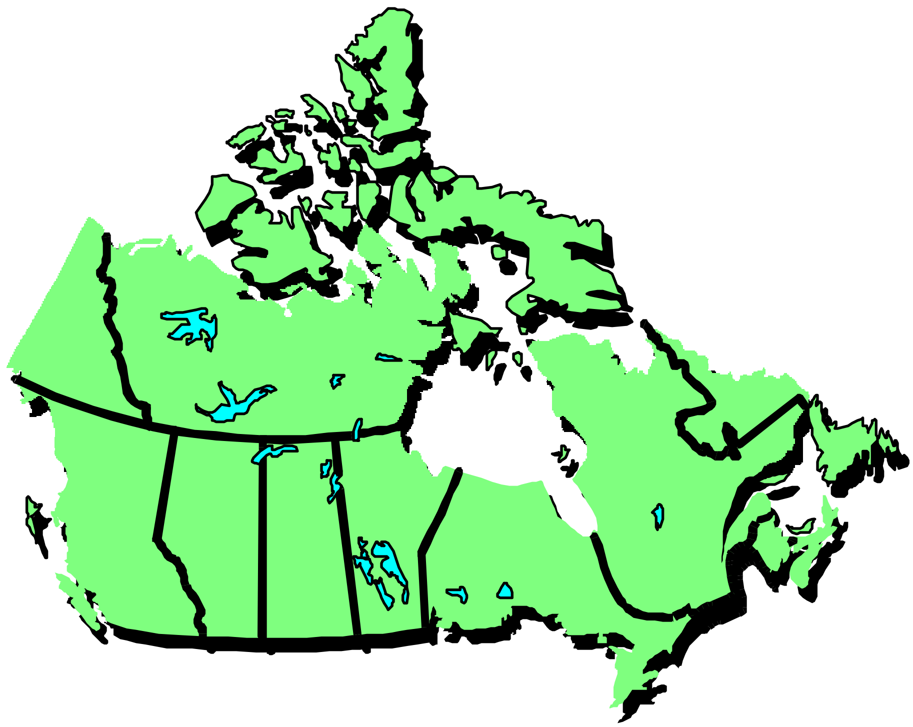
CHAPTER TWO

CLIMATE CHANGE AND EXTREME EVENTS: CANADA

David Etkin[1]



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EXECUTIVE SUMMARY AND RECOMMENDATIONS

As Canada's climate changes in the future due to an enhanced greenhouse effect, changes in the frequency of some extreme events are bound to occur. Heat waves will become more frequent, while cold snaps will be less so. The frequency of drought, hail, tornadoes and heavy rainfall events will also probably increase in some parts of Canada. It is not clear how the frequency of strong synoptic or meso-scale storms will change, if at all. Especially, there is little evidence that hurricane frequency will increase. These changes will not be equally distributed across Canada - our large geography suggests regionally different responses. For example, western Canada has shown greater warming in spring and winter over the past 10-15 years, and larger variances of maximum daily temperatures during hotter summers, than has eastern Canada

Our adaptive responses to extremes are based upon various assumptions such as:

- How likely they are to occur in the future,
- What benefit might be gained from living in hazardous areas such as flood plains, and
- What constitutes an acceptable level of risk.
- Some of these assumptions are currently being challenged not only as a result of our understanding of global change, but also under present conditions, as a result of recent costs associated with extreme hydrometeorological events such as droughts, floods, hail and ice storms.

The implications of climate change are profound, in light of the historical socio-economic costs to Canada of these kinds of events. It is likely that extreme events in Canada in the future will be a costly affair, requiring a greater commitment to adaptation, in order to minimize their impact.

It is recommended that:

- Databases related to the costs and adaptations of natural hazards be developed and maintained.
- Scenarios of climate change be developed based upon real case studies of extreme events, and the assumption that the return period of these events is significantly diminished.
- Social science research related to how Canadians perceive their risks related to natural hazards and climate change be conducted, in order to better understand how adaptive decisions are made.

INTRODUCTION

There is a difference between natural hazards and natural disasters. A hazard is an extreme event of some sort (eg. strong winds, heavy rains, etc), while a disaster occurs when a vulnerable society is exposed the extreme. A tornado is an example of a natural hazard; a tornado disaster occurs when a severe tornado destroys part of a town, causing significant loss of life and property, often beyond the ability of the local community to recover from, without assistance.

In one sense, coping with natural hazards is like a game (the Natural Hazards Game). Once you know the rules, you can devise a winning strategy. If the chances of good or bad events occurring are fairly well known, then tradeoffs can be calculated with some level of comfort.

But what if after playing the Natural Hazards Game for some time, it turned out that the rules were about to change? Not only that, exactly when they were going to change, or precisely what the new rules would be was not known? Even worse, the new set of rules would not be constant, but would evolve over time, and not planning for them could result in 'losing' the game. That is what climate change does to the Natural Hazards Game.

Society is not just a passive player, however. We play a major role in making up the rules of the game. The purpose of this section is to explore what we know about how climate change will alter the Natural Hazards Game, to consider the role society has in formulating the rules and to overview some Canadian impacts.

CLIMATE CHANGE AS A HAZARD

How Climate Change is Hazardous

Climate can be represented as a probability function, or a histogram of the frequency with which weather events occur. Depending upon the weather element selected and the location, a variety of probability distributions are possible. For example, temperature is often represented by a normal distribution (Wigley, 1988), storm waves by a Rayleigh (Khandekar and Swail, 1995) and precipitation by a lognormal. These distributions are characterized by their means and variances.

Though many extreme events occur at the tails of the probability function of a single homogeneous population, some events are 'hybrids', and result from the unfortunate convergence of more or less unrelated events. One example is Hurricane Hazel, a tropical storm which was picked up by a strong mid-latitude jet stream and gained new energy. Another is the Alberta flood of June, 1995, where an intense rainfall event coincided with the rapid melt of a deep winter snowpack.

There are several ways in which climate can change:

1. The mean of a distribution could shift towards more positive or negative values. An example of this is the average global warming of around 0.5^{o}C over the past century.
2. The variance of the distribution could change. Examples of this are decreased variability of the daily temperature range over the U.S., Soviet Union and China (Karl *et al.*, 1995), or the increased variability of rainfall over the Sahel (Hulme, 1992).
3. A distribution could become more or less skewed. An example of this is presented in Lambert (1995, 1996) who found a decrease in weaker storms but an increase in intense storms in a doubled CO_2 GCM experiment, where the variance decreased by about 20% and the skewness by about 25%.
4. The autocorrelation could change, which would impact the frequency of sequential runs of events. For example, a higher autocorrelation of daily maximum temperatures would result in more frequent runs of extremes, even if the number of extremes remained the same.

The incidence of hybrid events could change. For example, if the mid-latitude jet stream migrates northward in a warmer climate but there is no change in the areas of hurricane occurrence, then hybrid events such as Hurricane Hazel might become less likely. The likelihood of a hybrid hazard depends not only on the probability distribution of the relevant components, but also on their geographical distribution.

Rates of climate change can be linear or non-linear. A ‘sudden’ change can occur due to the superposition of more than one forcing (constructive interference of waves), or because the climate system reaches a bifurcation point and switches into a different stable mode. An example of the latter would be a switch in the ocean circulation patterns from the current conveyer belt to one with greater symmetry between the Atlantic and Pacific circulations (Manabe and Stouffer, 1988). There is mounting empirical evidence that climate tends to exist in several states or modes, and switches rapidly between them (Broecker, 1995).

Though a change in mean, such as average precipitation, can be hazardous in the sense that it represents a change from what society has adapted itself to, it seems likely that the greatest impact of climate change will be due to increases or decreases in the frequency of extreme events.

How Climate Change Affects the Natural Hazards Environment

Understanding the effect of climate change on hazards can be approached from several perspectives. Trends of some relevant parameter can be tested for statistical significance; empirical data can be used to relate hazards to causal phenomenon; or models can be used for prediction or scenario development. Each of these approaches have value, and can be used to make inferences about how the future may or may not evolve.

Tropical Cyclones

It has been suggested that tropical cyclones and hurricanes might become more frequent or intense in a warmer climate. Tropical cyclone frequency can be related to six physical parameters (Ryan et al, 1992), three dynamic (low-level relative vorticity, the Coriolis parameter and the vertical wind shear), and three thermodynamic (the ocean thermal energy, moist instability and relative humidity). The basis for arguments of increasing frequency rest upon prognoses of increasing sea surface temperatures (SST) or ocean thermal energy.

Since the mid-1970s there has been a decrease in the number of intense Atlantic hurricanes (Landsea, *et al.*, 1996), though globally there seems to be no trend. The Atlantic decrease has been correlated with more frequent El Nino episodes and Sahel rainfall. There is some evidence, however, that more frequent hurricanes in 1995 and 1996 represent a return to a cycle of increased frequency of activity, after the relatively quiescent decades of the 1970s and 80s. Pielke and Landsea (1997), noting that hurricanes are the costliest natural disasters for the U.S., found no trend in damages when data was corrected for inflation, population and changes in wealth.

Emmanuel (1987) looked at this issue by modelling the tropical cyclone as a Carnot heat engine, and concluded, using thermodynamic arguments that emphasize SST, that warmer SST in a doubled

CO_2 world would increase the maximum sustainable pressure drop in the storm, potentially increasing storm intensity by 40-50%. He also suggested the possibility of ultra-powerful hurricanes (hypercanes) if the SST rose by 6°C or more.

Idso et al (1990) used empirical data to support the hypothesis that hurricanes would not be more frequent in a global climate warmer by 1/2-1°C, and might be less intense.

Broccoli and Manabe (1990) examined tropical cyclone frequency in an equilibrium CO_2-doubled GCM, and found a large increase in storms when cloudiness was constrained to climatology, but a lower frequency of storms when cloud feedback is allowed. Interestingly, SST increases were larger in the cloud feedback case, which points to the importance of factors other than SST as important to cyclone development, especially cloud feedbacks. In another GCM experiment, Haarsma et al (1993) found a 50% increase in the number of cyclones, with relatively more intense ones.

Evans (1993) examined empirical data relating SST to cyclone intensity, and found no obvious relationship, concluding that the availability of increased ocean thermal energy is not the limiting factor for the intensity of tropical cyclones, though it might define an upper bound.

Ryan et al (1992) used the Gray Seasonal Genesis Parameter (SGP) to examine cyclone frequency changes from a GCM, and found large increases resulting from the increased SSTs, though they note that it is the dynamical factors that determine cyclone frequency, once the minimum thermodynamic factors are satisfied. This study points to the danger of using empirically derived relationships and extrapolating them to different environments.

As part of the WMO/ICSU program on tropical cyclone disasters, a workshop was held 22 November - 1 December, 1993. The participants (Lighthill *et al.,* 1994) concluded through an examination of observational data that ***"though the possibility of some minor indirect effects of global warming on tropical cyclone frequency and intensity cannot be excluded, they must effectively be "swamped" by large natural variability"***, and felt that the use of climate models to assess changes in cyclone frequency was not at a useful stage. In a critique of Lighthill *et al.,* 1994, Emmanuel (1995) argues that though the frequency might be unchanged, the arguments presented regarding intensity are flawed, and that the potential for more severe storms exists as a result of a climate warming scenario.

Extra-Tropical Storms

It has commonly been argued that since polar latitudes are expected to warm more than mid or tropical latitudes, then the decreased temperature gradient will result in weaker mid-latitude storms, where the energy source is baroclinicity in the atmosphere. This assumption is complicated by the prediction of an increased temperature gradient in the upper troposphere, as a result of a large warming in the tropical upper troposphere. It is not clear therefore, whether baroclinic storms will become stronger or weaker (Held, 1993), though some theoretical calculations suggest that the lower troposphere gradients dominate. The effect of moisture also complicates the issue. Latent heat release should increase in a warmer climate, thus strengthening storms, though the transport of latent heat in large scale eddies from the tropics to the pole may reduce the requirement for balancing the global energy budget, the ultimate driving force behind mid-latitude storms. Changes in the circulation pattern may well alter storm tracks, an effect which on a regional scale may swamp other considerations. Balling and Lawson (1982) found a shift in winter circulation patterns over North America in the early 1950s, from predominantly zonal to meridional, a change that would have major impacts on storm tracks. They also noted that the interior plains and northeast quarter of the U.S. appear to be most sensitive to the change in circulation. Prediction of storm tracks in a warmer climate remains a major challenge (Held, 1993).

Agee (1991) examined storm frequencies during periods of hemispheric warming and cooling, and found statistically significant linear relationships between the two. During periods of warming, cyclone frequency increases, while during periods of cooling, it decreases. In the 1950 to 1975 cooling period, storm frequencies dropped by 30%, while in the 1905 to 1940 warming period, they increased by around 19%. Stein and Hense (1994) found a higher frequency of extreme storms in the North Atlantic winters since 1988/89 than at any time since 1880. Lambert (1996) found an increase in severe winter cyclones near the Aleutian Low and the Icelandic Low after 1980.

Lambert (1995) using the CCC GCM, found a 4% decrease in cyclones in the northern hemisphere though the frequency of intense cyclones increased. Lambert hypothesizes that the latent heat effect is responsible for the greater number of intense storms. No change in storm tracks was evident. A few areas showed increased frequencies, such as off Cape Hatteras, over Hudson Bay and west of Alaska. These results are similar to Rowntree (1993) who found a 40% increase in Atlantic gales, though fewer intense storms over eastern North America. Hall et al (1994) and Carnell et al (1996) found an intensification and northward shift of storm tracks.

How severe ice storms may be affected by climate change is also of concern, given the magnitude of the Ontario/Quebec January 1998 event - possibly Canada’s worst disaster in terms of socio-economic impact. This storm has been associated with the El Nino of the same time period, the largest on record. If El Ninos become more frequent in the future due to global warming, a question to which we do not yet have an answer, then so might severe ice storms.

Evidence on how storminess will change in a warmer climate is conflicting, and conclusions, especially regarding severe storms, must be viewed as uncertain.

Convective Storms

Convective storms (severe thunderstorms producing hail, lightning, tornadoes, heavy rain and strong winds) remain a particularly difficult issue for GCMs because of their small scale. Intuitively, one would expect more frequent and more intense convection since a warming surface and a cooling stratosphere in mid-latitudes will destabilize the troposphere. Mitchell and Ingram (1990) found deeper convection in a GCM forced by doubled CO_2. Noda and Tokioka (1989) in another similar GCM experiment found that the global precipitation increased, though the precipitation area decreased. Both these studies suggest more frequent intense convective rainfall in a warmer climate. Thus the frequency of both floods and droughts may increase (Meehl, 1993). The issue of dynamics also needs to be addressed though, and it is not clear how changing wind fields will affect storm intensities.

Price and Rind (1993) found, also using a GCM, that in a 2xCO_2 climate with a 4.2^{o}C warming global cloud-to-ground lightning strokes increased by 72% over continental regions.

Etkin (1995) in an empirical examination of tornado occurrence in the prairies of western Canada found that tornado frequency is greater in warmer springs and summers. This implies that the number of tornadoes may increase there as a result of climate change. Interestingly the number of observed tornado events in southern Ontario was lower in some hot summers. Mike Leduc (personal communication) thought this might be because the polar front migrated to the unpopulated regions of northern Ontario where events go largely unreported.

Griffiths et al (1993) discuss the difficulties in assessing convective changes and suggest three approaches; one by correlating data with general circulation indices, a second by using models to compare the frequency of pre-conditions to severe storms, and a third by comparing present and projected climatologies of synoptic situations.

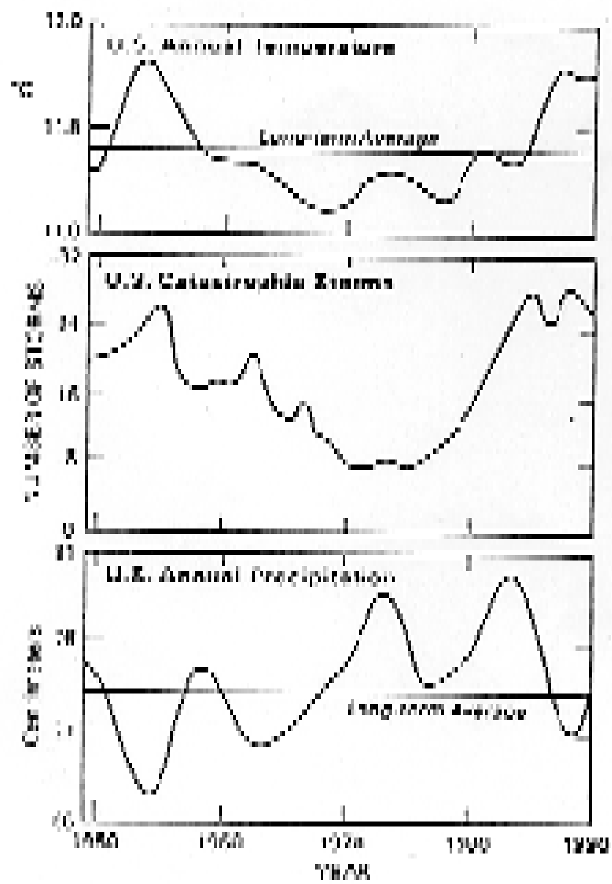
Hogg (1996) examined hydrological extremes in Canada, and found a slightly positive but not significant trend. This may not be to surprising, in light of Ross and Elliot (1996) who found significant increases in precipitable water in the U.S. but not in Canada. Also, Karl et al (1995) found that the proportion of precipitation contributed by extreme one-day summer events in the U.S. increased significantly from 1910 to 1990.

It seems likely that the number of convective events will increase in most areas in a warmer climate, due to the thermodynamic changes. This assumes that the dynamical contribution to severe convective storms (associated with wind fields) does not diminish and thereby compensate for temperature and humidity changes.

Weather Disasters and Temperature

Changnon and Changnon (1992) did a study of trends in weather disasters in the U.S., attempting to correlate them with global temperature trends. A disaster was defined as a storm which produced more than $100 Million in losses (1991 dollars), which provided 142 cases from 1950 to 1989. These storms produced $66 Billion in losses. Included were hurricanes, winter storms, convective storms and windstorms. The ten worst storms, 7% of the disasters accounted for almost half of the total losses. This figure becomes more extreme if hurricane Andrew is included. Figure 2.1 shows five year averaged trends of storm frequencies against annual temperature and precipitation, which show relatively more storms causing damage after 1970, mainly due to thunderstorm-related events. These events occurred mainly in the southern and eastern U.S. Figure 2.1 is particularly interesting, as it shows a correlation between weather disasters and the U.S. annual temperature. The correlation was strongest with the convective storms, followed by winter storms. Hurricane relationships were weak. The authors conclude that warmer climates may cause higher extreme storm frequencies in the eastern two-thirds of the U.S.

Figure 2.1 Five year moving average of national US frequency of weather disasters and annual mean temperature and precipitation. Note the correlation of storms with temperature.



Extreme Temperature Events

In a warmer climate, heat waves would become more frequent, while cold waves would become less so. Evidence suggests that even a warming of a couple of degrees Celsius can have a major impact on this hazard, due to non-linearities in the system.

The frequency with which extreme temperature events occur has been analyzed by Mearns et al (1984), Wigley (1988) and Katz and Brown (1992). Mearns et al (1984) note the strong non-linear relationship between changes in the mean and changes in the probability of extremes, which may be the principal way in which climate change is felt. They found large changes in the likelihood of heat waves at Des Moines (by a factor of 3), with relatively small changes in mean temperature (1.7^{o}C). As well, changes in the variance and/or autocorrelation of a temperature time series can significantly affect the probability of extreme events, potentially being as or more significant than changes in the mean.

Wigley (1988) found that risk is extremely sensitive to changes in the mean (assuming that the extreme events come from the same parent population). He found, for example, that for an event with a 10% risk of occurring in 100 years, that risk is increased to 90% if the mean were increased by 0.02 standard deviations per year during the 100 year timeframe (assuming a normal distribution). Thus, if GCM models are correct, then rare events will become commonplace before the middle of the next century.

Katz and Brown (1992) analyzed the sensitivity of extreme events to changes in the mean and standard deviation (for a normal distribution), and found that extreme events are more sensitive to variability than to its average, and that this sensitivity becomes greater the more extreme the event. This conclusion was also noted by Barrow and Hulme (1996). In an analysis of temperature extremes, a 0.5^{o}C change in mean resulted in a 35% increase in probability of daily exceedence of 38^{o}C, while the same change in standard deviation results in a 71% increase. This occurs because the sensitivity to mean increases linearly while the sensitivity to standard deviation increases quadratically. They conclude that any climate change impact study that holds variability constant while only changing the mean may not be realistic. The question of how to incorporate variability issues in climate change studies remains problematic; for example, Skaggs et al (1995) demonstrate how temperature variance changes over time for the eastern USA. Spatial and temporal analogues may provide insight regarding this issue. It must be noted though, that changes in the mean are expected to be more significant than changes in variance, according to climate models (IPCC, 1995 - Ch. 6). Zwiers (1994) found significant changes in the 10 year return period maximum temperature at 2 m, ranging from 4-6^{o}C over all continents except the Antarctic.

Hennessy and Pittock (1995) using a global warming scenario of 0.5^{o}C found 25% more days over 35^{o}C in summer and spring at Victoria, Australia, and 50-100% more in a 1.5^{o}C warming scenario.

Mearns et al (1995) examined temperature variability and diurnal range in a nested GCM, and compared their results to others. They found, on average, a decrease in daily temperature range though with large regional and seasonal variations, mainly resulting from changes in absorbed shortwave radiation. The largest change in the variability of daily mean temperature was a decrease in winter in high latitudes. Changes in variability are mainly explained by changes in atmospheric circulation patterns (e.g., storm tracks) though changes in the Arctic ice regime are important for high latitudes. These results broadly agree with several other authors, though they note that there are considerable differences between models, and that research is needed for diagnosis.

Some recent research at the University of Toronto (Columbo, 1997) has suggests that, in the summer in western Canada, the variance of maximum daily temperatures increases with mean maximum temperature, though this is not true for central and eastern Canada. Evidence points to much more frequent heat waves as a result of climate warming. The data implies that the frequency of heat waves in the west would increase about twice as much as would be expected from only changes in the mean maximum summer temperature. Similarly, cold waves would become rarer.

Floods

Canada is subject to several different kinds of floods, including rainstorm floods, ice-jam floods and snow-melt floods. Rainstorm floods result from synoptic, meso- and microscale events, and can be of particular concern to urbanized areas, where the impermeable surface increases runoff. A shorter winter season may result in a reduced snow-pack in many areas and thereby a reduced risk of snow-melt and ice-jam floods, though greater snowfalls might compensate. Leathers and Ellis (1996) found large historical increases in lake-effect snowpacks to the lee of the Great Lakes. Floods can also occur along coastlines, from storm surges and tsunamis. Rising sea levels associated with climate warming is likely to exacerbate the impact of storm surges, though there are few parts of Canada, aside from Richmond, B.C. and Charlottetown, PEI, with large vulnerable areas near sea-level. Slivitzky and Morin (1996) examined spring runoff in Quebec using four GCMs and found increases ranging from 1.6-13.3% as a result of increased snowmelt. These results suggest possible future increases in flooding during the spring.

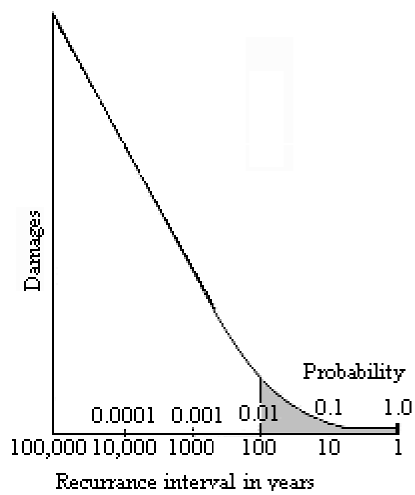
Mainly, concern about increased flooding in a $2xCO_2$ world result from the fact that warmer atmospheres can hold more moisture, and precipitation is expected to increase as a result. As well, the precipitation is expected to become more convective in nature, and therefore more intense over smaller areas, which suggests greater flooding problems. In Canada, concern regarding floods was highlighted in 1996 and 1997, when severe flooding in Saguenay, Quebec (due to heavy rainfall) and southern Manitoba (due to the rapid melt of a heavy snowpack) occurred. The Saguenay flood is one of the costliest natural disaster thus far to the Canadian insurance industry, while the Manitoba flood has large financial implications for the public sector.

Gordon et al (1992) while noting that GCMs cannot provide meaningful quantitative estimates of how extreme rainfall events may change, note that their GCM shows a marked increase in convective rainfall events and a mid-latitude decline of non-convective events. The frequency of large rainfall increased (with return periods decreasing by around a factor of two for the central U.S. but by up to 5 elsewhere) while the frequency of light rainfall days decreased for all regions, especially in mid-latitudes. These results are similar to Noda and Tokioka (1989) , Hansen et al (1988), and others. Also, Whetton et al (1993) found increased extreme rainfall events from a GCM run for Australia, though noting the significant caveats with which such results must be treated.

This increase in variability (resulting from more favoured convection) suggests potentially large changes in the probability of extreme events, as discussed by Katz and Brown (1992). In one example by Smith (1993, see Figure 2.2), a 25% increase in half-hour rainfall intensities for Sydney changed the 1 in 100 year event into a 1 in 17 year event. While noting the severe limitations of estimating changes to flood probabilities, he observes that for Australia, there is a consensus that the frequency of extreme floods will increase. He also shows that changes in the occurrence of low probability extreme events result in relatively large increases in damage . In fact, historically in Australia, damage caused by greater than 1 in 100 year event is about equal to all the events below that return period.

Rind et al (1989), Wilson and Mitchell (1987) and Parey (1994), contrary to other results, did not find evidence of increased heavy rainfall in a GCM experiment.

Figure 2.2 The relationship of flood damage to flood probability



Lawford et al (1995) found no clear evidence of historical trends that indicate changes to extreme flood events in Canada, though the data is suggestive that Alberta may be experiencing more heavy rainfall storms now than in the 1960s.

In summary, climate models suggest an increase in flooding events, as a result of a trend towards more convective precipitation and greater atmospheric absolute humidity.

Drought

If floods are the Yin of the precipitation hazard, then drought is the Yang. The concern is that if precipitation becomes more convective with an increase in heavier events, then the number of dry days will increase and drought will become more severe (IPCC, 1995). This could be exacerbated by increases in potential evapotranspiration due to higher temperatures.

An interesting paper by Hughes and Brown (1992) indicates that central California has had fewer droughts in the period from 1850 to 1950 than at any time in the last 2000 years. This suggests that the current climate is anomalously benign, and that increased drought frequency in the future is not unlikely for that region. Vance (1991) found that drought on the northern Great Plains are not cyclical, but rather that intervals of intense drought are interspersed between longer periods when drought is rare.

Oladipo (1993) analyzed drought in northern Nigeria, and found a statistically significant abrupt transition towards lower precipitation in the Sahel region beginning in 1968.

Whetton et al (1993) notes that GCMs cannot adequately simulate soil water balances and examined drought in Australia using a stand alone soil water balance model. His results found unclear signals about the soil water regime, and he was not able to draw any conclusions about the future probability of drought.

Some GCM studies show reduced summer soil moisture values over the mid North American continent, suggesting more frequent droughts, though Maybank et al (1995) indicate that the trend is not clear. Cubash et al (1995) found a doubling from 1% to 2% in the frequency of 3 month droughts in central North America in a $2xCO_2$ run. Laird et al (1996), reconstructed drought patterns in the Northern Great Plains, USA using 2300 year fossil diatom assemblages, and concluded that extreme droughts of greater intensity than occurred during the 1930's were more common prior to AD 1200, and that today's favourable climate is not representative of the long term. Wetherald and Manabe (1995) attribute increased drought to a reduction in mid-latitude soil moisture as a result of more evaporation

Though the evidence is still not clear, there is a reasonable basis for concern that the frequency of meteorological droughts will increase in the future.

Other Hazards

Various other hazards are tied to the more primary ones discussed above. For example, wildfires are a function of temperature, the precipitation regime and lightning, and are quite sensitive to climate variability and change. This can be seen by examining fire damage in Canada in the 1980's and 1990's, which increased significantly above 1920-1980 levels (Kurz and Apps, 1996). Street (1989), using the current GCMs, depicts a longer and more severe forest fire season in Ontario, with the most severe fire period to develop later in the season.

Storm surges and storm waves result from ocean or lake based storms. It is not clear how these hazards will evolve if the climate warms (Khandekar and Swail, 1995) due to uncertainty about storm intensities. Karl et al (1995) developed a climate extremes index for the U.S. and found that it's trend supports the argument that the climate has become more extreme since about 1976 (mainly as a result of changes in precipitation, not temperature), though the pattern does not lie outside historical variability.

Summary

Table 2.1 summarizes the scientific consensus of the above discussion. Trends are most likely to occur in the frequency of heat and cold waves, followed by more frequent convective storms and floods. Drought is also expected to become more frequent, though confidence is not as high for this hazard.

Table 2.1 Hazard Trends as a Result of Climate Warming

Hazard	Trend with Climate Warning	Confidence
Tropical Cyclones	No significant trend foreseen	
Extra-Tropical Storms	Conflicting evidence	
Convective Storms	More frequent and severe	High
Heat Waves	More frequent and severe	Very High
Cold Waves	More frequent	Very High
Floods	More frequent	High
Drought	More frequent, possibly prolonged	Moderate

ADAPTATION AND THE COSTS OF NATURAL HAZARDS

Not a great deal of research has been directed towards adaptation and climate change (for example, Smit (1993) refer to the *"paucity of research"* on adaptation and climate change and variability), though it appears to be increasing as it is recognized that a certain amount of climate change is inevitable (IPCC, 1995), even if severe global limitation measures were immediately adopted. Most of this research, though, does not deal with extreme events, though its importance is occasionally noted (eg. anonymous, 1995; Smit, 1993; IPCC, 1995).

Six basic strategies for adapting to climate have been identified (IPCC, 1995), these being:

(1) prevention of loss, (2) tolerating the loss, (3) spreading or sharing the loss, (4) changing use or activity, (5) changing location and (6) restoration. North American society seems to have put particular emphasis on loss prevention through technology (eg: dams), sharing the loss (eg. insurance) and restoration. This emphasis is based upon the view that current loss rates are sustainable, and that the social and other costs resulting from extreme events beyond design safety factors are not prohibitive. The costs of natural hazards are a combination of the cost of adapting to prevent damage plus the costs associated with damage when adaptations fail or extreme events overwhelm our protective systems. Recent experience has suggested that the above assumptions may not be valid, as the social costs of natural hazards has escalated manyfold in the past 15 years.

In the United States, it is estimated that natural hazards cost about $1 Billion per week (National Science and Technology Council, 1996). In the period from 1980 to 1997, there have been 28 U.S. weather related disasters each costing over $1 Billion, for a total of about $162 Billion (Table 2.2a), that have resulted in many thousands of deaths. The greatest costs in terms of dollars and especially

Table 2.2a

Weather Related Natural Disasters in the U.S.
Where The Cost Exceeded $1 Billion US (1980-1997) - Ordered By Rank in Economic Cost

EVENT	RANK by COST	DATE	ECONOMIC COST ($ Billions)	LIVES LOST
Drought/Heat Wave	1	Summer 1988	40	5,000 to 10,000
Hurricane Andrew	2	August 1992	25	58
Drought/Heat Wave	3	June-Sept. 1980	20	10,000
Midwest Flooding	4	Summer 1993	15 to 20	48
Hurricane Hugo	5	Sept. 1989	7.1	57
Hurricane Fran	6	Sept. 1996	>5	37
Drought - southern plains	7	Fall 1995	>4	0
Texas, Louisiana Mississippi Flooding	8	May 1995	>3	27
California Flooding	9	Jan-March 1995	>3	27
Southeast Ice Storm	10	Feb. 1994	>3	9
Storm/Blizzard	11	March 1993	>3	270
Blizzard / Flooding	12	January 1996	3	187
Flooding - west coast	13	Winter 1996/97	3	36
Hurricane Opal	14	October 1995	2-3	21
Florida Freeze	15	Dec. 1983	2	0
Hurricane Allicia	16	Aug. 1983	2	21
Hurricane Iniki	17	September 1992	1.8	6
Hurricane Bob	18	August 1991	1.5	18
Hurricane Juan	19	Oct.-Nov. 1985	1.5	63
Flooding - northern plains	20	April - May 1997	1 to 2	11
Nor'easter 1992	21	December 1992	1 to 2	19
Hurricane Elena	22	Aug.-Sept. 1985	1.3	4
California Wildfires	23	Fall 1993	>1	4
Flooding/Tornadoes Mississippi and Ohio valleys	24	Dec. 96 / Jan. 97	1	67
Flooding - pacific northwest	25	February 1996	1	9
Texas Flooding	26	October 1994	1	19
Tropical Storm Alberta	27	July 1994	1	32
Drought/Heat Wave	28	Summer 1993	1	unknown

Source (National Climate Data Center, 1997) deaths have been due to heat waves and droughts (a hazard which seems more likely to be increased by climate change than any other), though some hurricanes and floods have been almost as severe. Canada has also felt the impact of disasters (Table 2.2b). For example, the drought of 1988 cost Canada $1.4 Billion CAN in insurance and government subsidies. The costliest single Canadian event, in terms of insurance, is the 1998 Ice Storm, which may cost as much as $1.5 Billion CAN, followed by the Calgary hailstorm of 1991, which cost $360 Million CAN, the Saguenay flood of 1996 ($350 Million) and the Winnipeg floods of 1993 costing $160 Million CAN (Ross, 1996). Adapting to climate in Canada is estimated to cost $14 Billion annually (Burton, 1994).

More extreme events have larger return periods (ie., they occur more rarely), which is illustrated by increasing values along the X axis. The impact of these events increases with return period, that is society is more vulnerable to rarer events of greater magnitude. The dotted line (#1) depicts a situation where society has not mitigated the hazard, and is exposed to it at all levels of magnitude. Therefore the vulnerability of society and the resulting impact of the event increases with the magnitude of the event. Where mitigation has occurred (for example, dams or levees built to protect society against the 100 year flood, illustrated by the dashed line #2), vulnerability remains relatively low up to that return period. However, if increased development has occurred in, for example, flood prone areas, then vulnerability may well have increased for events with return periods longer than 100 years, hence the large increase after the 100 year event. The areas of ‘A’ and ‘B’ in the figure represent the changes in vulnerability between the natural system and the protected system. Hopefully the area of A is greater than that of B, or the overall vulnerability of society has increased. If, due to climate change, the return period of some design value decreases (say, a 100 year event becomes a 50 year event), then the area of B would increase whereas the area of A would decrease, and an overall increase in vulnerability would occur. This implies that an adapted society could become maladapted.

The relevance of climate change to natural hazards is that the frequency of extreme events may increase, and thus current adaptation measures may prove to be less adequate than at present. This is illustrated in Figure 2.3.

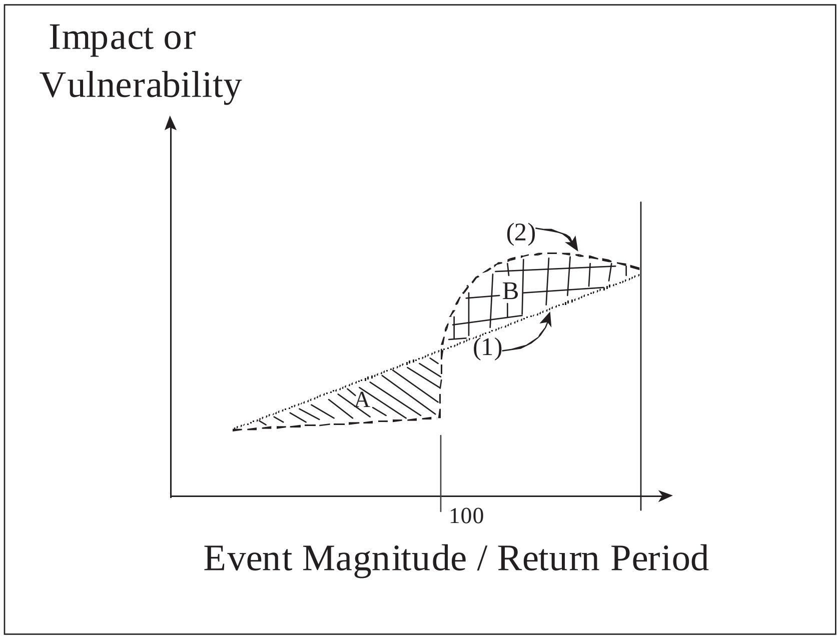
Climate change is expected to have, overall, an adverse effect on our society and the earth’s ecosystems. This is because we have (imperfectly perhaps) adapted to the climate we have at present, not the one we expect in the future. In part, the adverse impacts will be reduced by some unknown amount as we adapt to them, and as society debates the costs of limiting climate change by reducing greenhouse gas emissions, understanding our ability to adapt becomes increasingly important. Though society has had a great deal of experience adapting to climate through the use of building codes, design practices etc., adapting to climate change is a new experience, at least on the time scale projected by climate models. Thus research on adaptation to climate change is urgently needed.

Table 2.2b:

The Most Expensive Natural Disasters in Canada

Date	Disaster	Location	Casualties	Economic Impact (real $)
Summers 1979-80	Drought	Prairies	no information	CAN$2.5 billion in 1989 dollars
Summer 1988	Drought/Heat Wave	Prairies + Ontario	no information	CAN$1.8 Billion of production losses in 1981 dollars, CAN$4 billion of export losses
January 1998	Ice Storm and subsequent cold	Eastern Ontario and Southern Québec	at least 24 dead	possible CAN$1-2 Billion
1984	Drought/Heat Wave	Western Provinces	no information	CAN$1 billion
July 19-21, 1996	Flood	Saguenay region, Québec	7 dead	CAN$1 billion
1961	Drought	Prairies	no information	CAN$668 million of wheat losses in 1989 dollars
1936	Drought/Heat Wave	all provinces	780 dead	CAN$514 million of wheat losses in 1989 dollars
September 7, 1991	Hail Storm	Calgary, Alberta	no information	CAN$450 million
May 1997	Flood	Red River, Alberta	1 dead	approximately CAN$300 million
July 1985	Forest Fires	British Columbia	no information	CAN$300 million
July 31, 1987	Tornado	Edmonton, Alberta	27 dead, 253 injured	CAN$250-300 million in 1989 dollars
July 14, 1987	Flood	Montréal, Québec	2 dead	CAN$229 million
December 22, 1996 to January 3, 1997	Winter Storms	British Columbia	at least 1 dead	CAN$200 million
1993	Flood	Winnipeg, MB	no information	CAN$175 million
July 16, 1996	Hail Storm	Calgary, Alberta	no information	CAN$175 million
May 1-30, 1995	Forest Fires	Saskatchewan	no information	CAN$122 million
July 16, 1996	Hail Storm	Winnipeg, MB	no information	CAN$105 million
July 28, 1981	Hail Storm	Calgary, Alberta	2 dead	CAN$100 million in 1989 dollars
May 31, 1985	Tornado	Barrie, Ontario	12 dead, 155 injured	CAN$100 million
September 6, 1995	Flood	Alberta and BC	no information	CAN$100 million
Spring 1950	Flood	Red River, Southern MB	0-1 dead	CAN$125.5 million

Figure 2.3: Frequency vs. Impact of Extreme Events



Extreme Events and Public Perception

The perception of an event can be more important than the event itself, in terms of decision-making. How do Canadians perceive climate change?

Kearney (1994) noted that,

- "the direct perception of climate change by humans is practically impossible because of the temporal scales associated with this change", and
- "the vast spatial scales characteristic of global change are difficult to relate to everyday life."

Rebetez (1996) says that "...people... react to climate change issues mainly on the basis of their own everyday experience, when they feel that they themselves have been subjected to tangible signs of climate change." The ability of people to perceive long-term trends is quite limited, whereas they are quite able to perceive natural catastrophes and abnormal weather situation (White, 1985, Farhar-Pilgrim, 1985). In one study, a 30% increase in precipitation over 30 years was not noticed. As well, Stehr and von Storch (1995), emphasize that public perception is formed by extremes, which are often misunderstood as climate change. (*An interesting example of this is shown in an article in Newsweek following the east coast storm of the century in January, 1996. Headlines blazed 'This is Global Warming?', and the text discussed how the blizzard was an example of the sort of storm that could accompany global warming*.)

This research suggests that the public perception of climate change and any associated risks will be mainly modulated through extreme events. This observation has important consequences for understanding how the public responds to scientific information on climate change, how their perceptions are formed), barriers to adaptation, and how and when information on global warming should be communicated For example, Stehr and von Storch note that Athe public never obtains a perspective of climate as elaborated by the physical experts in an unmediated fashion but only a filtered image of it." More research is needed on this topic, in order to learn how to effectively communicate risks from climate change to the public, so that they can be appropriately accounted for in the political arena.

Natural Hazards and Sustainable Development

Communities are not economically sustainable when the cumulative costs from natural hazards and disasters exceed the value gained from use of the hazardous area. Science and technology are powerful tools, in terms of changing vulnerability, and a central question that is often asked is "How can they be used to reverse the growth in losses of … property from natural hazards?" (White, 1995). It can be argued, however, that though science and technology have reduced vulnerability to the more common events that occur within design limits, their ultimate effect is to increase vulnerability to extreme events. White (1995) suggests that emphasis should be shifted to "ways in which information in various formats and channels can or may influence decisions on emergency or mitigating action", and that when "assistance policy seeks to aid those who knowingly or unknowingly have exposed themselves to hazard with little or no regard for the feasibility of measures to reduce its severity, an important incentive to avoid vulnerable locations and structures is diminished." Similarly insurance plays an important role in encouraging mitigation (or not). Costs from natural disasters, worldwide but also in Canada over the last few years have escalated. These costs may well be unsustainable for some communities or sectors, and will probably be exacerbated by climate change. As the return period of certain extreme events shortens, many communities will be faced with more frequent disasters, which may well in many cases overwhelm the value gained from use. Thus, climate change works against sustainable development. From this perspective, a useful scenario of a future climate would be to consider case studies of historical extremes, with smaller return periods. A better understanding of how land use, building design and construction, insurance and public assistance relate to sustainable development is needed, in order to provide for a viable future.

THE SOCIAL AND ECONOMIC IMPACT OF HYDROMETEOROLOGICAL HAZARDS AND DISASTERS IN CANADA: A PRELIMINARY INVENTORY

Caveats - Please Read!

This paper is incomplete. It is incomplete for a number of reasons:

1. Data on the social and economic impacts from natural hazards are frequently not available.

2. Often the data is archived or stored in such a way that it was not practically or economically feasible to obtain it, given the resources currently available for this work.

3. There are holes in the data resulting from the facts that (a) not all relevant organizations (there are a huge number of them) have yet been contacted and (b) not all contacted organizations have responded.

4. The analysis of this data is being done by a meteorologist. Clearly, it should be done in cooperation with an economist and/or social scientist.

Introduction

Canada is subject to a variety of natural hazards, both geophysical and hydrometeorological. From time to time, these hazards have had significant social and economic impacts on Canadians, and they are sure to continue to do so in the future. Recent examples that had significant social and economic impacts are the damaging hailstorms over Calgary and Winnipeg July 1996, the severe flooding that devastated the Saguenay region of Quebec July 1996, the flooding of the Red River spring 1997 and the horrendous Ice Storm in eastern Ontario, southern Quebec and New Brunswick January 1998.

Understanding the historical and potential costs resulting from natural hazards and disasters is important because:

1. People, if they are aware of their risks, are able to make more informed personal decisions regarding the purchase of insurance and other mitigative and adaptive options.

2. Governments at various levels can devise better policy tools to deal with hazards, in terms of prevention, response and recovery.

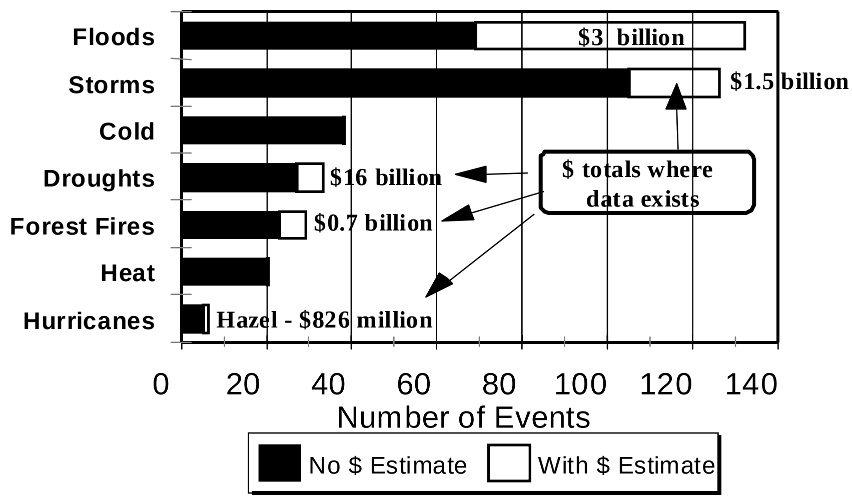
3. Industries (e.g., Insurance) can base their cost-benefit analyses on the best available data.

This paper will only inventory hydrometeorological events, though other natural hazards are certainly important (in fact the greatest risk Canadians face in the future from a natural hazard is probably due to an earthquake). The inventory upon which this paper is based is summarized, in part, in Figure 2.4, which shows the number of identified events by hazard for which cost estimates could or could not be made. The total of known costs are provided at the end of each bar, in 1995 dollars. Tornadoes are not included, since there are over 2,200 known Canadian events. Events are included if the information source suggested a significant impact of some sort, either meteorological, social or economic. No precise definition of significant is used. The data collection was done primarily by undergraduate and graduate students during their work terms. For some categories, such as heat and cold, a number of events were identified, though no cost estimates were found. Further research in these categories may reveal some economic information. Some categories such as floods and storms have a number of estimates, though there are still a large proportion of events with no estimate. Droughts, by far, are cumulatively the most costly hazard, though they rank fourth on the list of frequency. It is worth noting that for hurricanes, only Hazel had an economic impact that was known. Severe ice storms can also be very costly, though less frequent than other disasters.

An historical survey of Canadian disasters (Jones, 1991; Jones, 1995) shows that 44% of them were weather or climate related. Almost one-third of all disasters occur at sea, and 80% of those are weather related. A listing of these disasters follows in Table 2.3 and Table 2.4.

Figure 2.4

Number of Identified Hazard Events (tornadoes not included), 1961-1996. Totals in 1995 dollars. These estimates do not include the 1997 Red River flood ($300 Million) or the Jan. 1998 Ice Storm ($2-3 Billion).



What Are Natural Disasters?

Natural disasters are the extreme of natural hazards, and occur when social vulnerability is triggered by an extreme event. A disaster is said to occur when recovery is not possible using local resources. There have been numerous recent examples, including the 1998 Ice Storm, Red River flood of 1997 and the Saguenay flood of 1996. Blaike *et al.*, (1994) emphasizes the importance of understanding the social roots of disasters (while nature causes the event, man makes the disaster). The costs we incur from hazards are a function of our adaptive decisions. For example, if nobody lived in trailer parks or attended schools in portables, then there would be many fewer deaths from tornadoes. Unsafe conditions result from a number of social forces which are rooted in limited access to power, economic resources and the nature of political and economic systems. Figure 2.5 (adapted from Blaike et al, 1994) illustrates this relationship.

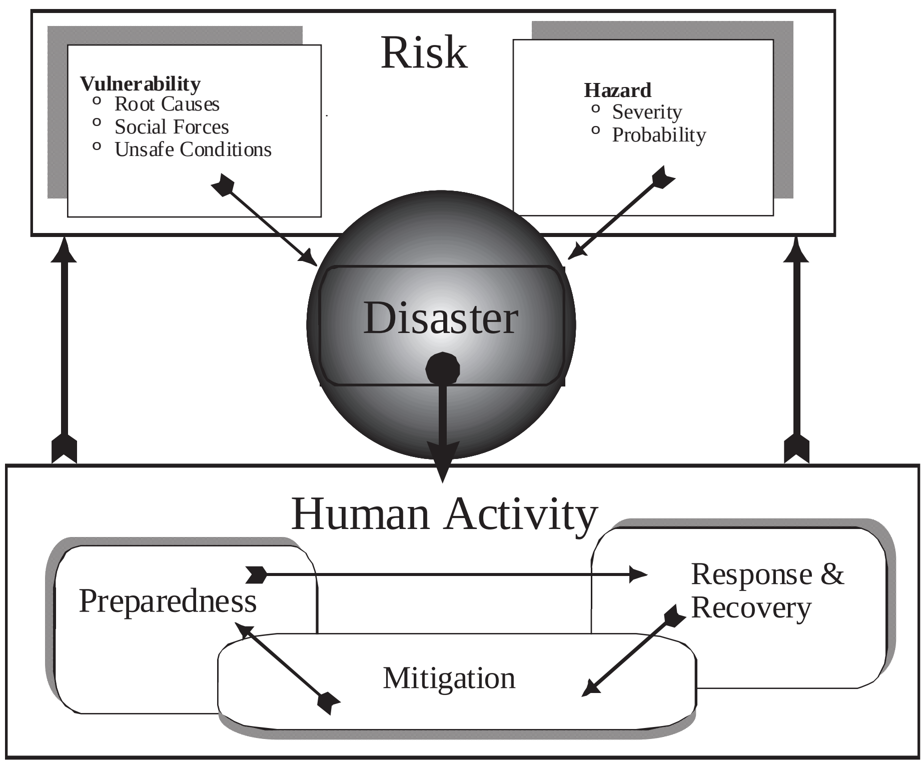
Table 2.3 Canadian Weather-Related Disasters that had a death toll greater than 20 and were a single event.

Disaster	Year	Deaths
1. wreck of *Delight* off Sable Island, N.S.	1583	85
2. fleet of ships aground in fog, Quebec City	1711	884
3. hurricane hits Grand Banks, Nfld	1775	4000
4. sloop *Ontario* sinks in Lake Ontario	1783	190
5. *Hamilton* and *Scourge* sink in Lake Ontario	1813	53
6. Miramichi, N.B. fire	1825	200-500
7. hurricane-force winds on Lakes Ontario and Erie	1844	200
8. hurricane hist Nfld.	1847	300
9. PEI gale sinks 70 US fishing vessels	1851	150-300
10. wreck of *Hungarion* off Sable Island	1860	205
11. wreck of *Anglo Saxon* on Cape Race, Nfld.	1863	238
12. St. Lawrence River floods (Sorel and Trois Rivieres)	1865	45
13. *City of Boston* disappears in storm off N.S.	1870	191
14. wreck of *Atlantic* if fog of Prospect, N.S.	1873	535-585
15. forest fires near Lake Huron	1881	500
16. *Asia* sinks in Georgian Bay gale	1882	126
17. *Algoma* sinks in Lake Superior	1885	48
18. great fire of Vancouver	1886	30-40
19. *La Bourgogne/Cromartyshire* collision off N.S.	1898	549
20. wreck of *Valencia* off Vancouver Island	1906	126
21. avalanche in Rogers Pass, BC	1910	62
22. forest fire, Porcupine, Ontario	1911	73
23. Regina tornado	1912	29
24. 34 ships sink in Great Lakes storm	1913	270
25. *Southern Cross* vanishes off Nfld.	1914	173
26. 4 seal ships caught in ice off Nfld.	1914	77
27. *Empress of Ireland/Storstad* collision off Rimouski, Que.	1914	1014
28. Britannia mine avalanche, Howe Sound, BC	1915	57
29. forest fire, Cochrane/Matheson, Ontario	1916	233
30. *Princess Sophia* runs aground, northern BC	1918	343
31. forest fire, Haileybury, Ontario	1922	44
32. *John B. King* hit by lightning	1930	30
33. 3 Great Lakes ships wrecked	1940	69
34. *Truxton* and *Pollux* aground off Nfld	1942	204
35. Hurricane Hazel	1954	83
36. TCA Northstar crash, Mt. Slesse, BC	1956	62
37. 22 fishing boats sink in storm, Escuminac, NB	1959	35
38. winter storm hits Maritimes	1964	23
39. Granduc Mt. avalanche, Stewart, BC	1965	26
40. *D.J. Morrell* sinks in Lake Huron	1966	28
41. crater opens in rainstorm, St. Jean-Vianney, Quebec	1971	31
42. wreck of Edmund Fitzgerald, Lake Superior	1975	29
43. PWA 737 crash, Cranbrook, BC	1978	42
44. Ocean Ranger sinks off Nfld	1982	84
45. Edmonton, Alberta tornado	1987	27
46. Air Ontario crash, Dryden, Ontario	1989	24
47. *Johanna B* and *Capitaine Torres* sink - Gulf of St. Lawrence	1989	39
48. Gold Bond Conveyor sinks off Yarmouth, N.S.	1993	33

Table 2.4 Supplemental list: Weather-related disasters that occurred over more than a few days or possibly outside Canadian territory, or had a death toll less than 20

Disaster	Year	Deaths
49. Two Quebec City fires	1845	23
50. loss of Franklin expedition, NWT	1847-48	129
51. Cape Breton hurricane sinks 1200 ships	1873	'untold'
52. great fire of Saint John, NB	1877	18-100
53. *Titanic* hits iceberg south of Grand Banks	1912	1513
54. longest Canadian summer heat wave	1936	780
55. '*Dirty Thirties*' on Canadian Prairies	1930-39	?
56. Lake St. Clair tornado	1846	16
57. Red River Flood, Manitoba	1950	1
58. freighter sinks in Lake Superior due to winds	1953	17
59. 60 hour snowstorm in Montreal with 70 cm snow	1969	15
60. Barrie, Ontario tornado	1985	12
61. trawler *Hosanna* sinks 400 km off Cape Race	1987	34
62. *Protektor* disappears 400 km east of Nfld.	1991	33
63. *Salvador Allende* sinks 900 km south of Nfld.	1994	29

Figure 2.5 Disaster Adaptation Cycle

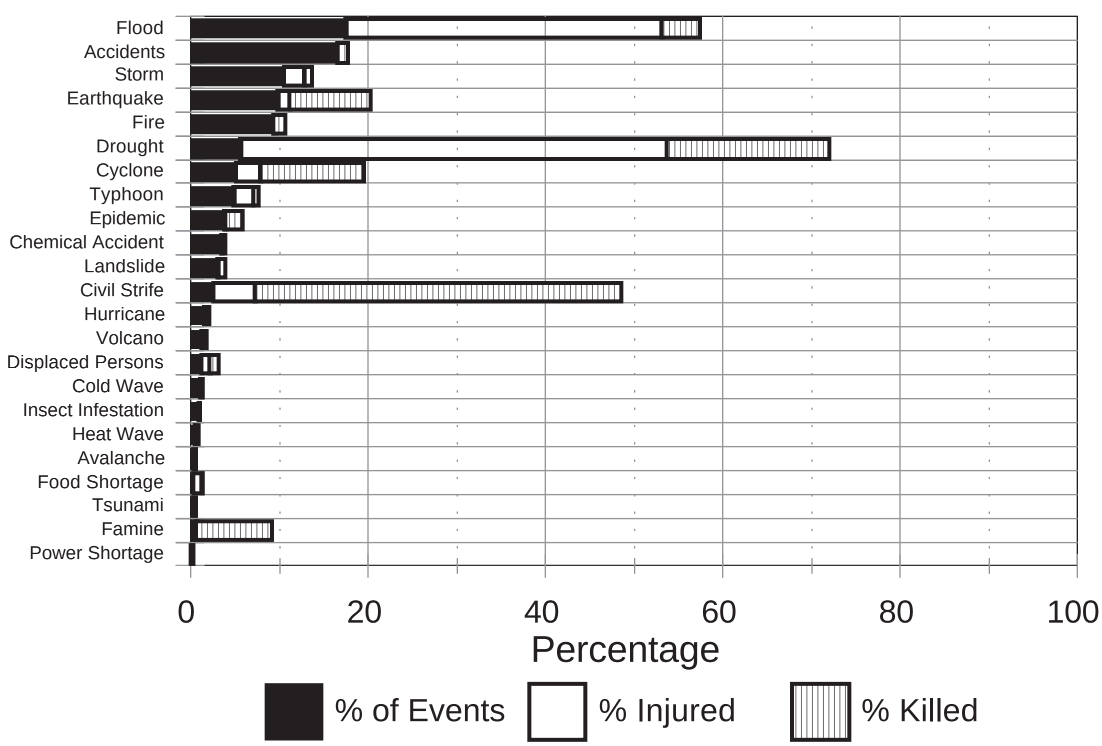


A disaster typically triggers a cycle of human response of response and recovery, mitigation and preparedness. This response can alter our vulnerability and thereby influence future disasters.

Natural Hazards in Context

Worldwide, people die from many causes, the dominant ones being civil strife and famine. Figure 2.6 shows the number of disasters worldwide from 1967-1991, including numbers injured and killed. Note that floods are the most frequent disaster, though drought claims the most victims. Most natural hazards cause relatively few deaths directly, especially in developed countries though their economic impact can be large. The one possible exception is famine, which is often drought or flood related, though some would argue that the number of fatalities are more related to social issues than the physical hazard itself.

Figure 2.6 World Disasters, 1967 to 1991



As a result of 7,766 events, 3 Billion people were injured and 7.5 Million killed. Weather related hazards accounted for 47% of the events, 91% of the injuries and 36% of the deaths.

Source: World Disasters Report, Int'l. Red Cross

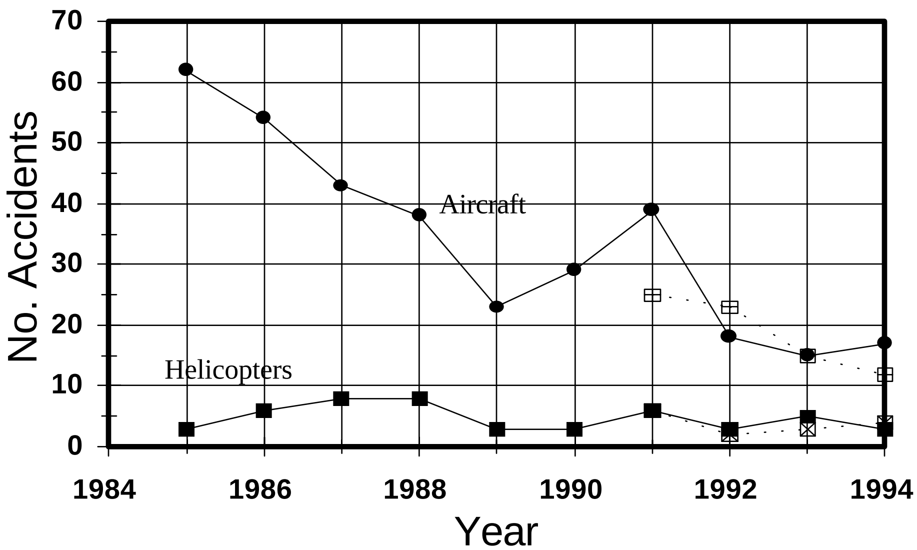
These numbers vary greatly from country to country for obvious reasons. Countries that are not at war and that are wealthy enough to support good health care systems and infrastructures that reduce vulnerability would be quite different from countries such as Somalia, which suffers from a variety of social and economic woes. Costs incurred in Canada are summarized below.

Social Costs in Canada

Transportation: Aircraft Accidents (Source: Transport Safety Board of Canada)

Figure 2.7 shows aircraft and Helicopter accidents in Canada from 1985 to 1994. The filled-in icons illustrate weather related events while human-environmental interactions are shown from 1991 onward by the empty circles and squares. The values were adjusted to the number of hours flown in 1994. Note the downward trend in weather related aircraft accidents of over 60 in 1985 to less than 20 per year in 1994. Helicopter accidents have shown a much smaller trend.

Figure 2.7 Weather Related Aircraft Accidents

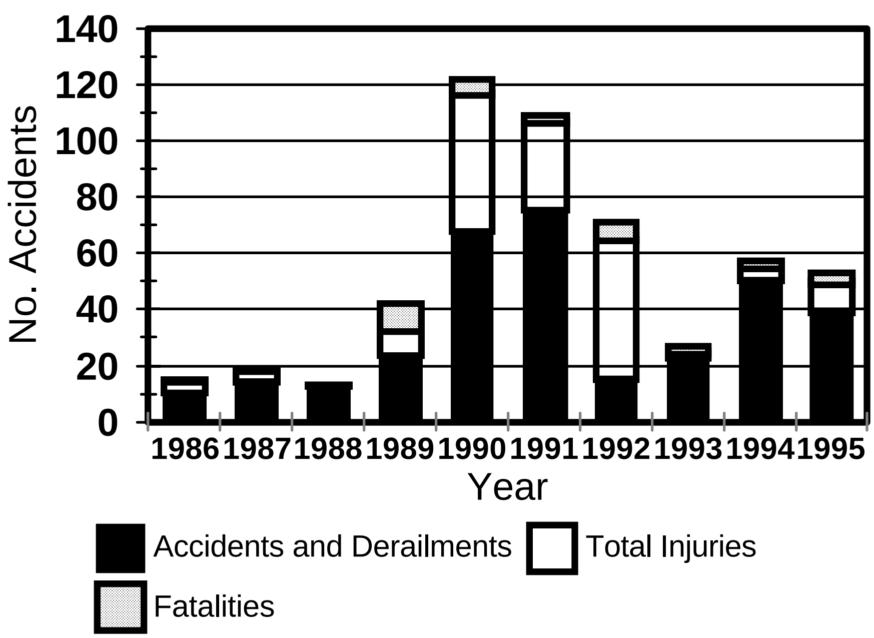


Solid icons are weather related. Cross-haired icons represent Human-Environmental Interaction
Source: Transport Safety Board of Canada

Railway Accidents (Source: Transport Safety Board of Canada)

Significant numbers of weather related railway accidents occur in Canada - over 120 in 1990 - though there are few fatalities (Figure 2.8). The number of accidents showed a sharp increase from 1988 to 1990, for an as yet undetermined reason, with a subsequent decrease after 1991, though not to the pre-1989 levels.

Figure 2.8 Weather Related Railway Accidents

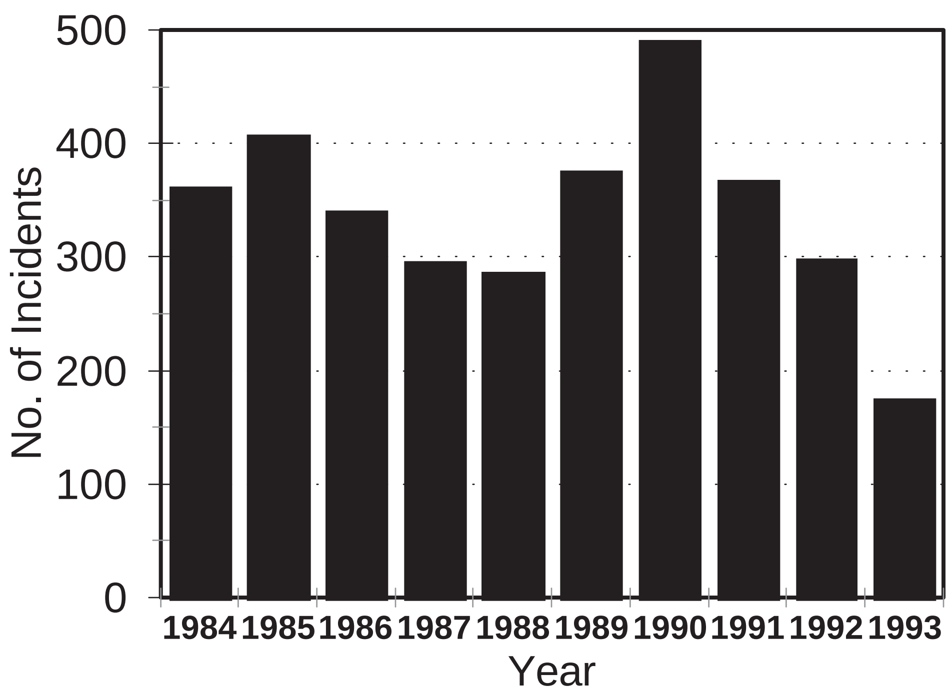


Source: Transport Safety Board of Canada

Marine Accidents (Source: Transport Safety Board of Canada)

Historically, many of Canada's worst disasters have been ocean based (Jones, 1995). Figure 2.9 shows the number of weather related marine incidents from 1984 to 1993. The worst year was in 1990, as for railway accidents, with almost 500 incidents. Overall there has been a gradual decline of debatable significance. A history of weather related marine disasters is shown in Table 2.3.

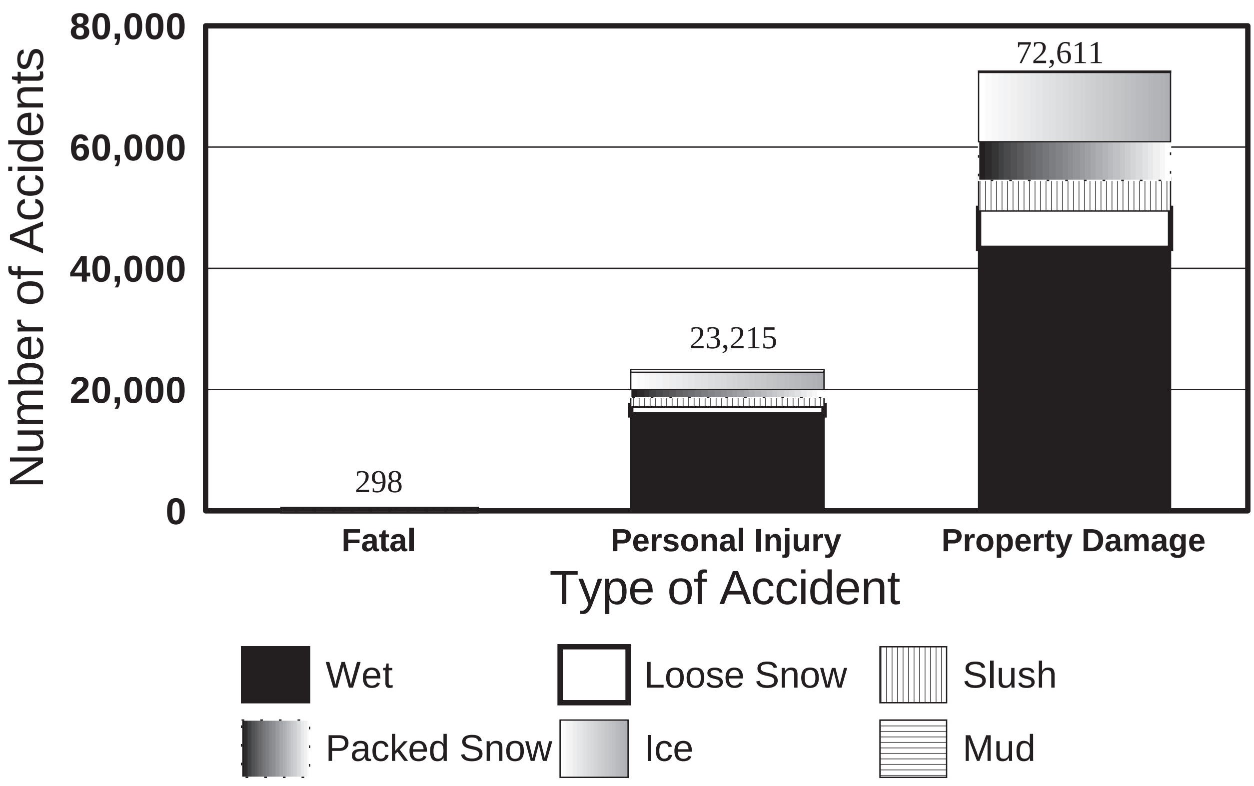
Figure 2.9 Weather Related Marine Incidents



Ontario Road Accidents (Source: Ontario Ministry of Transportation)

Figure 2.10 shows the 1992 statistics for weather-related Ontario road accidents, which accounts for about one-third of the cases. There were 298 fatalities, over 23,000 personal injuries and over 72,000 property damage cases. This does not include minor incidents not reported to the police. The majority of the accidents resulted from wet conditions, followed by ice, snow, slush and mud. Data from the other provinces is not currently available, but it is clear that weather related car accidents are of great significance.

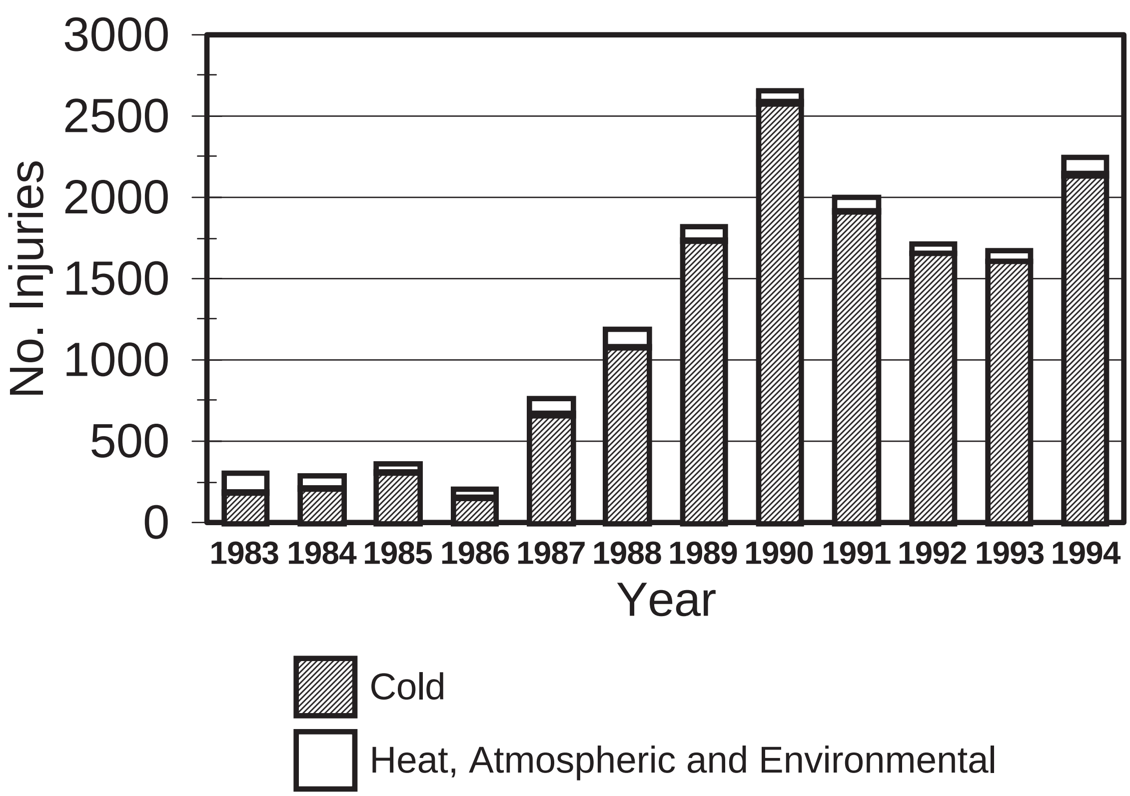
Figure 2.10 Weather Related Ontario Road Accidents



Number of Time Loss Injuries (Source: Statistics Canada)

Time loss injuries result mainly from cold, and are shown in Figure 2.11. Note the large increase after 1986, which is likely to be a function of non-climatic factors, such as policies in the Workman Compensation Boards. In recent years, injuries have occurred at a rate of between 1,500 and 2,000 per year. Costs to employers from these injuries can be very large, and are worthy of further investigation. The largest number of injuries from 1990-94 was in Quebec (56%) followed by Nova Scotia (15%) and Alberta (9%).

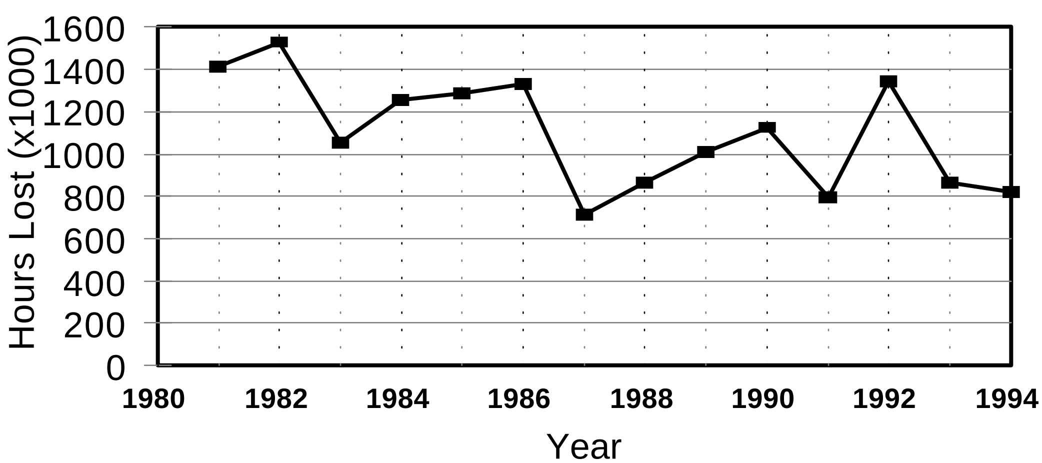
Figure 2.11 No. of Time Loss Injuries, Population Adjusted to 1995
(source: Stats Canada)



Time Lost at Work (Source: Statistics Canada)

Figure 2.12 shows the number of hours lost at work due to bad weather from 1981 to 1994, adjusted to the number of employed Canadians in 1994. The curve shows a gradual decrease in time lost, in disagreement from what one would expect as a result of the number of time loss injuries shown in Figure 2.11. Further investigation is required in order to understand this trend.

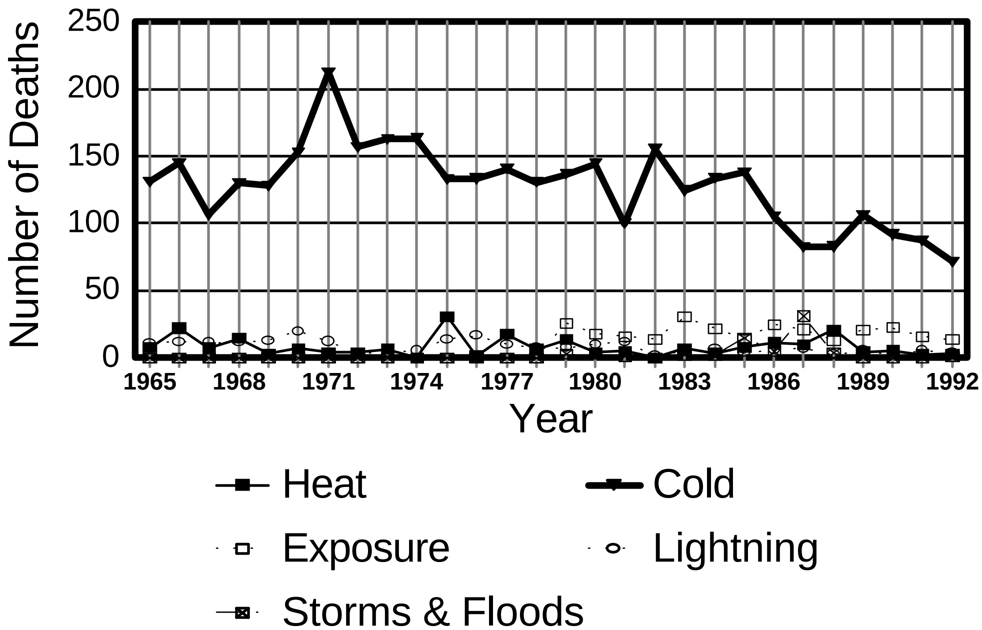
Figure 2.12 Time Lost at Work Due to Bad Weather,
(Adjusted to Number Employed in 1995, Source: Stats Canada)



Deaths (Source: Statistics Canada)

Canadians occasionally die from atmospheric hazards, as shown in Figure 2.13. Note that most deaths occur as a result of cold. By comparison, weather related fatalities due to car accidents in the province of Ontario alone are much larger (see Figure 2.10). In the past decade, the number of deaths from cold have shown a gradual decrease, while those resulting from other atmospheric causes have remained fairly constant. How Statistics Canada assigns attribution of cause requires further investigation.

Figure 2.13 Deaths from Natural Hazards, Population Adjusted to 1995
(Source: Stats Canada)



Economic Costs

There are two fundamental costs associated with natural hazards:

1. **Adaptation costs -** the costs related to protecting ourselves from hazards (e.g., building codes or dams), and
2. **Impact, response and recovery costs -** the costs that society incurs when our protections fail.

Adaptation Costs

Estimating adaptation costs is a difficult task, and little research has been devoted to it. One preliminary estimation of Canadian adaptation costs is provided in Table 2.5. The total shown in this table is likely an underestimate (by some unknown amount) since it is not comprehensive.

Table 2.5 Annual Climate Adaptation expenditures in Canada by Economic Sector
(Source: Burton, 1994)

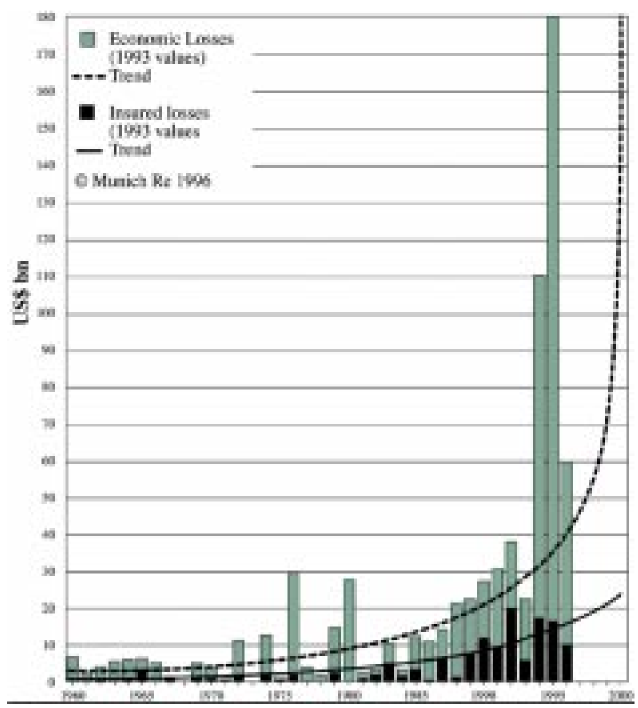
Sector	Annual Expenditures (Billions $)
Transportation	1.7
Construction	4.0
Agriculture	1.3
Forestry	0.4
Water	0.8
Household	5.3
Emergency Preparedness	0.01
Weather Services	0.2
Total	13.7

Costs due to Impacts

Other Countries and Worldwide:

Economically, natural hazards have shown some dramatic trends. Figure 2.14 (Swiss Re., 1994) shows impact data worldwide - note the increase in recent decades. This increase is due to (1) increases in population, (2) the migration of population towards more hazardous areas such as coasts, (3) increases in wealth in many countries and (4) possibly an increase in the number of hazardous events.

Figure 2.14 Economic and insured losses due to great natural disasters, 1960-1996, with trends extrapolated to 2000



The U.S. estimates that natural hazards cost them about $1 Billion per week (National Science and Technology Council, 1996), and some of the more significant events such as Hurricane Andrew (which caused a number of insurance companies to go bankrupt) and the Northridge earthquake have had massive impacts. It is worth noting that Changnon *et al.*, (1996), found that the 707 U.S. catastrophes in the $10-100 Million range from 1949-1994 have shown a continual increasing trend, not related to weather fluctuations, but to changing populations or targets. Disasters costing more than $100 Million have not shown the temporal increase, but correlate well with weather factors - not with population shifts. The Kobe earthquake in Japan set a new standard in the potential costs of natural hazards, with a price tag of around $100 Billion (numbers still vary quite a bit, depending upon the source). Table 2.2 shows a U.S. summary of recent costs due to natural hazards.

Economic Costs to Canada from Natural Hazards:

Forest Fires (Source: Canadian Interagency Forest Fire Centre)

Forest fires can have a direct impact due to the loss of a natural resource, though it is unclear how to account for them as they are now considered an essential part of the natural ecological cycle. Figure 2.15 shows the area of forests burned in Canada from 1986-95. Note that 1995 was by far the worst year with over 7 Million hectares burnt, followed by 1989. The data supports an upward trend in area burnt, a statistic related to weather, but also to decisions made regarding fire fighting. All provinces incur costs related to fire management, which are shown in Figure 2.16. From the period 1985-1995, Ontario spent over $800 Million, more than any other province. Annual fire management costs are shown in Figure 2.17. Costs peak in 1995 at over $450 Million.

Figure 2.15 Forest Fires in Canada: Area Burned
(Source: Canadian Interagency Forest Fire Centre)

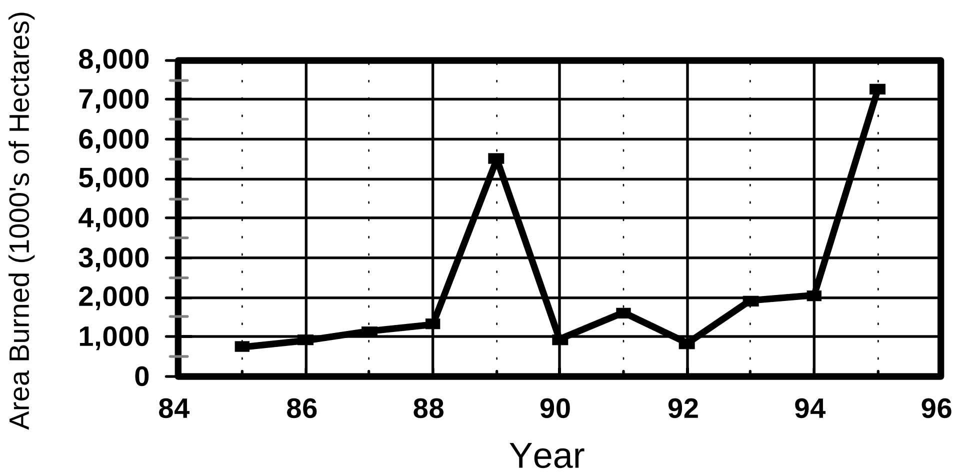


Figure 2.16 Fire Management Costs by Province, 1985-1995, Adjusted to 1995 $
(Source: Canadian Interagency Forest Fire Centre)

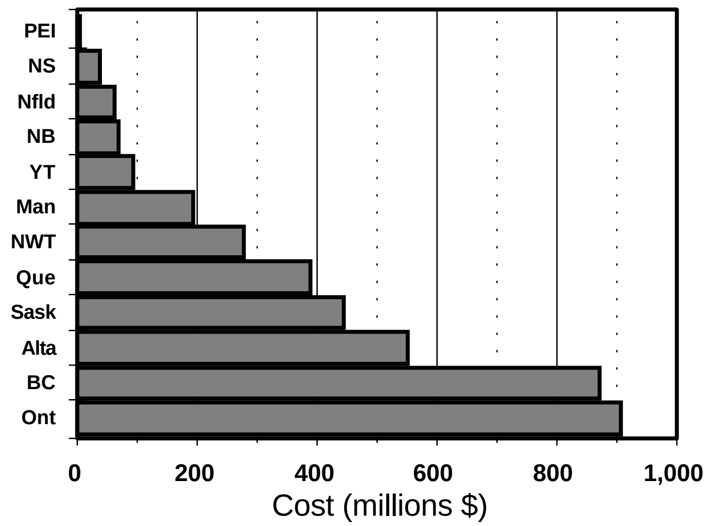


Figure 2.17 Fire Management Costs, Adjusted to 1995 $
(Source: Canadian Interagency Forest Fire Centre)

Hydro Costs

The provincial hydro companies were contacted in order to find impacts due to hazards. Ontario Hydro provided the best documentation, but only of the larger events, the cost of which are shown in Figure 2.18. Annual costs range from zero to $3 Million, and average $1.4 Million/year. Figure 2.19 shows a partial inventory of costs by hazard from several of the companies. This data set is VERY incomplete, and this figure is only provided for illustration purposes. The most costly hazard was wet snow+high winds, the total cost of which occurred due to one event at Vegreville and Lloydminster, Alberta. This two day storm destroyed 108 steel transmission towers, 300 wood transmission structures, and more than 3000 wood distribution poles. In addition more than 250 miles of conductor had to be replaced. Tornadoes (numbering 8) come second in terms of cost, though they were all from the Ontario Hydro list. Undoubtedly the prairies have experienced damaged towers from tornadoes, even though the information was not available. Costs from the January 1998 ice storm are not yet documented, but may well be in the hundreds of Millions of dollars to the Ontario and Quebec Hydro companies.

Figure 2.18 Weather Related Ontario Hydro Costs, Adjusted to 1995 $
(The January 1998 Ice Storm make previous costs appear trivial)
(Source: Ontario Hydro)

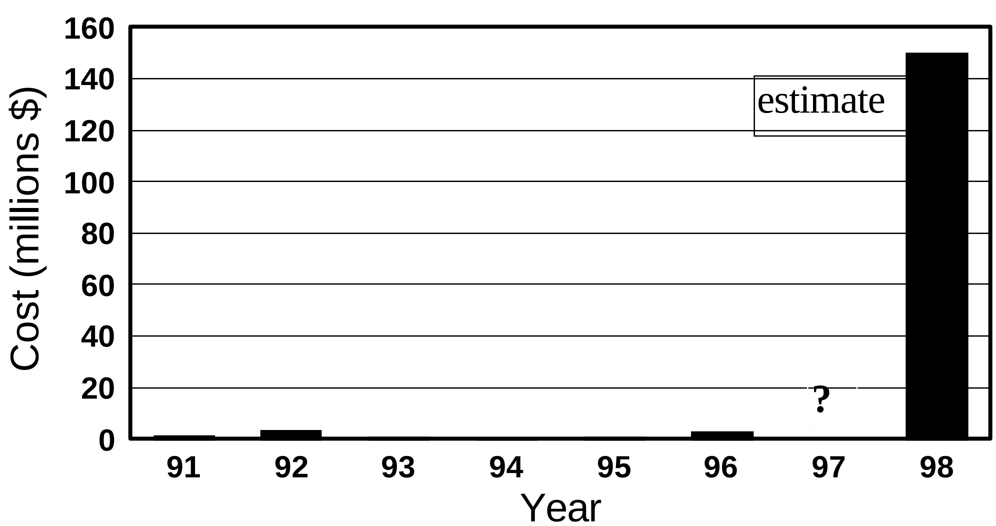
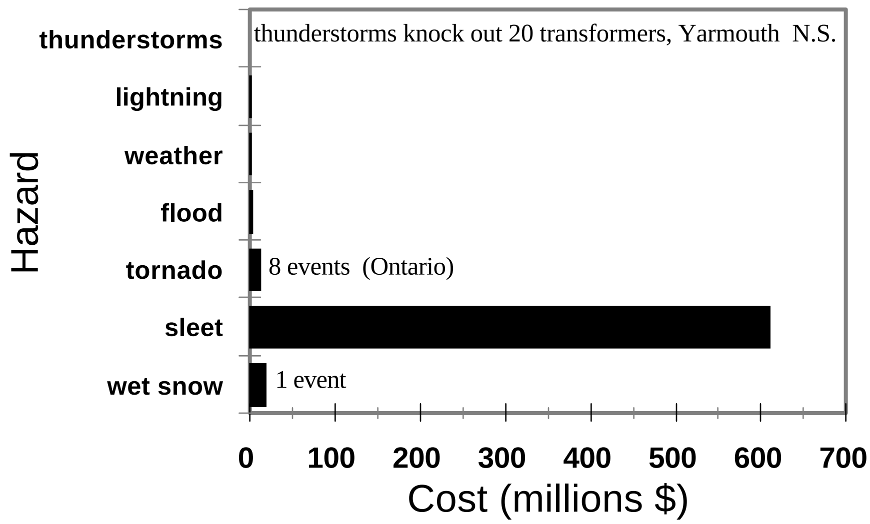


Figure 2.19 A List of Weather Related Costs to Hydro Companies, Adjusted to 1995



Sources: Ontario Hydro, B.C. Hydro and Power Authority, Nfld. Light and Power Co, Climatic Perspectives, Canadian Geographic. Important Note - this is a very incomplete list, but includes an estimate of the Jan. 1998 ice storm cost (about $150 Million for Ontairo Hydro and $500 Million for Quebec Hydro in 1998 dollars).

Figure 2.20 shows payments made by EPC to the provinces over the period 1970-1996. These numbers do not include 19 events not yet settled and costs after March 31, 1996, and therefore the prairie hail disasters and Saguenay, flood July 1996, Red River flood 1997 and the Ice Storm January 1998 are not included. A rough estimate of federal costs due to the Quebec flood is $280 Million and the Red River flood is $150 Million; the Ice Storm may well cost hundreds of Millions of dollars (Chris Tucker, personal communication). Audited totals are $425 Million ($16 Million/year) while the EPC payouts come to $263 Million ($10 Million/year), in 1995 dollars.

Figure 2.20 EPC Payouts from 1970 to 1998, Adjusted to 1995 $
(Preliminary estimates for the 1997 Red River Flood and the Québec Saguenay and Ice Storm disasters are included, Source: Emergency Preparedness Canada)

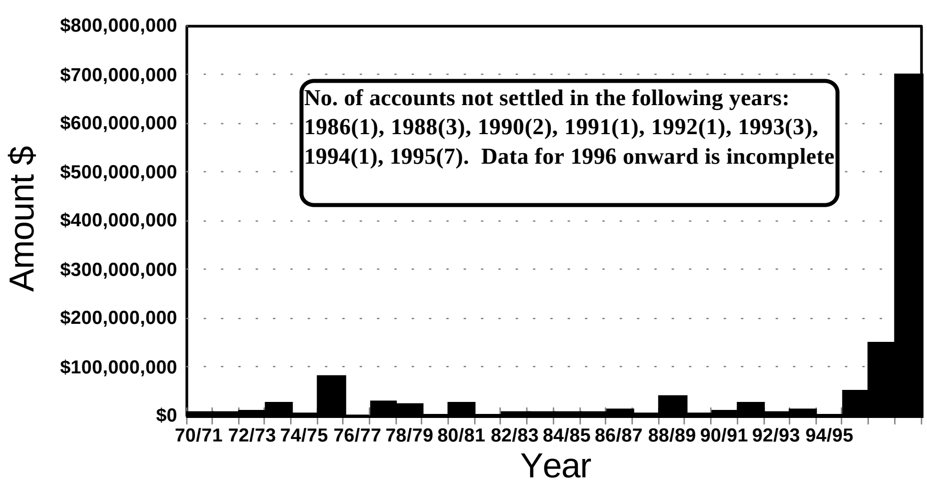


Figure 2.21 shows how these costs are distributed by province. Quebec has received the most support (around $134 Million in 1995 dollars- which amounts to 32% of all payouts - and which may increase to $414 Million if the Saguenay floods are included), Manitoba the next with $83 Million (20%) while Ontario has received the least ($75,000 - 0%). Clearly, natural hazards point to the importance of federalism for some provinces.

Figure 2.21 EPC Payouts by Province from 1970 to January 1998
(Adjusted to Fiscal Year 1995/96 $. This includes preliminary estimates for the 1997 Red River Flood, the 1996 Saguenay Flood and the 1998 Ice Storm. Data from 1996 onward is incomplete. Source: Emergency Preparedness Canada)

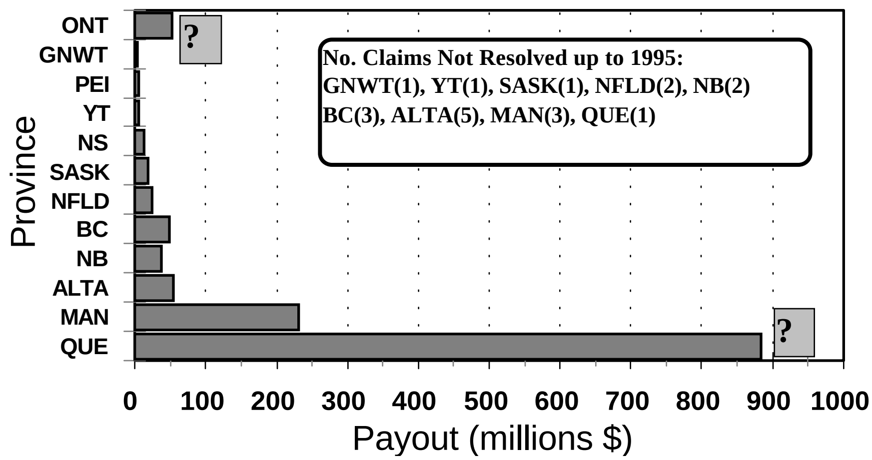
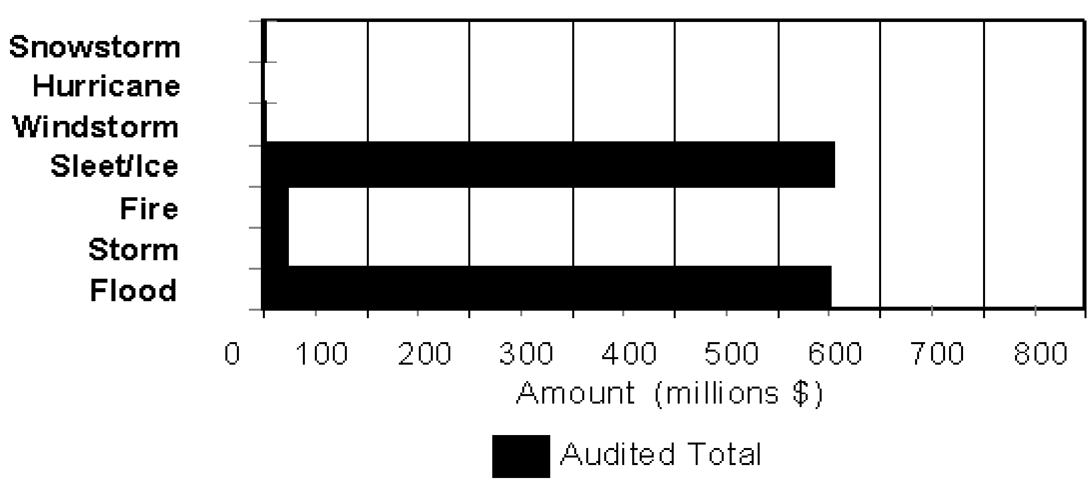


Figure 2.22 shows payouts by hazard type. Floods have cost the most, by far, with audited totals over $300 Million and federal payouts of $150 Million (73% of the total - unadjusted dollars) while storm and fire rank second and third with about 11% each. The Saguenay disaster makes floods even more prominent in comparison.

Figure 2.22 EPC Payouts by Disaster from 1970 to 1998 (Unadjusted $)
(Data after 1995 is incomplete, and includes preliminary estimates for the Saguenay and Red River Floods, and the Ice Storm. Source: Emergency Preparedness Canada)



Crop Insurance

Provinces incur costs due to crop damage from hail, flood, drought and a variety of other hazards. Figure 2.23 shows the average annual provincial costs. Saskatchewan incurs the greatest costs, over $130 Million per year (1995 dollars). Crop losses for Manitoba run around $30 Million per year, and are detailed in Figure 2.24, which shows the costs by hazard. Drought is the major hazard, almost $400 Million 1995 dollars from 1966-1994, followed by excess moisture, hail, heat, and frost. Other hazards are much smaller. Costs vary greatly from year to year, as shown in Figures 2.25a-d. The largest annual expenditure occurred in Saskatchewan, over $550 Million 1995 dollars.

(Sources: British Columbia Ministry of Agriculture, Fisheries and Food; Alberta Hail and Crop Insurance Corporation; Ontario Ministry of Agri-food and Rural Affairs; Manitoba Crop Insurance Corporation, New Brunswick Crop Insurance; New Brunswick Municipal Affairs Emergency Measures; Quebec Ministry of Public Security; Saskatchewan Emergency Planning; Manitoba Disaster Assistance Board; British Columbia Emergency Program; Alberta's Disaster Recovery Programs)

Figure 2.23 Provincial Crop Insurance Payouts (Average paid per year 1995 $)
(Programs began as early as 1959 in Manitoba and as late as 1974 in New Brunswick)

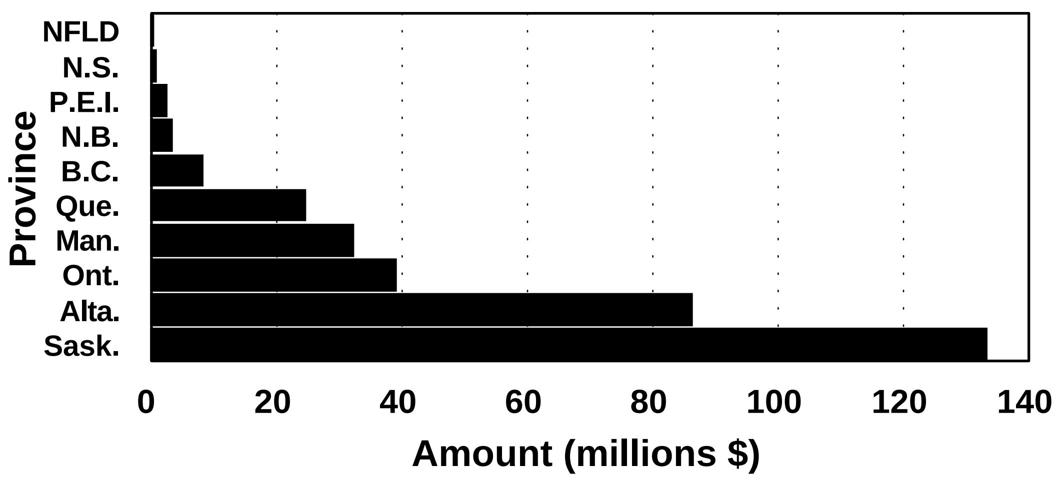


Figure 2.24 Crop Loss by Cause - Manitoba, 1966 to 1994, Adjusted to 1995 $

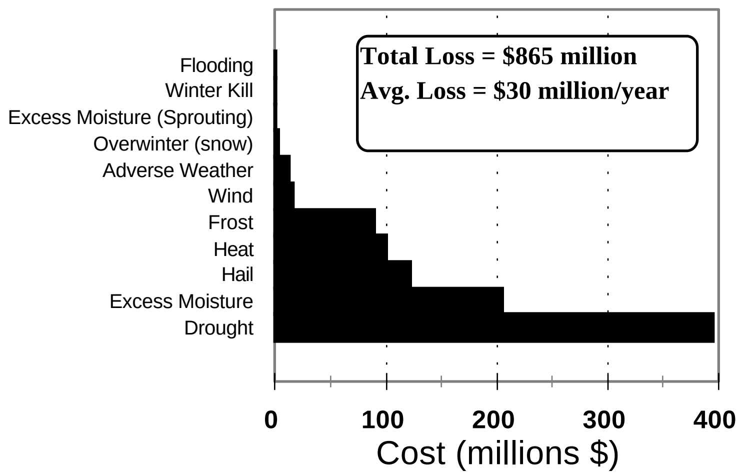


Figure 2.25a Manitoba Crop Insurance Payments 1995 $

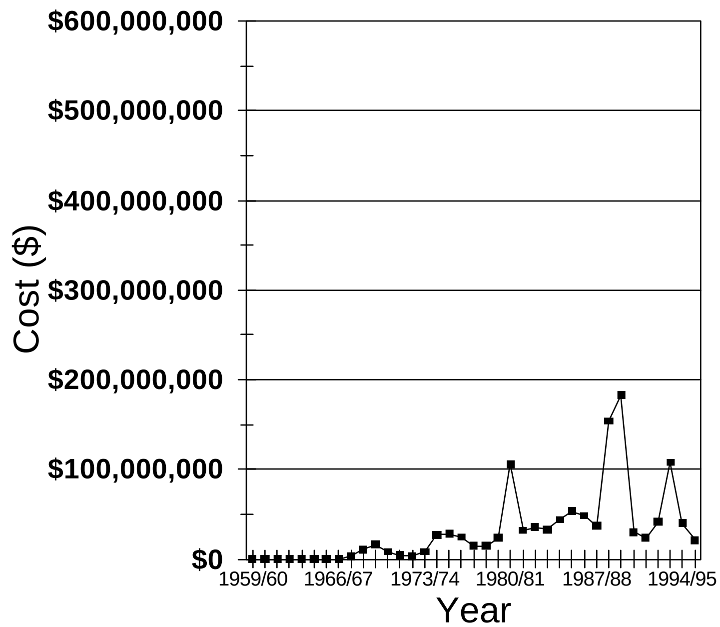


Figure 2.25b Ontario Crop Insurance Payments, 1995 $

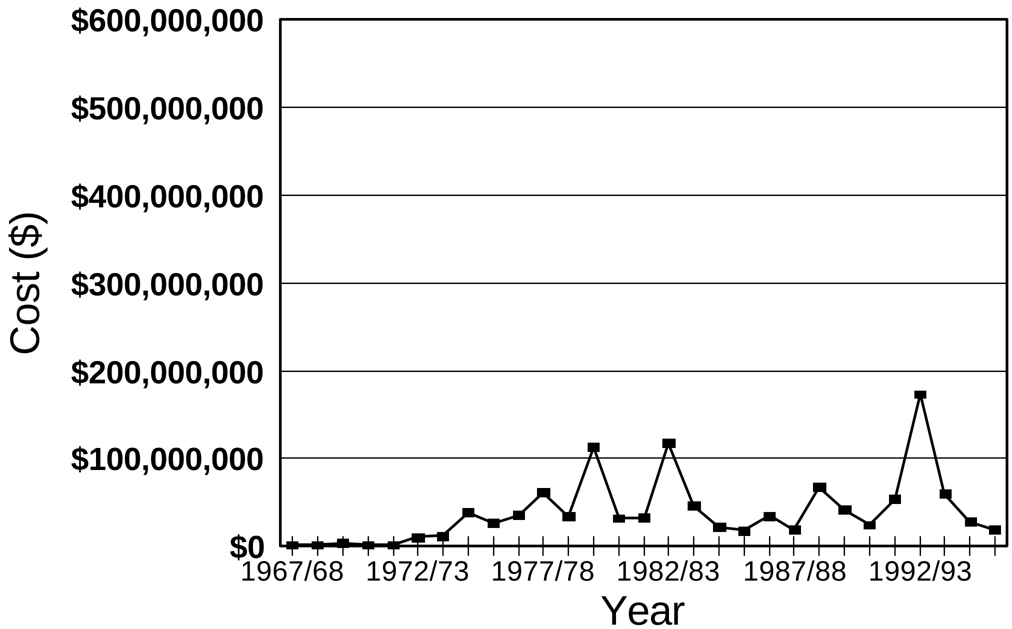


Figure 2.25c Québec Crop Insurance Payments, 1995 $

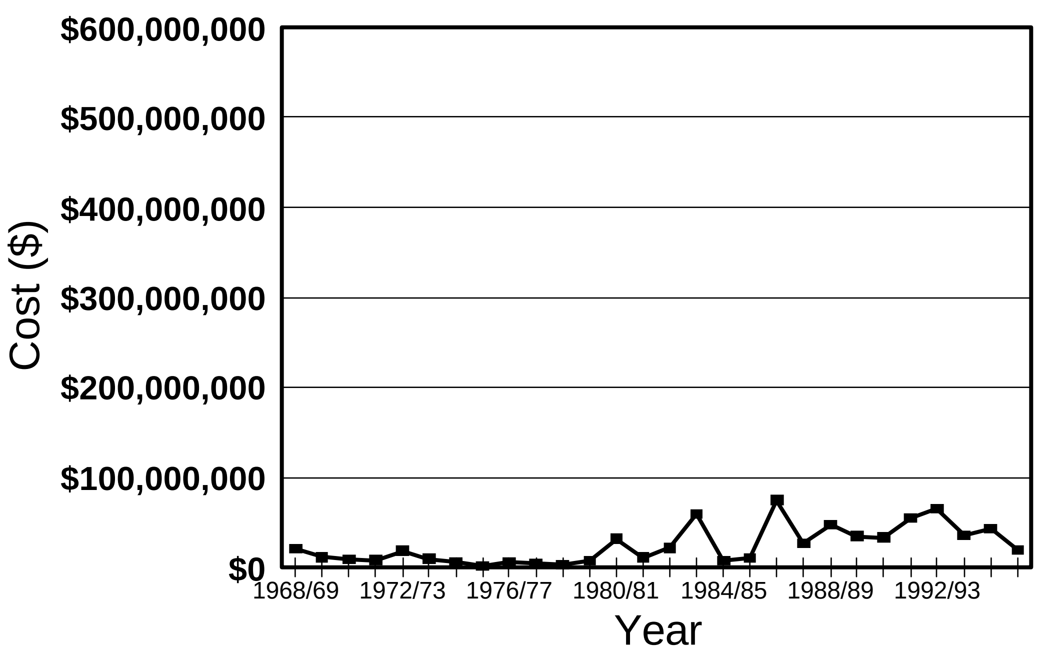
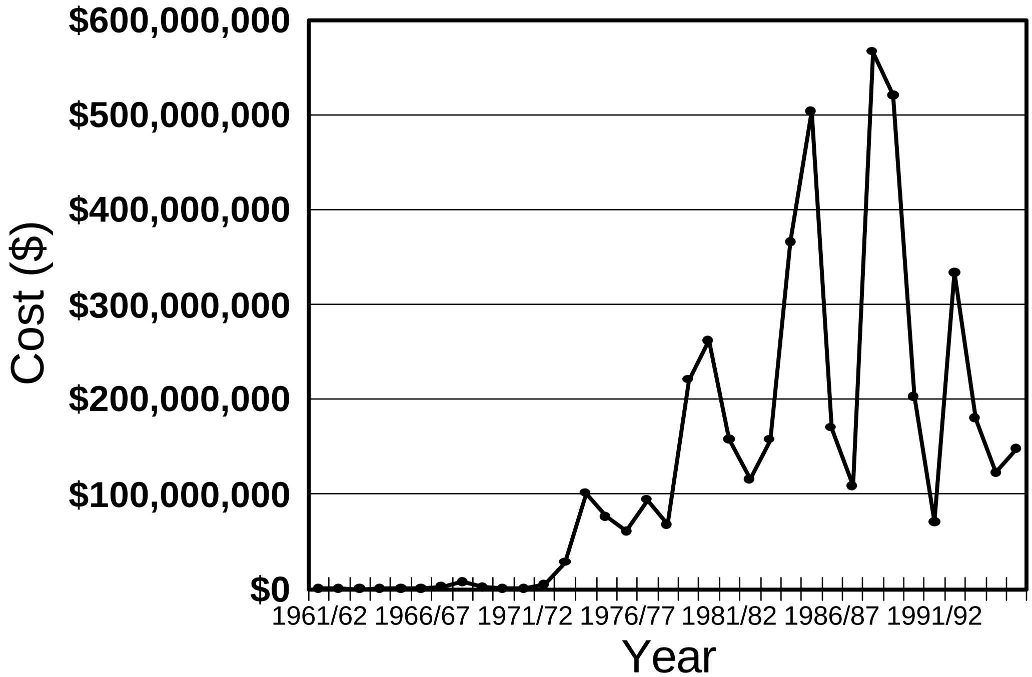


Figure 2.25d Saskatchewan Crop Insurance Payments, 1995 $



Disaster Financial Assistance

All provinces also have disaster financial assistance (DFA) programs. Data on these costs is very incomplete and requires more research. Of the $93 Million 1995 dollars paid by the Manitoba Disaster Assistance Board from 1974-95, 73% were for flood, 18% for fires, 7% for tornadoes and the remainder for miscellaneous causes. The recent Red River flood will highlight this hazard even further. All of the $74 Million B.C. costs from 1990-95 were for flood claims. In Alberta, of the $260 Million 1995 dollar cost from 1986-95, 89% were for flood and 9% for drought.

Insured Costs

Summaries of costs to the insurance industry are provided by the Insurance Bureau of Canada. Figure 2.26 shows the costs of multiple major payouts, from 1983-1994 (Source: Insurance Bureau of Canada, 1996)). This data does not include the costs of events less than about $4 Million, and therefore the true costs are much greater than those shown in this figure by an unknown amount. Hail (Figure 2.27) has caused the most damage (over $450 Million), followed by tornadoes, flood, storm and wind. There appear to have been 9 events in 1995 (Alan Pang, personal communication) which include significant damage from flood, hail, thunderstorms, wind and Hurricane Hortense. Two hailstorms in Alberta and a thunderstorm in Ontario each estimated to cost over $25 Million. Hurricane Hortense is expected to cost about $3 Million. In July, 1996 hailstorms in Calgary and Winnipeg are estimated to cost around $295 Million in total (Alan Pang, personal communication). The largest single insured disaster prior to the Ice Storm in Canada was the Calgary hailstorm of 1991, which cost around $400 Million The Saguenay floods are currently estimated at $350-400 Million. The Ice Storm may cost the industry as much as $1.5 Billion.

Figure 2.26 Weather Related Insurance Costs from Major Multiple Payouts (1995$)
(Source: Insurance Bureau of Canada)

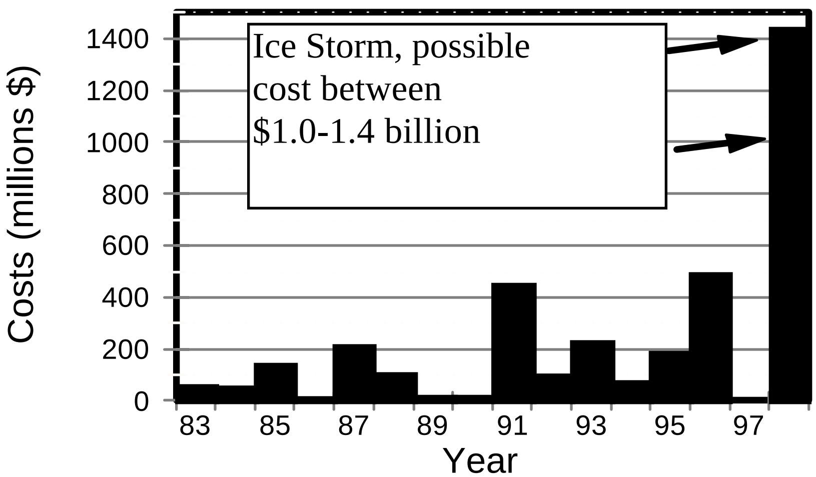
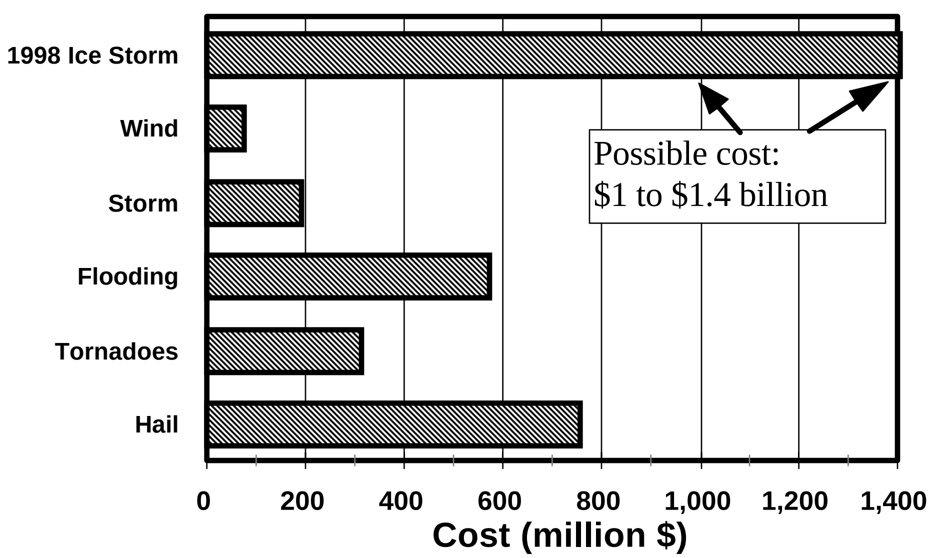


Figure 2.27 Weather Related Insurance Costs (1984-1996) from Major Multiple Payouts 1995 $ (Source: Insurance Bureau of Canada)



Municipalities

Almost no information is available on costs to municipalities. A few statistics follow, using unadjusted dollars:

Regional Municipality of Ottawa-Carleton:

- Winter 1993-94: $2.5 Million due to a record number of water services freezing.
- Winter 1995-96: Unknown cost due to freeze/thaw cycles causing potholes.
- Spring 1993: Deep frost from the winter caused a soil slip at a cost of $400,000. A preventative maintenance program was established at a cost of $40,000 per year.

City of St. Catherines:

They have recently experienced an increased number of intense, high volume thunderstorms (since 1994), resulting in flooding problems. One event that flooded hundreds of basements occurred on June 10/11, 1996.

City of Calgary:

- 1991 hail/rainstorm: City damage of $1.5 Million of which $1.2 was insured.
- Spring 1995: Severe river flooding with damages of $350,000 to city property such as parks, pathways and bridges.

A city report lists expected damages from flooding in Calgary (Table 2.6).

Table 2.6 Expected Flood Damage in Millions $ (1993) Due to a Riverine Flood

Return Period (years)	25	50	100
Elbow River	$46.3	$73.9	$93.3
Bow River	$5.6	$20.8	$38.5

Cumulative Costs of Hazards

Understanding the cumulative costs of various hazards would be an important synthesis, however, there have been almost no studies that provide such a summary, and this analysis is not at a stage where is can be attempted, though the data suggests that costs due to disasters are increasing. Clearly, the importance of floods has been shown and highlighted by the recent Saguenay and Red River disasters. The costs of droughts can also be very large, if not so dramatic (drought is a slow onset disaster, as compared to flood which is a fast onset disaster). For example, Wheaton and Arthur (1989) estimated the cost of the 1988 drought at $1.8 Billion (unadjusted), or 0.4% of real GDP. Other droughts of significance are: 1978/79 ($2.5 Billion), 1980 ($2.5 Billion), 1984 ($1 Billion), 1985 ($50 Million) and 1990 ($96 Million) - *[Note... these cost estimates need further tracking in order to confirm their reliability.*] Ice storms also have the potential to create devastating disasters that cost multi-Billions of dollars.

Natural hazards and disasters are expensive, but not inevitable. With appropriate planning to reduce vulnerability, their social and economic impact on Canadians can be reduced.

RESEARCH NEEDS

There are several questions which cannot be well answered given the current state of knowledge:

What is the cost to Canada of our adaptations to atmospheric hazards?

What is the cost to Canada when our adaptations fail?

What is the relationship between societal vulnerability and potential changes in the frequency of extreme events?

Research needs to be done which gives us the capability of better addressing these questions. Such research would involve the creation of socio-economic databases related to the impact of extreme events, costs of adaptive mechanisms and vulnerability analyses.

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CHAPTER THREE

THE CASE FOR INTEGRATED ASSESSMENTS OF AIR ISSUES

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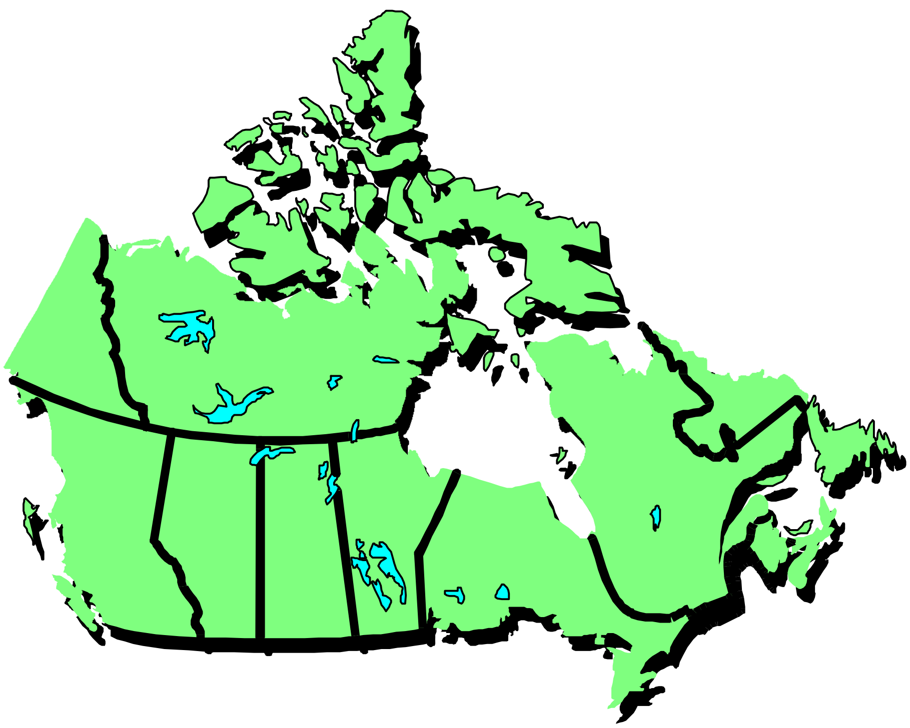

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EXECUTIVE SUMMARY

Six air issues are currently being assessed by scientists and policymakers in Canada: climate change, stratospheric ozone depletion, acidic deposition, smog, suspended particulate matter, and hazardous air pollutants. Historically, each air issue has been dealt with as a separate problem resulting in single-issue policies to slow down or eliminate unwanted impacts. In recent years, however, recognition has been growing that all air issues are interrelated through complex physical and chemical processes, including feedbacks, lags and synergisms. For example replacing CFCs may slow down stratospheric ozone depletion, but the replacement chemicals may contribute to climate warming. As another illustration, sulphate and nitrate aerosols cause acidic deposition while at the same time reflecting some solar radiation back to space, thus off-setting climate warming to some degree. The lesson to be learned is that strategies for dealing with a particular air issue may not be optimal for the whole. It is therefore recommended that an integrated 'multi-issue' approach be developed to assess the effects of proposed strategies on all air issues, not just climate change. Similarly, attempts should be made to undertake an integrated approach in assessing the impacts of multiple atmospheric stresses on human health, socio-economic sectors, and ecosystems. Integrated assessments can provide decision makers with the tools to develop policies of multiple benefits. Finally, it is emphasized that lack of complete scientific understanding of the interactions and linkages amongst the various air issues should not delay mitigative actions and adaptive strategies that are believed to have low risk or are justified for other reasons (precautionary principle), or known to be environmentally sound (no-regrets principle).

INTRODUCTION

Six air issues are currently on science and policy agendas in Canada: climate change; stratospheric ozone depletion; acidic deposition; smog (mainly ground-level ozone); suspended particulate matter; and hazardous air pollutants. Atmospheric scientists and decision makers in Canada and elsewhere have largely addressed these issues individually resulting in single-issue policies, e.g., the Montreal Protocol and its amendments to ban stratospheric ozone-depleting substances. While banning CFCs may slow down stratospheric ozone depletion, the replacement gases may contribute to climate warming. As another example, sulphate aerosols cause acidic deposition while at the same time scattering solar radiation, thus off-setting climate warming to some degree. It is now recognized that all air issues are interrelated, and they may interact to cause negative as well as some beneficial effects. The linkages among these issues must therefore be better understood in order to develop effective policies to deal with this ensemble of related issues (Munn, 1995, 1997).

Several studies have already recognized the need for integrated assessments of the impacts of a single air issue on a suite of receptors, e.g., the effects of acidic deposition on lakes, soils, vegetation and ground water. A few studies have attempted to understand the most important interactions amongst various combinations of 2 or 3 air issues and their joint effects on the biosphere and human and ecological systems [see e.g., White (1989); Krupa & Kickert (1989), Schindler *et al*. (1996); Yan *et al*. (1996)]. Attempts to examine science and policy interactions amongst several air issues have also been done [(SENES, 1996); Maarouf & Smith (1997)].

Recognizing that Phase I of the Canada Country Study (CCS) focuses mainly on the climate change issue, this chapter provides several examples of the known linkages between climate change and the other air issues, and it emphasizes the need for more integration of air issues. It also points to potentially conflicting policies arising from the single-issue approach, and makes some recommendations for Phase II of CCS (see also Maarouf & Smith, 1997; Munn & Maarouf, 1997).

WHAT ARE THE AIR ISSUES?

The six air issues are listed below, with general remarks about each of them.

Climate Change

Increases in greenhouse gas (GHG) concentrations lead to a positive radiative forcing of climate, tending to warm the Earth's surface and to produce other changes in the climate. Global climate models (GCMs) predict a global warming of between 1.0-3.5C by 2100 (IPCC, 1996). Recent GCMs suggest that the greatest temperature change will be in northern latitudes. GCMs are predicting that a doubling of CO_2 could result in temperature rises ranging from 2^{o}C to 8^{o}C in southern Canada with regional and seasonal variations. Greater increases in temperature could be experienced in higher latitudes and arctic regions. Climate change is by far the air issue which has the potential to cause the greatest impacts, influencing across the largest geographical area in Canada over the long term (Hengeveld, 1995; Munn and Maarouf, 1997). Undoubtedly this is an urgent issue in terms of the need for an effective policy response. Canada was therefore one of the first countries to sign the Framework Convention on Climate Change at the Rio Earth Summit in 1992, and has developed a National Action Program on Climate Change, calling for Canadian stabilization of greenhouse gas (GHG) emissions at the 1990 levels by the year 2000. Unfortunately, however, Canada and several other industrialized countries are not meeting this target, and a revised target date has been proposed at the 1997 Conference of the Parties in Kyoto, Japan.

Stratospheric Ozone Depletion

In recent decades the stratosphere has been perturbed by a number of synthetic organic chemicals, including CFCs, halons and other chemically similar substances involved in ozone destruction. Ozone depletion is causing an increase in solar UV-B radiation reaching the Earth's surface, leading to an increase in skin cancer and other adverse biological effects.

Global monitoring of the stratospheric ozone layer began in Canada in 1957 as part of the International Geophysical Year (IGY), mainly as a potential tracer of stratospheric phenomena. In the late 1970s and early 1980s, some countries including Canada phased out non-essential uses of CFCs as propellant in some aerosols. Following the discovery of the Antarctic ozone hole by British scientists in 1985, Canada became the first country to launch studies of the Arctic ozone layer. Canada was also instrumental in the creation of the Montreal Protocol on substances that deplete the ozone layer which was signed by 24 countries in 1987. Subsequently, Canada ratified all amendments to the Protocol and participated in several international meetings which are committed to reverse the damage of the ozone layer.

Acidic Deposition

Sulphur and nitrogen oxides are transformed into sulphate and nitrate particles, which then combine with water vapour to form sulphuric and nitric acids. These pollutants can travel long distances before being washed out by precipitation or deposited directly on lakes, vegetation, buildings and other surfaces.

Acid rain became a Canadian environmental issue in the 1970s following reported losses of fish populations in some highly acidified lakes of northern Ontario. In the late 1970s a Long-Range Transport of Air Pollutants (LRTAP) Program was established to investigate the occurrence and effects of airborne pollutants transported within and into Canada. Throughout the 1980s Canada and the United States conducted extensive research and assessment programs on acidic deposition. A Canadian Acid Rain Control Program was formalized in 1985 by establishing federal-provincial agreements with the seven provinces east of Saskatchewan. Sulphur dioxide (SO_2) emissions decreased from 3.8 million tonnes in 1980 to 1.7 million tonnes in 1994, significantly surpassing the emissions goal for eastern Canada. In 1991, Canada signed an agreement with the United States for the reduction of SO_2 and NOx emissions. Unfortunately, even with full implementation of the Canadian and U.S. programs in 2010, about 95,000 lakes in southeastern Canada will remain damaged by acid rain (AETG, 1997).

Smog

This term usually refers to a harmful mixture of gases and particles primarily caused by the combustion of fossil fuels. The smog issue in this chapter will focus on ground-level ozone (O_3) which is the main component of smog in and downwind of many Canadian cities.

Based on human health and vegetation studies in the 1970s and early 1980s, Canada set the maximum acceptable level of ground-level ozone at an average of 82 parts per billion (ppb) for one hour. However, this air quality objective has been exceeded several times in many Canadian cities since mid 1980s. In 1990, the federal and provincial governments, in consultation with industry, environmental groups and the public, initiated a Management Plan to reduce ground-level ozone through the control of NOx and VOCs. The plan identifies three areas that are particularly affected: the Lower Fraser Valley in B.C., the Windsor-Quebec City Corridor, and the Southern Atlantic Region. The Canadian Ambient Air Quality Objective for ground-level ozone is currently under review.

Suspended Particulate Matter

This term includes a wide variety of solid particles and very small droplets. Natural particles include sea salt, soil dust, smoke from biomass burning, terrestrial and marine biogenic emissions and volcanic eruptions. Anthropogenic particulate matter includes sulphate, nitrate, soot, organic particles, and smoke from human-induced biomass burning.

This issue developed as a result of three environmental concerns. First, increased concentrations of particulate matter causing light scattering and deterioration of visibility became a problem in the Arctic and elsewhere. Second, epidemiological studies confirmed the adverse effects of fine particles on human health. And more recently, climate change studies have demonstrated a radiative cooling effect on ‘regional’ climates due to sulphate aerosols.

Hazardous Air Pollutants (HAPs)

HAPs are defined as gaseous, aerosol or particulate contaminants present in the ambient air in trace amounts with characteristics (toxicity, persistence) so as to be a hazard to human health, plant or animal life. HAPs come from many man-made and natural sources and include pesticides, industrial chemicals, combustion by-products and heavy metals. These chemicals are released or emitted into the atmosphere and may travel long distances before being deposited.

Epidemiological studies over many years have shown the adverse effects of HAPs on human health and the biosphere, particularly downwind of sources. In recent years, the role of the atmosphere as a pathway for toxic chemicals to remote Canadian areas has also been recognized. For example, HAPs originating in low and mid latitudes have been detected in polar regions. The discovery of PCBs and the pesticide *toxaphene* in remote parts of Lake Superior in 1978 was one of the first indications of the significance of atmospheric transport in the Great Lakes region. The Great Lakes Water Quality Agreement, established in 1972 between Canada and the United States, was amended in 1987 to address air toxics. Recently, the National Air Issues Coordinating Committee (NAICC) formed a ‘Hazardous Air Pollutant Task Group’ to coordinate and manage all HAPs programs and initiatives in Canada.

EFFECTS OF CLIMATE CHANGE ON THE OTHER AIR ISSUES

Climate change has the potential to exacerbate the other air issues. Excess GHGs and predicted higher temperatures can be expected to alter atmospheric chemistry, especially through interactions between the key GHGs [(CO_2, CH_4, N_2O, CFCs and O_3), the most important oxidants (hydroxyl radical (OH) and hydrogen peroxide (H_2O_2)], and other trace gases/particles that are involved in one or more of the other five air issues. A few examples are given below.

Stratospheric Ozone

Carbon dioxide (CO_2) contributes to modification of the temperature structure of the atmosphere, cooling the stratosphere. Normally, less ozone is destroyed if the stratosphere is cooler, so the effect of CO_2 is to decrease ozone depletion. However, increasing atmospheric CO_2 concentrations are expected to cause further cooling of the lower stratosphere and this could enhance the formation of polar stratospheric clouds in some regions, which convert potential ozone-depleting species to their active forms.

Methane (CH_4) contributes to the destruction of stratospheric ozone through its effect on the amount of water vapour in the stratosphere. On the other hand, when a free chlorine atom reacts with CH_4, it is bound up into a molecule of hydrogen chloride (HCl), which can be carried from the stratosphere into the troposphere, where it can be washed away by rain.

Nitrous oxide (N_2O) is a GHG but when converted to NOx it destroys stratospheric ozone in a catalytic cycle similar to that of chlorine radicals.

Acidic Deposition

Climate warming will increase the physical and chemical transformation rates of primary and secondary acidifying materials. The general circulation of the atmosphere and precipitation patterns will change, and the overall tropospheric reactions and instability will also change affecting the acid rain issue. These changes will alter the transport trajectories of acidifying gases and the subsequent deposition patterns and regional concentrations. Summertime emissions of sulphur and nitrogen compounds from power plants could increase because of increased demand for air conditioning of buildings and automobiles. Hydrogen peroxide (H_2O_2) is also produced, which is a strong oxidant and catalyst in the production of sulphuric acid, thereby increasing the acidic deposition.

Smog and Particulate Matter

Natural and anthropogenic emissions of several pollutants (e.g., NOx and VOCs) and particulate matter are sensitive to weather conditions. For example, VOCs released from fuel tanks, solvent use and chemical plants are more volatile at high temperatures. Also, nitrogen compounds emitted by soil microbes and VOCs from vegetation are temperature dependent. Climate change is also expected to increase the potential for smog episodes as a result of increased frequency of hot summer days.

Hazardous Air Pollutants (HAPs)

Organochlorine chemicals, including chlorinated pesticides and PCBs are transported by the wind from temperate and tropical latitudes to the Arctic. These compounds are volatile enough to evaporate at source, but their volatility decreases at lower temperatures to cause appreciable deposition and partitioning (Wania and MacKay, 1993). Climate warming can be expected to play a role in the volatilization, evaporation, cold condensation, global fractionation and deposition of several HAPs in arctic regions.

EFFECTS OF THE OTHER AIR ISSUES ON CLIMATE CHANGE

Stratospheric Ozone

Decreased ozone in the stratosphere results in reduced flux of ozone to the upper troposphere where it acts as a GHG. A thinner ozone layer allows more UV-B radiation to penetrate into the lower atmosphere, where it increases the production of OH radical (a primary sink for methane, a GHG about 20 times more powerful than CO_2). Thus, permitting destruction of stratospheric ozone would result in a decrease in the rate of climate warming.

The oceans play a key role with respect to global warming. Marine phytoplankton are a major sink for atmospheric CO_2, and they have a decisive role in the development of future trends of CO_2 concentrations in the atmosphere. It is likely that increased levels of exposure to UV-B radiation will adversely affect the productivity of marine systems, thus limiting CO_2 sink and exacerbating climate change.

Acidic Deposition

Precursors of acidic precipitation (SO_2 and NOx) oxidize in the atmosphere and form sulphate and nitrate aerosols. These particles reflect some solar radiation back to space, causing negative radiative forcing (climate cooling).

The eutrophication effects of nitrogen deposition can increase carbon storage in marine sediments and forest calcareous soils, which are likely to be important components in the global carbon budget (Rodhe *et al*., 1995). The rate of CH_4 oxidation in forest soils may be reduced due to N deposition and N_2O emissions may increase, causing some increase in the greenhouse effect. However, this rise in greenhouse contribution seems considerably smaller in magnitude compared to the reduction in greenhouse effect caused by carbon sequestration.

Recent changes in technology and industrial processes to alleviate the acid deposition problem indicate some benefits and disbenefits to the climate change issue. For example, nonferrous smelters, coal washing and low NOx burners result in substantial reductions in the emissions of SO_2, NOx and CO_2, benefiting the acidification, climate change and other air issues. As an example of a disbenefit, scrubbers installed in power plants reduce certain particulate emissions that often neutralized the acids because of their relatively high pH. In addition, scrubbing necessitates more power to operate, i.e. more coal burning, and therefore increases CO_2 emissions.

Smog

A major component of smog is ground-level ozone, which is an important GHG and contributes to the positive radiative forcing of climate.

Suspended Particulate Matter

Atmospheric particles and aerosols in the troposphere influence climate in two ways, directly through the scattering and absorption of solar radiation, and indirectly through modifying the optical properties, amount and lifetime of clouds. Both the direct and indirect effects of aerosol particles are strongly dependent on their concentration, size, reflectivity and chemical composition. Although some aerosols such as soot are efficient light absorbers and cause slight warming, the net (direct and indirect) global mean radiative forcing of anthropogenic aerosols is negative and the magnitude is significant (IPCC, 1995, 1996). Some studies suggest that, on a global average, anthropogenic sulphate particles mask about 25% of the warming caused by CO_2 and other GHGs.

Hazardous Air Pollutants (HAPs)

The effects of HAPs (as defined in this chapter) on climate change are not yet clearly understood.

INTERACTIONS AMONGST MULTI-AIR ISSUES

Table 3.1 provides a simple and qualitative summary of the main interactions amongst five of the six atmospheric issues (Maarouf and Smith, 1997). For example, climate warming is expected to exacerbate the extent of stratospheric ozone depletion and suspended particulate matter episodes to a moderate degree (score +1), and of acid deposition and smog to a major degree (score +2). On the other hand, the depletion of ozone in the lower stratosphere is causing a moderate net cooling effect on climate (score -1). As another example, suspended particles in the upper troposphere (mainly sulphate and nitrate) cool the atmosphere, thus reducing ‘regional’ greenhouse warming to a major degree (score -2) and ‘global’ greenhouse warming to a moderate degree (score -1).

Table 3.1: A qualitative summary of the linkages among the air issues.

AIR ISSUE	Climate Change	Stratos. Ozone Depletion	Acidic Deposition	SMOG	Suspended Particulates
Climate Change		**-1** but several counteracting effects	**-1** but several counteracting effects	**+ 1**	**-1** (globally) **-2** (regionally)
Stratos. Ozone Depletion	**+ 1**		**0**	**- 1**	**+ 1**
Acidic Deposition	**+ 2**	**+ 1**		**U**	**+ 1**
SMOG	**+ 2**	**+ 1**	**+ 1**		**highly correlated**
Suspended Particulates	**+ 1**	**+ 1**	**+ 1**	**highly correlated**	

Effects of the atmospheric change issues listed in the top row on the air issues listed in the left column are shown as 0 (no effect); 1 (some effect); 2 (strong effect); U (unknown). Positive and negative signs indicate increasing (worsening) and decreasing effects. HAPs are not included because of the great variety of types. (Modified from Maarouf and Smith, 1997).

Next we discuss multi-issue interactions which often cause adverse but sometimes beneficial effects on both natural and managed ecosystems. In the field of limnology, for example, climate warming, acid deposition and stratospheric ozone depletion are linked to one another through their influence in deepening the penetration of UV-B radiation into clear-water lakes damaging their ecosystems (Schindler *et al*., 1996; Yan *et al*., 1996). Dillon *et al.* (1997) attributed the slow recovery of acidified lakes in central Ontario, in spite of the decline of sulphur emissions, to the reoxidation and release of stored sulphur in catchments following severe droughts. That two or more of the atmospheric stresses may reinforce one another is illustrated by the likely drier climate expected in the 21st century in mid-latitudes, in parallel with increasing frequencies and intensities of ozone episodes (due to increasing energy production and automobile emissions). In combination, these stresses could lead to major reductions in crop yields (Chamiedes *et al*., 1994). Some agricultural crops and forests might benefit from fertilization by increased concentrations of ambient CO_2; however the net effect of climatic changes (CO_2, temperature, precipitation, soil moisture, etc.), enhanced UV-B radiation and ground-level ozone is mostly unknown (Krupa, 1997). These studies demonstrate the need for better understanding and integration of the linkages among the various air issues in order to evaluate synergistic effects on ecosystems and socio-economic activities.

There are numerous other indirect or secondary effects involving a number of the air issues. Some examples are listed below.

- Ecosystems receive substantial inputs of anthropogenic nitrogen, which in non-acidic soils and waters can act as a fertilizer and could increase terrestrial and marine carbon storage (IPCC, 1995). Reducing anthropogenic N emissions to control the smog and acid rain issues may reduce the effectiveness of carbon sinks, thus enhancing climate change.

- Ozone-depleting substances, including CFCs, are being replaced with HCFCs and HFCs, some of which are potent GHGs (IPCC, 1995).

- Catalytic automobile converters have dramatically cut NOx emissions from the transport sector, but release a small amount of N_2O, an important greenhouse gas.

- Electric automobiles will produce zero pollution at the point of use, but other HAPs, e.g., Pb (lead), may be generated in manufacturing and recharging the batteries (Lave *et al.,* 1995).

- The increased acidity of soils can affect the removal of methane, N_2O and CO by soils as the microorganisms will be affected.

Feedback Loops

Natural and anthropogenic sources of GHG emissions are sensitive to climatic conditions. For example, hotter and longer summers would raise the demand for air conditioning, thus for fossil fuels to generate electricity. It is not certain whether a corresponding lower heating demand in winter would compensate for the high summer energy demand.

Another climate-sensitive process is the rate of methane (CH_4) release from permafrost regions, northern wetlands, and decomposition of methane hydrates (clathrates) in continental shelf regions. Measurements show that increases in either temperature or duration of water-logging increase methane emissions (a positive feedback). Conversely, a lowering of the water table in northern wetlands/peatlands may lead to a reduction in emissions of methane (a negative feedback) (IPCC, 1995). The major sink mechanism for CH_4 is its reaction with OH. Increasing tropospheric CH_4 concentrations will lead to decreased OH concentrations and to an increased CH_4 lifetime, and hence amplify the original CH_4 perturbation. Reduction in tropospheric OH can also indirectly increase the abundance of some other GHGs and ozone-depleting substances (IPCC, 1995). When CH_4 is destroyed in the stratosphere, water vapour is produced, which acts as a GHG, and also plays a role in stratospheric chemistry.

Climate change will influence the state of the land surface (e.g., soil moisture, vegetation, roughness, albedo, etc.). In turn, the altered land surface will affect the overlying atmosphere (moisture content, clouds, weather systems, etc.). As the atmosphere warms, its holding capacity for water vapour increases which enhances the warming trend. Another feedback loop is related to the loss of reflectivity of the Earth's surface (albedo) due to polar ice melting, leading to accelerated warming (IPCC, 1996). A further complication involves the cloud/radiative feedback. Clouds can both reflect solar radiation (which cools the surface), and absorb and emit long-wave radiation (which warms the surface) depending on cloud height, thickness and cloud radiative properties (IPCC, 1996).

PUBLIC PERCEPTION

Climate change and other atmospheric stresses are the cumulative effect of myriad decisions about transportation, energy use, land use and other natural resource management made at the national, local and individual levels. Public opinion often drives the policy-making process, and policymakers need to know which control measures would be cost effective as well as most socially acceptable. Public understanding of climate change and its linkages to the other air issues is therefore important in examining adaptation options and implementing mitigation measures that could have multiple benefits.

In a recent public opinion survey, concern for climate change ranked last among a list of 8 environmental issues (Environment Canada, 1997). The manufacturing, use and disposal of toxic chemicals was considered the major environmental concern for Canadians. When asked as an open question (no issues prompted), climate change is cited by only 2% of Canadians as the environmental issue which concerns them most. When asked which atmospheric phenomenon poses the most serious problem for humankind and the planet, a majority (59%) of Canadians are more likely to choose the thinning of the ozone layer than climate change (28%). We believe, however, that most Canadians are confused and do not have a clear understanding of the differences between these two air issues.

About half of Canadians (49%) believe there is nothing they can do personally about climate change. Moreover, there seems to be a lack of understanding about the interactions and linkages between climate change and the other air issues. Generally, public attention turns to the environment when a disaster occurs or a public health concern surfaces. For example, in February 1992 NASA reported the potential for severe stratospheric ozone depletion over the Arctic, possibly spreading into mid-latitudes. Overwhelming media attention and public fear from the consequences of enhanced UV-B exposure prompted Environment Canada to provide 'Ozone Watch' and 'The UV-index' for several locations in the country, beginning in the spring of 1992 (O'Toole, 1993). Therefore, a period of an extreme event (e.g., heat-wave, flood, drought, smog episode, high UV-index, etc.) could be used to provide the population with valuable information about climate change (also climate variability and extremes) as well as the other air issues.

AIR ISSUE POLICIES

Regulatory strategies and policies that are currently in place in several countries, and the international agreements that ban or control certain atmospheric emissions have dealt mainly with single air issues. Examples include the United Nations Framework Convention on Climate Change (FCCC) to stabilize GHG emissions; the Montreal Protocol and its amendments to ban stratospheric ozone-depleting substances; the Canada-US Air Quality Agreement to reduce emissions of acid rain precursors; and Canadian Council of Ministers of the Environment (CCME) NOx/VOC Management Plan to resolve Canada's smog problem. However, policies designed to reduce acidification, for example, also have effects on other air issues (both benefits and disbenefits), e.g., the role of sulphate aerosols in cooling the climate is not negligible. Within certain industrialized regions, where sulphate concentrations are particularly high, this aerosol-induced cooling may actually be as large as greenhouse warming (Rodhe *et al*., 1995). Regional reductions in sulphate aerosol emissions could therefore lead to regional temperature increases, e.g., in the Atlantic provinces of Canada. It has become obvious that these issues cannot be looked at in isolation and their interrelation will have important policy implications.

An integrated assessment implies an activity that is at the interface between science and policy. One of the main objectives of an integrated assessment of air issues is to provide decision makers with the tools to permit them to respond to a broad spectrum of current and future atmospheric stresses in a more holistic manner. It is conceivable that a few environmentally sound actions could result in multiple benefits.

CONCLUSIONS AND RECOMMENDATIONS

This chapter has given examples demonstrating that climate change and the other air issues are interrelated through complex feedbacks, lags and synergisms. It has become obvious that strategies for dealing with a particular air issue may not be optimal for the whole (Munn, 1995, 1997). The climate change issue has been the focus of Phase I of the Canada Country Study (CCS), and admittedly it is the air issue which has the potential to cause the greatest impacts, influencing across the largest geographical area across Canada in the 21st century. However, a more integrated approach to all air issues is needed to provide policymakers with the tools to develop mitigative actions and adaptive strategies of multiple benefits. Therefore, in designing large-scale integrated assessment studies such as Phase II of CCS and the Toronto-Niagara Region Study (Chiotti, 1997), one should examine the effects that policies will have on all air issues, not just climate change. Some other recommendations and considerations for multi-air issue assessments are suggested below (see also Munn and Maarouf, 1997).

a) Several gaseous and particulate emissions contribute importantly to the climate change issue, and an integrated assessment of the climatic effects of all of these emissions as well as the physical and chemical processes involved should be made. Similarly, the multiple role each emission plays in contributing to the other five air issues should be assessed.

b) Because of interactions amongst several of the air issues, an integrated assessment should be made of the impacts of various control strategies on all of the air issues. For example:

- Which control measures would be most cost effective, and the most socially acceptable?
- Would any of the proposed control measures of one air issue have beneficial (or detrimental) effects on attempts to mitigate the harmful effects of the other five air issues?
- What relative uncertainty is associated with each control option? Can we apply cost effective mitigative measures in spite of scientific uncertainty?

c) Climate change has often been linked to possible increases in the frequencies and intensities of extreme events. Again, the whole suite of atmospheric issues should be examined, for example:

- What effects might an increase in UV-B radiation, and in frequencies of heat-waves and smog episodes have on human health?
- What implications might an increase in UV-B radiation, air pollution episodes, severe weather and other extreme events have for building standards, infrastructures, safety measures, community planning and urban design?

d) Because individual ‘receptors’ are subjected to several stresses simultaneously, it is important to make an attempt to understand and evaluate their integrated effects on socio-economic sectors (e.g., crop yields) and ecosystems.

The inclusion of such considerations will immensely complicate the development of an integrated assessment study, but the analysis would otherwise be incomplete. It should be emphasized, however, that scientific uncertainty about the linkages between the various air issues should not be used as a reason for postponing mitigative actions that are cost effective, low risk, or justified for other reasons (precautionary principle). Similarly, while scientific research is in progress, various environmentally sound adaptive and mitigative policies (e.g., tree planting, energy efficiency, energy conservation, etc.) and lifestyle changes could be justified and promoted (no-regrets principle).

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CHAPTER FOUR

EXTRATERRITORIAL INFLUENCES OF CLIMATE CHANGE: EFFECTS OUTSIDE CANADA AND THEIR IMPACT ON CANADIAN INTERESTS

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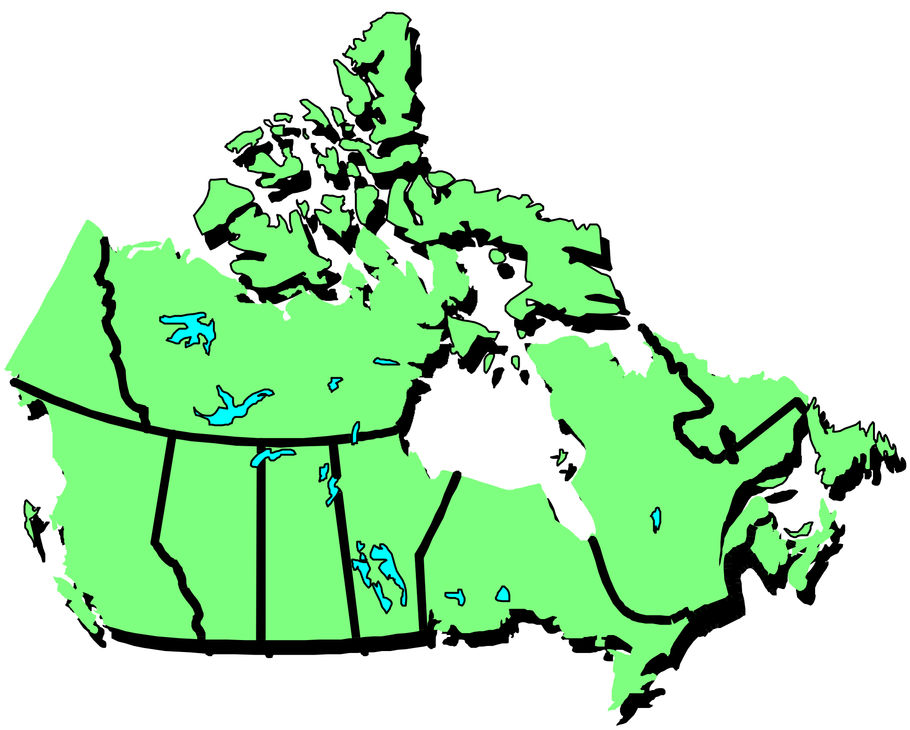

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EXECUTIVE SUMMARY

The Extraterritorial Issues chapter examines the effect of climate change outside Canada on Canadian interests, specifically on the areas of international trade, security (both food security and military security), and refugees. A review of the available literature in these areas reveals many gaps and areas for further study. However, while specific outcomes are impossibly difficult to predict, several general trends can be found.

Analysis of the international trade field yields the most indefinite results. The agriculture, forestry, fisheries, and energy sectors will all be affected to a large or small degree by climate change. Since Canada relies heavily on exports from these four production sectors, Canada's trade balance will also be affected. Whichever sectors benefit or suffer from climate change effects, climate change response policy and international trade policy must be complimentary if they are to achieve their twin goal of climate change mitigation without undue economic hardship.

The effects of climate change on the security field appears to be more definite. Canada's geopolitical position buffers it from most military offenses, and its abundant agricultural sector and peaceful border with the United States insulates it from the vagaries of climate change-induced variations in food production. However, as climate change is likely to produce increasingly variable weather events, the role of the national defense forces in assisting civilian authorities in the face of natural disasters must be further examined.

The effect of climate change on the number of environmental refugees coming to Canada is unknown. Estimates of the number of refugees generated by climate change effects ranges as high as 150 million, though only the most mobile of those would make their way to Canada. This would put an unprecedented strain on Canada's refugee assimilation mechanisms, though the exact cost would be impossible to quantify at this time.

INTRODUCTION

The effects of climate change on Canada's environment and economy are many, and direct effects such as temperature increase may result in indirect effects such as changes in Canada's trade balance and foreign policy. This chapter will examine some of the indirect, extraterritorial effects, those changes occurring outside Canada's territory that affect Canada's interests. The first part of the chapter will look at the effects of climate change on the international trade regime, and how changes in primary production may affect relations with Canada's trading partners. The second part will examine the security implications of climate change for Canada, both food security and military security. The third part will focus on the problem of environmental refugees created by climate change-induced environmental effects in the developing world and the possibility of a large number of these refugees migrating to Canada.

INTERNATIONAL TRADE

In academic circles, the link between international trade and the environment is becoming ever clearer, thanks to the work of scholars such as Herman Daly, Daniel Esty, and Robert Costanza

(Daly and Cobb 1989, Daly 1993, Esty 1994, Costanza, et al 1995). This literature is filled with predictions of the economic instability of even prosperous nations if environmental limits on production and waste assimilation are not observed. However, there has been very little work done on the effects of specific environmental issues, such as climate change, on specific economic sectors. Consequently, in order to assess what is known about the indirect links between climate change and international trade, we will have to extrapolate somewhat from literature devoted to the general discussion of trade and the environment. In addition, while most of the literature addresses 'the environment' as a whole, very little of it specifically relates to climate change and its effects.

Many in the international trade community see environmental concerns, such as climate change, as nothing more than thinly-disguised barriers to trade, while environmentalists often see free trade as the despoiler of ecosystems. The trend towards global free trade has often had mixed effects on the environment. It improves efficiency through economies of scale, but can also create unsustainable consumption by fostering the illusion of infinite supply (Charnovitz 1995). Climate change and other environmental concerns have generally not been included in the international trade regime, but recently the North American Free Trade Agreement (NAFTA) and its environmental side agreement, the North American Agreement on Environmental Cooperation (NAAEC), have brought an unprecedented awareness of environmental concerns to the international trade community (Magraw 1994). Environmental interests were represented from the beginning in the NAFTA negotiations, and those concerns not addressed in the NAFTA proper were grist for the side agreement. In addition, regional agreements, like NAFTA or the Asia-Pacific Economic Cooperation Forum (APEC), may offer a better opportunity for addressing the effects of climate change on international trade than global organizations like the World Trade Organization (WTO), since the ecosystems affected by regional agreements are more 'local' in scale (Charnovitz 1995).

Regardless of the size of the trade regime, trade policy and climate change policy will need to be mutually reinforcing in the coming years, both for environmental legislation to be obeyed without economic hardship and for free trade to occur without undue environmental damage. Konrad von Moltke (1992) discusses the links between international trade policy and climate change response policy, and how trade priorities can support the goals of climate change policy. He insists that international policy makers should ensure the compatibility of trade and climate change policies, for without such harmonization, disputes in one arena can and will be fought in the other, destabilizing both policies. The institution of 'no-regrets' policies, defining economic growth to include an environmental component, and the selective use of subsidies are all ways in which trade liberalization and climate change response policies can harmonize their goals. (von Moltke 1992). The IPCC has also considered the use of international economic instruments to achieve climate change response goals (See Appendix 1), but implementation of instruments like these has been limited.

In Canada, climate change will affect most of our primary production resources. Chapter 6 of Volume VII of the Canada Country Study examines the effects of climate change upon the forestry sector. The authors predict that forest production (growth) may increase by as much as 20% - or more - but actual harvesting levels may increase only by 3%, due to a 50 year lag as young stands reach harvesting age. Economic studies of the forestry sector show that both domestic and foreign consumers of wood and wood products benefit, and Canada will certainly export more lumber to the United States if its own domestic production increases as predicted. In this industry, climate change would likely increase Canada's competitive position relative to that of its trading partners.

Chapter 5 of Volume VII examines the effects of climate change on Canada's fisheries, another important natural resource for export. The author predicts that, while it is impossible to say at this point whether the effects of climate change will increase or decrease Canada's commercial stock of fish, what is certain is that commercial fisheries will not be able to continue doing business as usual. Climate change effects will be responsible for changes in: traditional fishing patterns, species available for consumption, and location of the best fishing grounds. These changes will result in disruption of the international fish market, to which Canada is a large supplier. However, loss of volume does not necessarily mean loss of revenue for Canada's fisheries. Between 1990 and 1994, the volume of fish commercially available had fallen by 620 kilotonnes, but the revenue received for the year's harvest rose by $276 million (seeVolume VII, Table 5.2). In this industry, climate change may well result in an improvement in Canada's competitive position. If the rest of the fishing industry also suffers a drop in catch volume, the commercial price of fish may rise enough to offset the loss financially.

Agriculture is another area where changes in production opportunities resulting from global climate warming could affect the basic structure of international and interregional trade in agricultural products, with potentially major implications for Canada's competitive position. It has been estimated that climate change could account for a 10% reduction in world wheat crop production three times per decade (Myers 1993). However, Canada has the potential to fill some of this shortage. Table 4.1 shows the expected increases or decreases in grain production as a result of climate change warming only, and does not include synergistic changes such as sea-level rise or crop damage from insects.

Table 4.1. Expected Changes in World Grain Production under Climate Change Warming

REGION	Wheat	Corn	Barley	Oats	Soybeans	Rice
Canada	↑	↑	↓	↓	↓	n/a
Other North/Central America	↓	↓	n/a	n/a	↓	n/a
South America	↓	↓	n/a	n/a	↓	n/a
Europe	↓	↓	↓	↓	n/a	n/a
Africa	↓	n/a	n/a	n/a	n/a	n/a
Former Soviet Union	↑	↑	↓	↓	n/a	n/a
Asia	↓	n/a	n/a	n/a	n/a	↑
Oceania	↓	n/a	n/a	n/a	n/a	n/a

Source: Smit, 1989.

Climate change-induced warming could mean that Canada's production and trade of corn and winter wheat will increase significantly. Coupled with an expected decrease in corn and wheat production in other grain-producing parts of the world, Canada's wheat export potential to Europe, Africa, and Asia could be greatly enhanced. Canada may also be able to reduce current imports of grain corn from the Midwestern United States (Smit 1989).

Thompson (1993) discusses the cross-border system of forward contracting between farmers and food processing firms, which rely on a stable harvest forecast. Precipitation fluctuations will generate larger *force majeure* clauses in contracts and can drive up food processing prices. Unlike Smit, Thompson estimates that, since the United States has an inherently better land base climatically, it enjoys a 30%-50% productive advantage over Canada. Thus, the combination of climate change and free trade may result in a massive displacement southward of Canadian agricultural capacity (Thompson 1993), possibly forcing Canada to import the food it once grew. Chapter 4 examines the implications of climate change effects on agriculture in much greater detail. The various climate change models in Chapter 4 show that, while the amount of suitable cropland will likely increase across most of Canada, the crops grown on that land may drop in value, resulting in a worsening of Canada's competitive position. As with the fisheries industry, the net economic gain or loss to Canada cannot yet be determined.

Chapter 7 of Volume VII of the Canada Country Study examines the effects of climate change upon domestic energy production, and this change may differ from province to province (*e.g.*, hydro production may increase in Quebec and decrease in Ontario). The tentative conclusion of Chapter 7 is that overall domestic demand for energy will decrease due to warmer temperatures, offset somewhat by increased energy use for air conditioning and irrigation. Therefore, more energy resources will be available for export. Since Canada's biggest export market for energy is the United States, depending on the state of their domestic supply, this could represent an opportunity for increased revenue, although it is impossible to identify exactly how much.

Climate change-induced fluctuations in the production of these four sectors will likely occur at different times. Agriculture may experience a 1-2 year lag, fisheries a 5-10 year lag, and forestry a 50 year lag, all of these resulting in Canada's export situation changing from year to year. Table 4.2 indicates the extent to which Canada relies on products from natural resources to satisfy its export demand.

Table 4.2. 1995 Domestic Exports to Principal Trading Areas (all figures in million $)

	Agriculture and Fishing Products	Energy Products	(60 percent derived from hydro)	Forestry Products
United States	9561.4	20240.7	12144.42	25440.6
Mexico	357.7	51.9	31.14	62.9
Japan	2887.9	1230.6	738.36	4867.7
EU	1979.5	297.4	178.44	4617.5
Others	4680.2	762.1	457.26	4186.8
TOTAL	19466.7	22582.7	13549.62	39175.5

Source: Statistics Canada, 1995; 1994 Energy Statistics Yearbook, United Nations, 1996

These products total approximately $72 Billion, and represent 41% of Canada's total domestic exports in 1995, the latest year for which there is complete data (Statistics Canada 1995). The bulk of the products in each category are exported to the United States, with energy comprising the largest percentage in trade, depending upon U.S. import demand. Clearly, any decrease in hydroelectric capacity, agriculture, fishery, or forestry production will result in a decrease in Canada's ability to meet its export commitments. Under the terms of NAFTA, member states must honor export contracts on the same footing as domestic contracts. For example, should Hydro Quebec contract to sell 15% of its production to Niagara-Mohawk in New York, it must maintain that percentage regardless of its total volume of output. Even if overall domestic production falls, Hydro Quebec cannot reallocate its production to meet domestic demand at the expense of its export contracts.[1] Thus, climate change-induced shortages or overages in hydro production would affect exports as well as domestic consumption. Modelling these changes, however, is nearly impossible. There are so many factors affecting the production and value of Canada's goods on the international market that one cannot devise a system to model the effects of climate change factors while holding all others constant. The results would not be meaningful in any sense.

Canada's response to the international trade implications of climate change may have foreign policy ramifications themselves. In a reiteration of the famous 1991 GATT tuna-dolphin case, Canada may choose to impose environmentally-related trade measures upon its trading partners, if it feels that they are not adhering to the spirit of multilaterally negotiated restrictions (Thomas 1997). Neither is Canada likely to initiate new environmental restrictions for itself with the hope that other countries will adopt them as well. Further, Canada would oppose imposition of trade restrictions on its exports if another country claimed Canada was not living up to its new climate change obligations (Fawcett 1997, pers. comm.). The economic results of climate change-induced production changes may also alter Canada's stance in GATT and/or NAFTA. Typically countries will support trade initiatives that agree with their own domestic economic policy. For example, Canada has historically supported import restrictions for agricultural commodities. Under climate change, Canada may have a large surplus of such commodities to sell and may reverse its position on import barriers. Finally, climate change may alter the patterns of international migratory wildlife, perhaps prompting revision of treaties such as the Convention on the Conservation of Migratory Species of Wild Animals.

Unlike the international trade, security, and finance agendas, the international environmental regime lacks guiding principles, or even an accepted world view. Part of the challenge of deriving an international environmental agenda is the recent appearance of human-induced changes in the environment, such as climate change, (Sanderson 1994) and the scientific uncertainty as to how those changes might be mitigated. However, at the conclusion of the GATT Uruguay Round, many ecologically unsound subsidies were brought under scrutiny. In the energy sector, it has been estimated that the United States spends approximately US$ 40 Billion to subsidize conventional energy sources, especially fossil fuels, while other populous and developing countries like China and India subsidize coal-based infrastructures (Thomas 1997). Canada will

[1] NAFTA, like the Canadian-U.S. FTA, provides for a 'national security' exemption to this provision, but the definition of a national security situation has been tightened significantly from the definitions in the FTA and the WTO, making the 'national security' clause much more difficult to invoke successfully.

likely work with these countries in fashioning some sort of response to climate change reduction goals that is complimentary to our international trade goals.

Competitiveness
Some feel that the question to be asked is not, 'How will climate change affect international trade,' but rather, 'How will *climate change response legislation* affect international trade?' Many industries fear that more climate change response legislation means more regulations and emissions targets and hence greater production costs, reducing their competitiveness abroad. Consequently, they have urged the Canadian government not to endorse 'infeasible' targets. This fear is intensified under the current free trade regime, where Canadian companies, which follow relatively high environmental standards, must compete with companies in other parts of the world which do not impose such standards (Richardson 1992). However, Canada ranked fourth in the world in a recent World Economic Forum competitiveness survey. Within the survey environmental rules ranked last in a series of factors considered most important by investors when deciding where to make new investments. Other factors that preceded the environment were: profit repatriation, contract enforcement, market growth, market size, worker productivity, corporate taxes, expropriation risk, infrastructure, approval process, skilled labor, and intellectual property (Drohan 1997). The competitiveness issue has been argued on both sides (and will not be argued here) without consensus, but both business and environmental authorities must keep in mind that climate change response policy and trade policy must be complimentary for either to succeed in the long term.

SECURITY

Climate change and its effects can have ramifications for the security of Canada. Security, on a national policy level, means measures taken to reduce risk to and/or increase safety of the national population. This paper will examine the effects of climate change on two distinct types of security: food and military.

Food Security[2]

The World Bank defines food security as access by all peoples at all times to enough food for an active, healthy life (Chen and Kates 1994). On a national level, food security tends to be equated with the sufficiency of the national food supply, assuming equal access by all regional populations to food. Food security can be seen as a subset of traditional security in that a food-secure nation reduces the risk to its citizens of famine, malnutrition, and/or food-related diseases. In addition, food insecurity in the developing world can impact on Canada's security by generating refugees (this issue will be discussed later). Although food security is very vulnerable to year-to-year variations in climate, domestic agricultural policy, and international economic conditions (Appendini and Liverman 1994), with its extensive and bountiful agricultural resources, Canada does not worry about its food security. Rather, Canada exports food and serves as a measure of

[2] For further discussion of climate change and food security, see N. Rosenberg and M. Scott, "Implications of policies to prevent climatic change for future food security," and V. Ruttan, D. Bell, and W.C. Clark, "Climate change and food security: agricultural, health and environmental research," both in Global Environmental Change, Vol. 4, No. 1, 1994.

food security to other nations. According to Statistics Canada, Canada's net exports of agricultural and fishery products totalled $19,466.7 million in 1995, going primarily to the United States.

Chen and Kates (1994) postulate that the world food availability will have to increase three- to four-fold simply to meet the food requirements of an expected world population of at least ten Billion by the year 2060. Current advancements in agro-technology may make this possible, and these improvements are likely to benefit the developed countries first. However, agro-technological advances are limited by the concurrent effects of climate change: soil erosion, water loss, and insect damage. In order to assess fully the effects climate change will have on food security, we will need tools such as time-dependent climate scenarios, regional agricultural and natural resource models and data, community-level case studies and models, food system supply/demand analysis, national socio-economic models, and national and international food system models (Downing and Parry 1994).

Canada is fortunate in that, to ensure its own food security, it need not make any major changes in its agricultural and food distribution systems. As mentioned above, a climate change-induced decrease in agricultural production may require Canada to import foodstuffs it would otherwise grow. Canada is again fortunate in that it has a peaceable border with the United States, its primary trading partner and likely supplier of shortage foodstuffs. The long-standing Canadian/American trading relationship will insulate Canada somewhat from future climate change-induced food shortages.

Military Security

The effects of climate change on military security are much more difficult to outline. While much literature has been written about the relationship between the environment and armed conflict (Homer-Dixon 1991, 1994; Levy 1995; Hauge and Ellingsen 1997), it is almost exclusively theoretical or focused on developing areas. By contrast, Canada's relatively isolated geographic position reduces its vulnerability to direct territorial threats from foreign military forces. Even the Canadian Arctic, the area most likely to face a significant security threat from Russia, would suffer largely from indirect actions such as chemical or pollution spills, as opposed to direct attack from military forces.

Volume II of this study examines the effect of climate change on the Arctic. While overall global warming is predicted to be between 1.5 and 3.5 degrees C, it will be spread unevenly according to latitude. The equatorial regions will likely see only a small amount of warming, whereas the polar regions will experience the largest amount; the Arctic is anticipated to experience two to four times the global average (Arctic Environment 1991), and temperature increases can range, depending on area and time of year, up to 10 degrees C above normal. This may result in precipitation increases of 10-50% in summer and up to 60% in winter (Tucker 1992), resulting in a warmer, wetter Arctic and foggier coastal areas due to increased open water conditions and increased overall moisture.

A wetter, more meteorologically unstable Arctic will require a greater military meteorological presence to determine the extent of climate change effects, particularly permafrost shift, on such defense infrastructure as runways, roads, dams and reservoirs, and radar installations. Current DND missions in the North include interception of aircraft and airborne vehicles, surveillance/sovereignty, search and rescue, and tactical and logistical air support for land force exercises. With climatic warming, many of these roles could conceivably increase in the future (Tucker 1990). Additionally, increased temperatures will likely lead to increased shipping and military traffic through Arctic waters. This will give rise to foreign policy concerns, as Canada must to consider how to defend its 1973 claim to sovereignty over the Northwest Passage as 'internal' waters, a claim made by Canada to preserve the environment and its interests in Arctic waters. (Tucker 1992).

In addition, the mandate of the Department of National Defence is not only military security, but to assist local agencies in maintaining civil security, and, as the organization with one of the largest groups of personnel in the North, it will continue to be incumbent upon Canadian forces in the North to assist in forest fire fighting and other environmental disasters (Tucker 1992). Unfortunately, while these additional defense needs in the Arctic are easy to identify, there is no literature that predicts their occurrence. Thus, it is impossible at this time to attempt to quantify the costs involved in such increased activity. Further studies have been recommended (Judge, et al 1991; NATO CCMS Pilot Study 1996), and this area will certainly require significant policy analysis, but since the Arctic is not considered a serious threat to Canadian security, such studies may be shelved for other, more pressing projects.

REFUGEES

The most commonly-used definition of *refugee* is from the 1951 UN Geneva Convention on Refugees, which identifies refugees as people who are "outside their own country, owing to a well-founded fear of persecution, for reasons of race, religion, nationality, membership of a particular social group, or political opinion." (Black 1994). The recognition of refugees, however, is left to the receiving government, and the above definition reflects the Cold War idea that refugees are fleeing political persecution (*i.e.*, communism), and that refugees must demonstrate that they have suffered *individually* before being granted refugee status. Environmental refugees, however, are not covered under this definition because such refugees suffer as a population, and this phenomenon has only been recognized by the international refugee regime in the past ten to fifteen years (Ramlogan 1996). Consequently, environmental refugees are not yet included as a legitimate, and hence admissible, category of refugees.

Environmental refugees are defined as "people who have been forced to leave their traditional habitat, temporarily or permanently, because of a marked environmental disruption (natural and/or triggered by people) that jeopardized their existence and/or seriously affected the quality of their life" (El-Hinnawi 1985). Environmental refugees are often sorted into different groups within the literature: those who have been displaced by natural disasters and/or industrial accidents; those who have been displaced by long-term or irreversible environmental change; and those who are displaced by environmental degradation (McGregor 1993, see also Jacobson 1988). While the political and economic bases of refugee status often have environmental underpinnings, in this study we will examine only those refugees for whom environmental damage and/or degradation is the primary reason for movement.

Environmental refugees are created when their land is despoiled and rendered unfit for human habitation by a) environmental degradation, or b) brief but catastrophic weather (or human-made) events. Climate change can contribute to both of these circumstances via:

- sea level rise leading to displaced people;
- increased drawing of groundwater leading to drought;
- change in precipitation patterns leading to drought, flooding, desertification, and soil erosion, making farmland useless;
- change in disease vector areas leading to increased sickness;
- change in weather patterns leading to evacuations of areas suffering increased extreme events such as storms and cyclones;
- changes in crop growth patterns leading to famine.

Currently, land degradation is the leading cause of environmental refugees, but sea level rise will soon overtake it (Jacobson 1988).

Current estimates have placed the number of environmental refugees at approximately 10 million compared with 17 million refugees of other types, and, under business-as-usual carbon input scenarios, their numbers may well increase to 150 million by 2050 (Jacobson 1988; see also Myers 1993). These estimates, however, are a case of best judgment, and even if the estimate of 150 million worldwide were too high by a factor of two, such a future would still hold a refugee crisis of unprecedented proportions. The overwhelming majority of current environmental refugees are in the developing world (Ramlogan 1996), and for those who are able to migrate to North America, Canada may well be the destination of choice.

Canada is a signatory to the 1951 Geneva Convention on the Status of Refugees, and adheres strictly to its definition of ‘refugee;’ anyone claiming to be an economic or environmental ‘refugee’ will not be admitted to Canada on those grounds. While there is some elasticity in the definition as interpreted by Canada and the other implementing countries (such as the definition of what constitutes a social group), persons fleeing poor environmental conditions are not considered *bona fide* refugees (Gorman 1997, pers. comm).

A key concept in justifying international intervention to assist refugees is the notion that refugees are a burden and this burden should be shared by other states (McGregor 1993). This burden, previously defined as economic, now is recognized as having a large environmental component. The countries most likely to generate environmental refugees from sea-level rise, crop failure, and other climate change effects are Bangladesh (up to 15 million), Egypt (up to 14 million), and China (up to 26 million; Myers 1993), and it is likely that Canada will host some of these displaced people. This means an increased environmental burden for Canada, though less so than that suffered by countries nearer to the environmental disturbance.

It already costs $8 Billion a year for developed countries to accommodate refugees (Myers 1993). Canada, like most Western countries over the past decade, has been tightening its definition of admissible refugees and trimming its refugee mission staff from 282 officers abroad to 211 (Dubyk 1997, pers, comm.). Since the end of the Cold War, the number of political refugees has been dropping, and the number of environmental and economic refugees has been increasing. It is generally assumed that refugees have a much greater negative impact on the environment than does the local population (McGregor 1993), and this fear of increased environmental degradation can be used to justify policies that restrict the flow of refugees, though distinguishing the environmental effect of refugees separately from the effect of other human processes can be extremely difficult. In order to minimize the impact of the refugees on the host population, it has been suggested that refugees should ideally not make up more than 10% of the population in the host country (Black 1994). With Canada's current population of approximately 30 million people, this formula suggests a cap of three million admissible refugees, yet in 1995, the last year for which there is available data, Canada only admitted approximately 12,500 refugees. Unless environmental factors are linked to traditional human rights law in the international arena, it is not likely that Canada will be expanding its immigration policy to include environmental refugees (Scoffield 1997, pers. comm.).

Refugees often arrive in their host countries with what are perceived as alien customs, religious practices, and dietary habits (Myers 1993). These cultural differences can often engender upheavals with the local population, sometimes with political fallout. In addition, a refugee influx very often strains the social services and physical infrastructure of the receiving country (Ramlogan 1996). Refugees need identity documents, work permits, and other such papers as governments issue to citizens, and need to overcome language and work skills problems, and the Canadian government must provide for such needs to the refugees it accepts. Canada will not suffer the same degree of financial and territorial strain that an impoverished third world nation might suffer in accepting large numbers of refugees, largely because it limits the number of refugees it accepts. However, Canada provides social welfare benefits to its refugees, and the Immigration and Citizenship budget has remained steady at approximately $592 million since the middle of the 1990s (Dubyk, pers. comm.). As the number of refugees increases, the welcome Canada provides for refugees may be rescinded.

In addition, providing for refugees, especially in a relatively unclear category as 'environmental,' can have negative foreign policy ramifications for the host government. If Canada were to accept environmental refugees from another country, it may be tantamount to making a negative statement about the conditions in that country (Ramlogan 1996). Depending upon which country is sending the refugees, Canada may not wish to accept them if it does not want to make waves in its foreign relations with that country.

Complicating the issue further is the idea that refugees are essentially distress migrants, not voluntary migrants like economic refugees, who leave their countries to find better opportunities elsewhere. However, because there are often many different reasons acting simultaneously to cause migration (political strife, environmental degradation, economic decline), it is increasingly difficult to classify refugees into two separate groups. The decision of a developed nation to accept environmental refugees might result in dilution of the quality of reception available for all refugees. Australia may become a target country for environmental refugees from the Asia/Pacific area (Nolch 1994), and the Australian government's response to this wave of migrants may be seen as a precedent for future responses by Canada and other developed nations to this same problem. After the 1993 Rio Summit on Environment and Development, the Office of the UN High Commissioner for Refugees (UNHCR) has begun consider seriously the planning of assistance programs for environmental refugees. However, two of the parties to the Rio Summit, Honduras and Turkey, have decided not to accept any refugees, citing environmental problems (Black 1994).

Because migration is a last resort, occurring only when conditions become so poor that life itself is in imminent danger, the rising number of environmental refugees should be seen as an important indicator of the extent and severity of worldwide environmental deterioration (Jacobson 1988). Such indicators will be helpful in spurring Canada and other developed countries to develop policy responses to the possibility of environmental refugees. One such response would be for all internationally financed aid to environmental refugees to incorporate environmental protection as an obligatory component of such aid (Westing 1992). This aid could then be used to offset or repair the environmental conditions that originally generated the refugees.

To summarize the effects on Canada of refugees displaced by climate change, we can see that many of the environmental disasters that occur in refugee camps are not applicable here. However, increased levels of admissible refugees will strain both local physical resources such as water use, food consumption, housing, and sanitation services; and local economic resources such as employment opportunities and welfare benefits. The level of stress on these resources varies directly with the number of refugees admitted.

CONCLUSION

A review of the available literature for these important extra-territorial issues reveals many gaps and areas for further study. However, while specific outcomes are impossibly difficult to predict, several general trends can be found.

Analysis of the international trade field yields the most indefinite results. The agriculture, forestry, fisheries, and energy sectors will all be affected to a large or small degree by climate change. Since Canada relies heavily on exports from these four production sectors, Canada's trade balance will also be affected. Whichever sectors benefit or suffer from climate change effects, climate change response policy and international trade policy must be complimentary if they are to achieve their twin goal of climate change mitigation without undue economic hardship.

The effects of climate change on the security field appears to be more definite. Canada's geopolitical position buffers it from most military offenses, and its abundant agricultural sector and peaceful border with the United States insulates it from the vagaries of climate change-induced variations in food production. However, as climate change is likely to produce increasingly variable weather events, the role of the national defense forces in assisting civilian authorities in the face of natural disasters must be further examined.

The effect of climate change on the number of environmental refugees coming to Canada is unknown. Estimates of the number of refugees generated by climate change effects ranges as high as 150 million, though only the most mobile of those would make their way to Canada. This would put an unprecedented strain on Canada's refugee assimilation mechanisms, though the exact cost would be impossible to quantify at this time. What is known is that climate change will affect Canada's interests outside Canadian territory, and we must continue to work with other nations and world agencies to plan effective mitigation strategies and enforce them thoroughly.

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Appendix A: Selected Examples of Economic Instruments to Enhance Compliance with Climate Change Response Policies

Measures	**Climate and Other Environmental Effects**	**Economic and Social Effects**	**Administrative, Institutional and Political Considerations**
Subsidy Removal	- Depends on extend of existing subsidies and degree of reduction	- Increases real income in the long term - Changes distribution of income; effect depends on how revenues are redistributed	
Domestic Taxes	- Can be designed to achieve a specified international emission target	- Encourages implementation of most cost-effective mitigation measures - Carbon tax regressive, but effect depends on how revenue is recycled	- Could be linked to existing energy tax collection systems, if any
Tradable Permits	- Can be designed to achieve a specified international emission target	- Encourages implementation of most cost-effective mitigation measures - Effects depend on how revenue is redistributed	- Requires a competitive permit market - Administrative costs depend on system design - Futures contracts for permits can spread the risks of price fluctuation
Harmonized Taxes	- Can be designed to achieve a specified international emission target	- Encourages implementation of most cost-effective mitigation measures - Equity across countries depends on the transfer payments negotiated	- Little information on implementation available - Domestic policies could reduce the effectiveness of the tax
Tradable Quotas	- Can be designed to achieve a specified international emission target	- Encourages implementation of most cost-effective mitigation measures - Equity across countries depends on quota allocation	-Requires a competitive quota market -Little information on implementation available -Allows flexibility in the choice of domestic policy
Joint Implementation	- Can reduce emissions from levels that would otherwise occur	-Transfers resources and technologies to host countries	-Administrative costs can be high -Projects can be launched quickly

Source: from Watson, *et al*, IPCC 1996

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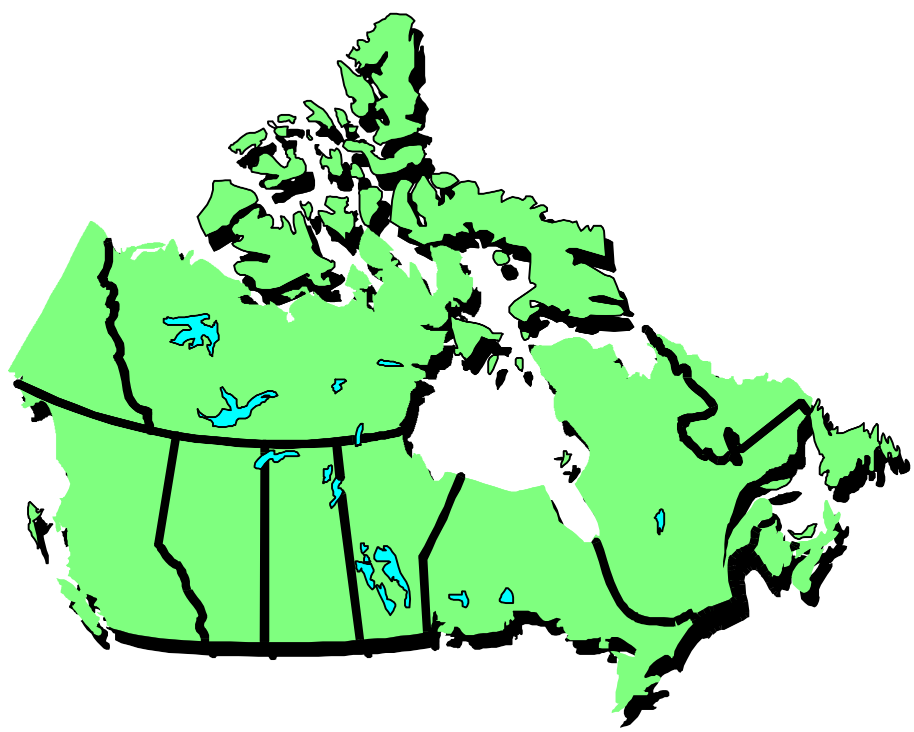
CHAPTER FIVE

CLIMATE CHANGE AND FLOWS OF DOMESTIC TRADE AND COMMERCE IN CANADA

Nairne Cameron, Philippe Crabbé[1], Karim Eslamloueyan, Daniel Lagarec, Nguyen Van Quyen



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EXECUTIVE SUMMARY

The volume of literature on Canadian domestic trade under climate change is quite meagre and originates mainly in Environment Canada. Statistics about interprovincial trade are lacking and the ones that exist are notoriously unreliable. This situation is currently being remedied by Statistics Canada (PIPES project).

The literature review seems to indicate that the aggregate benefits of climate change are likely to outweigh their costs for the Canadian Economy as a whole, but that the geographical distribution of the benefits will differ from the costs. The benefits will tend to be reaped in the North while the costs are likely to be borne in the South especially in the Great-Lakes Basin, the lower reaches of the St. John River and Southern Saskatchewan.

The Northern location of the net benefits of climate change in Canada are unlikely to be a sufficient incentive for the Canadian population to move northward. Though this opinion is not grounded in the literature review, it makes economic sense. Modern economies like the Canadian economy are knowledge-based and no longer natural resource-based. Population centres are also service centres and the service sector contributes over 50% of Canadian GDP. Natural resources and agriculture contribute a small fraction of GDP and of overall employment in Canada. This does not mean that regional impacts may not be significant in vulnerable regions.

INTRODUCTION

Literature summary and critical evaluation

This paper reviews the existing literature on domestic flows of goods and services in Canada as related to climate change. The volume of this literature is quite meagre. Most of the literature dealing with flows of domestic trade and commerce in Canada under climate change originates in Environment Canada.

Canadian data on interprovincial (including territories) trade are notoriously inadequate. This situation is currently being remedied through a major effort undertaken by Statistics Canada. The Project to Improve the Provincial Economic Statistics (PIPES) aims ultimately at being a policy tool for the distribution of the proceeds of the harmonized Goods and Services Tax. It will produce, by year 2000, an interprovincial input-output table that will illustrate the flow of goods across Canada. This will be done by collecting statistics from commercial enterprises and classifying them according to the Classification System for North-American Industries (CSNAI) and by modifying the information collected from commercial enterprises and household surveys (Statcan contact person: Philip Smith).

The best available indicator of interprovincial flows of goods and services are Statcan "Transportation and Storage to Provinces" 1996 figures (CANSIM Database date for reference required). The portion dealing with interprovincial trade represents 16% of all transportation and storage (whose 1996 value was about $52 billion); this includes trade with international as well as provincial origins. The regional entity with the largest proportion of interprovincial flow of transportation and storage is the Northwest Territories (29%), followed by Nova Scotia (24%), Saskatchewan (22%) and Newfoundland and PEI (21% each).

The largest uncertainty pertaining to domestic flows of trade and commerce under climate change concerns the resulting pattern of human resettlement. Many of the gains resulting from climate change will be reaped in Northern Canada; many of the costs will be borne in Southern Canada. This heterogeneous geographic distribution of benefits and costs will likely result in pressures towards a Northward movement of the population. On the other hand, factors of production other than land such as physical and human capital and proximity of markets contribute to a geographical distribution of economic net benefits which may be very different from the one dictated by the land factor alone. Modern economies are knowledge-based and no longer natural resource-based.

Whether climate change will affect population resettlement depends very much upon whether one believes in weak or in strong sustainability. Weak sustainability allows for substitution of human and physical capital to natural capital (the Neo-Classical paradigm). Strong sustainability limits these substitution possibilities to non-critical natural capital. Critical capital is the portion of natural capital which is essential i.e., without which there can be no production of some commodity or which provides unique services e.g., biodiversity. In other words, weak substitutability emphasizes substitution possibilities for natural capital while strong sustainability emphasizes the complementarity of natural capital to other factors of production. The significant possibilities for adaptation and mitigation i.e., for weak sustainability are not sufficiently emphasized in the literature reviewed.

The review of the literature available allows us to formulate the following conclusions.

Water resources in Southern Canada under climate change will be affected by increased evaporation and decreased precipitation. This is true especially for the Great-Lakes Basin and the Southern Prairies which will be affected by more frequent droughts.. The decreased availability of freshwater will in turn have a negative feed-back effect on water consumption which is expected to increase for irrigation and for home consumption (e.g., lawn watering) and perhaps for large-scale diversions.

As far as the Canadian agricultural sector is concerned, climate change may have an overall favorable impact on wheat, and grain corn production, thereby increasing exports and reducing imports of corn grain from the US Midwest, but less so for barley and oats. The regional impact of climate change on Canadian agriculture may differ substantially though. Climate change may shift the availability of agricultural land northward but soil quality may prevent reaping the benefits of temperature increases. In the Prairie region, slight increases in precipitation may be more than compensated by large increases in evapotranspiration especially in the northern part of Saskatchewan with resulting reduction of agroclimate and crop yield diversity. The severity of droughts will be increased, increasing pressure on freshwater demand for irrigation. Though it is generally agreed that wheat production will decrease in the Prairie region, adaptation through minor changes in seeding dates, crop selection and management techniques may reduce the impact of climate change on the Prairie agriculture quite substantially; opinion on this in the literature surveyed is divided though. The impact on Alberta agriculture may be small because Alberta is very dependent on meso- and micro-climates; this conclusion is derived from observed resilience to extreme weather events rather than to unobserved long-term climate change. In Ontario, corn and soybean cultures will shift northward. Quebec will benefit from an increase in degree-days which will allow a lengthening of growing seasons and be beneficial for apple and grape production. In New-Brunswick, floods in the lower reaches of the St. John Valley may be more frequent. Generally, the growing season may change everywhere in Canada and may sometimes be lengthened. Growing pressures on freshwater for irrigation will increase especially in the US Midwest thereby affecting the Great-Lakes, and Prairies. Climate change may have an impact on the severity and frequency of pests and plant diseases.

As far as energy production is concerned, the most dramatic impacts of climate change are likely to be on hydroelectric production in the Great-Lakes basin due to decreasing water levels - there is a lack on consensus about other watersheds - and on offshore fossil fuels production. The loss of hydro potential in Ontario will require building more thermal stations. Water for cooling nuclear stations may be lacking. On the other hand, the hydro-generation potential will increase in the James Bay region. Electricity demand for heating will be reduced considerably in Ontario and Quebec while demand for cooling may increase slightly during the Summer. On the other hand, increased demand for water for irrigation will result in increased electricity consumption for pumping. Offshore fossil fuels production may benefit from the elimination of sea ice and icebergs (iceberg calfing notwithstanding); resulting increased height of waves may increase shore erosion and, thereby, affect long-lived coastal and offshore structures. Thawing permafrost may affect pipelines in the North. In Alberta, electricity production and consumption is not much affected by climate. Natural gas demand for heating in Alberta will be reduced and the peak demand would be flattened. In the lower reaches of the St. John River in New-Brunswick, generating facilities may have to be moved because of the risk of flooding. If settlements patterns change considerably by shifting northward - an unlikely event as indicated earlier, energy consumption patterns may change considerably as well.

Fisheries may be affected by a northward migration of salmonids due to lower coastal salinities and warmer temperature with a major economic impact on the B.C. economy. Generally speaking, the geographical range for fish species will change but the change is not predictable given the current state of our knowledge. Warm water exotics will invade the Great-Lakes. Phytoplankton will increase but Summer fish productivity may actually decrease due to oxygen depletion. Wetland habitat will be affected as well. Aquaculture will benefit from warming temperature and fishing seasons could become longer.

Forests are bound to move northward as well with dramatic decreases of tundra forest areas, substantial decreases of boreal forest area possibly compensated by substantial growth of biomass and increases of hardwood forests in both area and biomass. Risks of fire - markedly increased since the 1980's - and pests would be substantially increased in the boreal forest. Alberta would loose because of increased costs of transportation for timber. Climate change would render carbon sequestering strategies through conversion of agricultural land to forestry inadequate economically and socially. Winter logging may become more difficult because of increased precipitation in northern areas.

Recreational impacts from climate change result generally from a longer Summer and a shorter Winter season. Skiing may adversely be affected while golfing may benefit. Fewer residents may leave an area in Canada for Summer activities while more non-residents may be visiting Canada. The impact on the Rockies is ambiguous due to uncertainties about precipitation. Increased fire frequency may affect Summer recreation activities in wooded areas negatively. Park size, location and selection will be affected. Land-use conflicts may result from more frequent droughts and affect parks' attributes listed above.

The net effect of climate change on transportation seems to be positive. Again the regional impacts vary. In the Great-Lakes Basin, water transport will benefit from ice free year-round shipping however, lower water levels will force the reduction of shipping loads causing infrastructure costs to increase because more frequent dredging becomes necessary. The Atlantic provinces will benefit from ice-free marine transportation but suffer from the competition of the ports located in the Great-Lakes Basin and Churchill, Manitoba. Again the transportation system in the lower reaches of the St. John River is highly vulnerable to flooding. In the North, shipping seasons become longer (barge transportation is the main mode of transportation) but air traffic may suffer from more frequent precipitation. An ocean level rise would affect port infrastructures on both coasts. A change in human settlement pattern will affect all modes of transportation especially roads and rail which will become more expensive.

Though most of the benefits from climate change will be reaped in Northern Canada and most of the costs borne by Southern Canada, the regional distribution of the costs and benefits may vary considerably. Clearly, the pressures on Great-Lakes Basin water, on Southern Prairies resulting from more frequent droughts and on South-Eastern New-Brunswick resulting from increased risk of flooding can reasonably be predicted.

One can offer the following critical remarks on the above literature review:

Domestic trade and commerce is likely to intensify with Northern regions (which have the largest proportion of interprovincial transportation and storage in Canada) which may become the new frontier. On the other hand, large population centres i.e., markets and service centers, are not likely to change location. Location of manufacturing activities is less dependent on natural resource location than on manpower cost and availability of services. The natural resource sector and agriculture employ less and less people and contribute less and less to Gross Domestic Product in modern economies. The scarcest natural factor - by no means critical natural capital - is likely to be freshwater in some areas such as the Great-Lakes.

Literature and data gaps

The next step should be the review of the documents produced by the Canada Country Study (CCS) in order to find out whether the conclusions derived from the literature review still hold. A cursory look at the CCS does not seem to generally invalidate these conclusions. Once a new set of conclusions or assumptions have been made, one should infer the likely patterns of domestic trade. Any rigorous scenario will have to wait though for the production of the 1997 interprovincial input- output table expected to come out in year 2,000. A methodology similar to MINK (Frederick et al., 1994) possibly connected to the G-cubed model (McKibbin et al., 1995) for consistency with global economic scenarios model could then be used.[1]

LITERATURE SEARCH

Several avenues were explored in the search for literature pertaining to the impact of climate change on domestic flows of goods and services in Canada.

The seven key sectors examined are:

1. agriculture
2. energy
3. fishery
4. forestry
5. recreation/tourism
6. transportation
7. water resources

A focus has been placed on the transportation sector, as it is a direct indication of domestic flows of goods and services.

Methodology for Conducting Literature Search

A sample search is illustrated in Figure 5.1. A more detailed search process for transportation literature is presented in the Appendix.

Key Word Search:

The general keywords used to direct the search are as follows:

- Canada AND climate change
- global warming
- climate warming
- climate change AND goods AND services
- Canada AND climate change AND (agriculture, energy, fishery, forestry, recreation, tourism, transportation, water resources)

Sources for the Literature Search:

The following general avenues were explored in the literature search including:

1) Commercial databases (for a detailed description of each, please see Appendix A-1):

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[1]Frederick, K.D. and N.J. Rosenberg (1994), Climate Change, 28, special issue on Assessing the Impact of Climate Change on Natural Resources Systems; McKibbin, W.J. and P.J. Wilcoxen (1995), The Theoretical and Empirical Structure of G-Cubed, Brookings Institution, mnss.

- Compendex (Engineering literature) 1987-Jan. 1997;
- EconLit (Economics Literature)1969-Sep.1996;
- Geography (Geography literature) 1990-Nov. 1996;
- MicroLog (Federal, Provincial, and Municipal documents) 1982-Dec.1996.

2) Internet search using various search engines (see Table 5.1)

3) Government organizations

4) Non-governmental organizations

Figure 5.1 Sample Literature Search

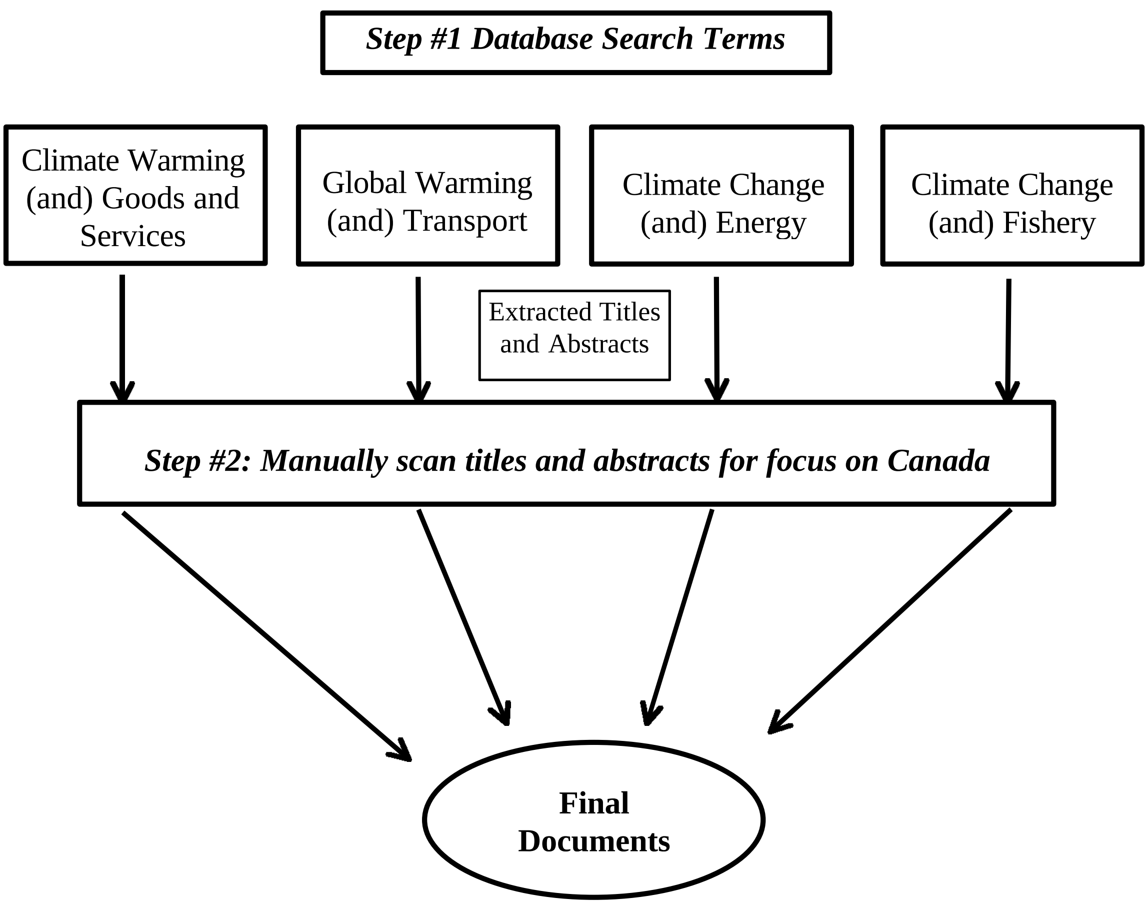

Table 5.1 Internet Sites Used for Literature Search

Internet Sites Used:
Alberta Department of Energy
British Columbia Ministry of Employment and Investment (MEMPR)
Canadian Environmental Assessment Agency (CEAA)
Canadian Institute for Climate Studies (CICS)
Environment Canada
Friends of the Earth Canada
Greenpeace
Hydro/Ontario
International Institute for Sustainable Development (IISD)
Natural Resources Canada (NRCan)
Pembina
Pollution Probe
Ontario Round Table on Environment and Economy (ORTEE)
OECD
Saskatchewan Energy and Mines
Sierra Club
Statistics Canada
United Nations Environmental Program
World Wildlife Fund

SUMMARY OF LITERATURE

Agriculture

- **Environment Canada (1987), *Implications of Climatic Change for Agriculture in Ontario,* Climate Change Digest, CCD 87-02.**

A warmer climate may mean crop failures in the agricultural heartland of Ontario; Crops like corn and soybeans may become very risky in Southern Ontario because of drought conditions; Corn, soybeans and other crops may become viable in Northern Ontario; Horticultural crops may be grown across much of Ontario; the regional pattern of agriculture across Ontario may be transformed by changes in climate. Without adjustment, the 'Greenhouse Effect' could be costly for Ontario agriculture due to production lost.

- **Environment Canada (1987), *Effect of a One Meter Rise in Mean Sea-Level at Saint John, New Brunswick, and the Lower Reaches of the Saint John,* Climate Change Digest, CCD 87-04.**

The richest farmland in the area is presently subjected to flooding and the impacts can only be expected to increase as the frequency and duration of flooding increases.

• **Environment Canada (1988),** ***The Implications of Climate Change for Agriculture in the Prairie Provinces*****, Climate Change Digest, CCD 88-01. [Also see** ***"Implications of Climate Change for Agriculture in the Prairie Provinces,"*** **University of Manitoba, Department of Agricultural Economics and Farm Management, Winnipeg, Manitoba, Phase III Report May 1987.]**

The initial response to expectations of global warming is that agricultural patterns will change dramatically, and that the prairie regions could suffer substantial crop losses. However, the result reported here suggest otherwise; even with minor adjustments in seeding dates, crop selection and management techniques, the losses can be attenuated or avoided entirely. The paper concludes that most of the economic impacts are small.

• **Environment Canada (1988*),*** ***Economic Perspectives on the Impact of Climate Variability and Change: A Summary Report*****, Climate Change Digest, CCD 88-04.**

Climate change could trigger considerable adjustment in regional patterns for agriculture throughout Ontario, and thereby affect agricultural and economic prospects at the farm, regional, and provincial levels. These and other impacts need to be assessed and linked to more general approaches (e.g., scenario modeling) in developing optimal future research activities.

• **Environment Canada (1988),** ***Estimating the Effects of Climatic Change on Agriculture in Saskatchewan, Canada*****, Climate Change Digest, CCD 88-06.**

In an extreme drought year Saskatchewan can expect moisture resources so reduced that the wind erosion potential is doubled, spring wheat production is about 25% of normal and losses to the agricultural economy in 1980 dollars exceed 1.8 billion and 8000 jobs with further reduction in other sectors of the economy of 1.6 billion, and 17000 jobs. A shift to a long term warm climate with precipitation increase, without major adaptive changes by agriculture, would reduce wheat yield by 16%. The impact of long term warming would be more pronounced in the northern agricultural zone of Saskatchewan, with the result that the overall agroclimate and crop yields would become more homogeneous.

• **Environment Canada (1988*),*** ***The Implications of Climate Change for Natural Resources in Quebec*****, Climate Change Digest, CCD 88-08.**

Substantial increase in the length of the growing season for all agricultural regions in Quebec; sharp increase in growing degree-days in all regions (40% to 105%); considerable potential for agricultural expansion in some regions; increased potential for the cultivation of grapes and apples in all regions.

• **Environment Canada (1989),** ***Climatic Warming and Canada's Comparative Position in Agriculture*****, Climate Change Digest, CCD 89-01.**

- Production prospects for wheat and grain corn may be enhanced in Canada.
- Conditions for the production of barley and oats in Canada may be less favourable.

- Canada's position in the production and trade of wheat and grain corn may improve relative to the rest of the world.
- Export opportunities for Canadian wheat to Europe, Africa and Asia could expand.
- New market for Canadian grain corn could open in regions such as North and Central America.
- Canada may be able to reduce current imports of grain corn from the mid-western US.
- Conclusions regarding changes in Canada's competitive position in the production and trade of other crops including barley, oats, soybeans and rice remain uncertain.
- Impacts are likely to vary among regions in Canada, with ramifications for regional development policies.

• **Environment Canada (1989), *The Effects of Climate Change of the Economy of Alberta,* Climate Change Digest, CCD 89-05.**

[In Alberta] regional agricultural economies are strongly affected by meso and micro scale weather and climate patterns. The overall provincial agricultural economy is less dependent on climate due to the likelihood of offsetting positive and negative regional impacts.

• **Acres International Limited (1989) "*The Environment/Economy Link in Alberta and the Implications under Climate Change Report,*" P08725.00, Calgary, Alberta.**

Because Alberta agriculture is relatively diverse adverse regional climatic conditions rarely generate a precipitous drop in the economic well-being of the entire provincial agricultural economy, i.e., the elasticity is low. Compared with the Saskatchewan agricultural sector, for example, Alberta is very resilient. This, of course, relates specifically to extreme weather events; not to the possibility of adverse long-term climatic change. Moreover, because of the slowly diminishing role of the agriculture sector in the Alberta economy, typically the performance of the overall economy is not greatly affected by climate-induced fluctuations in the agricultural sector. (p.19)

• **The U.S. National Climate Program Office and the Canadian Climate Centre (1989), *Impacts of Climate Change on the Great Lakes basin,* Symposium 1988 conducted on September 27-29, 1988 at Oak Brook, IL.**

Agriculture in the Midwest will likely require more water, including the possibility that the Great Lakes could become a source of water irrigation. In this connection, water allocation was identified as one of the major issues that may arise. Continued urbanization around the Great Lakes, which will likely occur whether climate change occurs or not, will tighten the competition for land. Urban land use may compete with agricultural land use, and cropped agriculture may compete with forestry.

• **Environment Canada (1991), *Climate Change and Canadian impacts: The Scientific Perspective,* Climate Change Digest, CCD 91-01.**

The potential exists for northward expansion of crops, but this is generally limited by soil capability; pests and plant diseases and the frequency would likely increase; the severity of agricultural drought would likely increase, which could lead to increased demand for irrigation services, and possibly more conflicts with other water users (depending on the hydrologic impacts); economic losses in drought years could be more severe than historical experience indicates.

- **Environment Canada (1992), *Global Warming: Implications for Canadian Policy*, Climate Change Digest, CCD 92-01.**

It is anticipated that crop production on the Canadian Prairies will become more vulnerable to drought, as slight increase in precipitation are outweighed by substantial rise in potential evapotranspiration. Opinion is divided on whether the industry will adapt easily to changed conditions.

- **Environment Canada (1994), *A Regional Response to Global Climate Change: New England and Eastern Canada*, Climate Change Digest, CCD 94-03.**

Changed growing seasons and precipitation patterns could affect crop selection and productivity. The region's farm produce is worth about $5.3 billion (U.S.) in dairy products, fruits, potatoes and small grains.

- **Environment Canada (1995), *Mackenzie Basin Impact Study: Summary of Interim Report #2*, Climate Change Digest, CCD 95-01. [Also see Brkhlacich, M. and P. Curran (1994), "*Climate Change and Agricultural Potential in the Mackenzie Basin*," in Cohen, S.J. (ed.), Mackenzie Basin Impact Study (MBIS): Interim Report #2, Environment Canada, November 1994.]**

A warmer climate could increase the capability of land to support commercial agriculture in areas with suitable soils that are currently limited by short growing seasons. Brklaich and Curran (Carleton University) are assessing potential opportunities for expanding production of spring-seeded grains (wheat, oats, barley, etc.) and forages (hay, etc.). Preliminary indications are that there would be an increase in marginal and suitable land.

Energy

- **Great Lakes Institute, *Implications of Climate Change for Navigation and Power Generation in the Great Lakes*, University of Windsor, Windsor, Ontario (Phase I Report, March 1985; Phase II Report, March 1986) A summary is appeared in Environment Canada, " *Implications of Climate Change for Navigation and Power Generation in the Great Lakes*," Climate Change Digest, 1987, CCD 87-03.**

Ontario residential heating requirements may decrease by 30 to 45%; Summer cooling requirements may increase by 7%.

- **Environment Canada (1987), *Implications of Climate Change for Navigation and Power Generation in the Great Lakes*, Climate Change Digest, CCD 87-03.**

For the Canadian hydro generating stations on the Great Lakes climatic change plus increased consumptive use could result in a loss of 4165 gigawatt hours of power generation. Replacing the lost production with a mix of nuclear and fossil fuel generation could cost Ontario Hydro $65 M ($US 1979) annually. Converting these costs to 1984 Canadian dollars give $111 M.

Warmer temperatures will result in a lower demand for energy in winter and slight increase in summer, resulting in an average annual saving of $172-204 M ($C 1984) for Ontario Hydro. Combining reduction in demand with reduction in generation will result in annual savings of $61-92 M. ($C 1984).

- **Environment Canada (1987),** ***Effect of a One Meter Rise in Mean Sea-Level at Saint John, New Brunswick, and the Lower Reaches of the Saint John*****, Climate Change Digest, CCD 87-04.**

The New Brunswick Power Plant in East Saint John is vulnerable to inundation is a storm surge.

- **Environment Canada (1988),** ***Socio-Economic Assessment of the Physical and Ecological Impacts of Climate Change on the Marine Environment of the Atlantic Region of Canada - Phase 1*****, Climate Change Digest, CCD 88-07.**

Costs to offshore oil and gas exploration and development of drilling downtime, because of sea ice and icebergs, could be practically eliminated ($40 million in 1984-85).

- **Environment Canada (1988),** ***The Implications of Climate Change for Natural Resources in Quebec*****, Climate Change Digest, CCD 88-08.**

Increase in net basin supply of the order of 7% to 20% for three drainage basins within the James Bay area; potential increase in hydro-electric generating capacity of about 9.3×10^{12} W/h for the three drainage basins combined; significant decrease in heating degree-days for Montreal (25%) and Quebec City (35%) which would diminish substantially winter heating requirements across Quebec.

- **Environment Canada (1989),** ***The Effects of Climate Change of the Economy of Alberta, Climate Change Digest*****, CCD 89-05.**

[In Alberta] Total provincial electrical usage is not strongly dependent on the climate. Natural gas consumption is strongly dependent on the climate; about 20% of consumption is independent of climate. The GISS scenario implies a 20% reduction in demand for natural gas with a flattening of loads in the winter.

- **Acres International Limited (1989) "*****The Environment/Economy Link in Alberta and the Implications under Climate Change Report,*****" P08725.00, Calgary, Alberta.**

Based on the GISS temperature change projections, electrical energy consumption would be expected to decrease slightly in the winter and increase slightly in the summer. The net result might only be a saving of about one-half of one percent per annum. (p.47) Specific electrical energy use requirements could shift very considerably, e.g., we could witness a 20 percent increase in the hours used to irrigate agricultural land.(p.48) Seasonal use [of energy] changes and a probable net saving. Total use [of energy] could still climb because of changing settlement patterns and growing industrial requirements. (p.63)

• **The U.S. National Climate Program Office and the Canadian Climate Centre (1989),** ***Impacts of Climate Change on the Great Lakes basin, Symposium 1988 conducted on September 27-29,*** **1988 at Oak Brook, IL.**

The energy papers each described changes in demand which would likely in response to future warming. While warming of the climate of the basin was found to benefit society by reducing the need for power in winter months, it was noted this apparent benefit could be offset by other factors. For instance, negative factors include a higher peak demand in summer due to increased air conditioning, lower water levels decreasing available hydropower capacity, and the possibility, under extreme conditions, that there might be inadequate supplies of cooling water in some locations within the basins of the Great Lakes.

• **Environment Canada (1991),** ***Climate Change and Canadian impacts: The Scientific Perspective,*** **Climate Change Digest, CCD 91-01.**

Pipelines and other facilities at high latitudes may become more difficult to maintain due to thawing permafrost; the seasonal demand for heating and cooling would probably change thereby affecting domestic power delivery, imports and exports; hydro-power production may be significantly reduced in the Great Lakes System due to projected lower water levels, but there is no consensus for other major watersheds.

• **Environment Canada (1992),** ***Global Warming: Implications for Canadian Policy, Climate Change Digest,*** **CCD 92-01.**

Federal and provincial, and energy utilities, are exploring ways to limit greenhouse gas emissions in energy production. However, present understanding of the direct effects of global warming on energy production, and on future energy demand, depends on a limited basis of research.

• **Environment Canada (1993),** ***Impacts of Climate Change on the Beaufort Sea-Ice Regime: Implications for the Arctic Petroleum Industry,*** **Climate Change Digest, CCD 93-01.**

This report considers the effects of climate warming on offshore ice and waves as they might affect the offshore oil and gas industry in the Canadian Sector of the Beaufort Sea. It find that within the Canadian sector of the Beaufort Sea, the projected climate warming would impact the offshore industry favourably by reducing design requirements and operating costs (due to reduced ice thickness and a longer open water season). It would adversely impact the industry through increased wave coastal erosion; i.e., the projected increased wave energy would increase the design requirements for long-lived coastal and offshore structures.

• **Environment Canada (1994),** ***A Regional Response to Global Climate Change: New England and Eastern Canada,*** **Climate Change Digest, CCD 94-03.**

A quarter of Eastern Canada's and five percent of New England's electricity generation come from climate sensitive hydropower. If climate warms, summer consumption could rise, but winter heating needs may be reduced.

- **Brklacich, M. and P. Curran (1994), *"Climate Change and Agricultural Potential in the Mackenzie Basin,"* in Cohen, S.J. (ed.), *Mackenzie Basin Impact Study (MBIS): Interim Report #2*, Environment Canada, November 1994. [Also see Environment Canada (1995), Mackenzie Basin Impact Study: Summary of Interim Report #2, Climate Change Digest, CCD 95-01.]**

Reduced maximum ice depth could significantly reduce the cost of development and production platforms, simplify the design of undersea gathering lines, and reduce the necessary ice breaking capacity of year-round tankers. The northward shift of the pack ice would facilitate exploration in the waters above 70^{o} N. Also, the increase in the open water season could increase the annual output of the seasonal tanker oil production scenario; Also, the increase in the height of waves could cause significant coastal erosion, which would have costly implications for the design and location of pipeline terminals and other facilities. Also, a longer summer would mean more ice-free days on the Mackenzie river, which is a vital transportation artery connecting Great Slave Region with the Delta. For the most onshore activities, however, the most active season is during the winter months For example, overland transportation is generally cheaper and easier in the winter because of the existence of ice roads for trucks and the ability to use snowmobiles.

Fishery

- **Environment Canada (1988), *Socio-Economic Assessment of the Physical and Ecological Impacts of Climate Change on the Marine Environment of the Atlantic Region of Canada - Phase 1*, Climate Change Digest, CCD 88-07.**

Although the effects of climate change on yields in the traditional capture fisheries are still uncertain, a warmer climate would be favourable to the continuing growth of the aquaculture industry and its expansion into new areas. Shorter winter and sea ice seasons would allow longer inshore fishing seasons, and thus longer employment of fishing capital and labour per year.

- **The U.S. National Climate Program Office and the Canadian Climate Centre (1989), *Impacts of Climate Change on the Great Lakes basin*, Symposium 1988 conducted on September 27-29, 1988 at Oak Brook, IL.**

Climatic change will cause the extension of ranges of various species of fish. We can expect an invasion of warmer water exotics, and with the greater productivity, there may be more fishing opportunities.

- **Environment Canada (1990), *Implications of Climate Change for Small Coastal Communities in Atlantic Canada*, Climate Change Digest, CCD 90-01.**

The timing of life cycles and migrations of fish species will change, and the areas of greatest concentrations of many commercially important fish species are likely to shift northward from their current positions. Fishermen will have to adapt their fishing methods in terms of areas, times, gear and species for harvesting. Some fishermen and communities may benefit, while others may lose.

- **Environment Canada (1991), *Climate Change and Canadian Impacts: The Scientific Perspective*, Climate Change Digest, CCD 91-01.**

(a) Freshwater Fisheries: more than 30 new species could invade the Great Lakes from the south while resident species could disappear; melting of the permafrost would disrupt the fish habitat in Northern Canada; in coastal areas fish species may shift from present zones; warmer conditions could be favorable to the continued growth of the agriculture industry; warmer water could lead to increase phytoplankton production and increases in habitable waters during winter; decreases in summer productivity due to excessively high water temperatures and oxygen depletion may occur; changes in shoreline wetland due to water level changes (e.g., projected reduction in Great Lakes levels) could affect fish populations.

(b) Salt Water Fisheries: changes would occur in the distribution, abundance, species mix and migration routes of fishes; for example, the natural southern limit of salmonids is determined by climate factors as in the species compositions of east coast fisheries. A warming of coastal waters would affect the geographical limits to the range of species such as squid and mackerel on the Atlantic Coast and hake and tuna on the Pacific Coast, possibly leading to increased abundance and new or expanded fisheries. Some northern salmonid populations might experience increased production through more favorable conditions. Our ability to predict the implications for marine species is, however, very limited since the knowledge base is insufficient; additional research is needed.

- **Environment Canada (1992), *Review of Models for Climate Change and Impacts on Hydrology, Coastal Currents and Fisheries in B.C.*, Climate Change Digest, CCD 92-02.**

Projected climate changes may reduce salmon stocks by lowering coastal salinities and increasing temperatures. Since salmon is a very important commercial fisheries, reduction in salmon stocks would have a major economic impact [in B.C.]. It is essential that research be undertaken to clarify these relationships(p.1). In considering the influence of climate change on saltwater fisheries, it is apparent that not all fisheries will be affected in the same way.(p.11)

- **Environment Canada (1994), *Potential Impacts of Global Warming on Salmon Production in the Fraser River Watershed*, Climate Change Digest, CCD 94-04.**

The Fraser River produces more Pacific salmon than any other river system in the world. Salmon population may increase in northern and high altitude areas, but decrease in southern and low altitude area, due to increased temperatures.

Forestry

- **Environment Canada (1988), *The Implications of Climate Change for Natural Resources in Quebec*, Climate Change Digest, CCD 88-08.**

Northward displacement of major forest ecosystems by several hundred kilometers; drastic decrease in tundra forest area ranging from 62% to 100%; potential decrease in boreal forest area of the order of 20% but compensated by a better forest growth rate; increase of about 200% in the acreage of hardwood forests.

- **Environment Canada (1989), *Exploring the Implications of Climate Change for the Boreal Forest and Forestry Economics of Western Canada*, Climate Change Digest, CCD 89-02.**

This report summarizes Phase I results of an exploratory study to assess the implications of CO_2 -induced climate change for the boreal forest of the Prairie Provinces and the Northwest Territories. The study area constitutes 82% of the forest land in Canada.

A climatic zonation model for the boreal forest was designed and tested. Results of the impacts of one of the climatic change scenarios were calculated and discussed. Preliminary results indicate that the aspen parkland ecoclimatic zone would extend northward into the western part of the study area and the boreal temperate ecoclimatic zone would extend westward into the eastern part of the study area under climate warming.

- **Acres International Limited (1989) "*The Environment/Economy Link in Alberta and the Implications under Climate Change Report,*" P08725.00, Calgary, Alberta.**

The presently anticipated climatic change could result in a net benefit to the Western Canadian forestry sector since accelerated biomass growth might augment supply by 60 percent while the forest area might increase by 37 percent. Thus, since the implied increase in harvest area and growth in the forest sector would generally be further north while product prices are expect to decline, it seems probable that the remaining forest sector within provincial boundaries would most likely suffer a net loss. It could shrink rather considerably.(p.42)

- **Environment Canada (1991), *Climate Change and Canadian impacts: The Scientific Perspective*, Climate Change Digest, CCD 91-01.**

The potential exists for a northward shift in forest ecosystems with, in some cases, narrower boundaries for some species; an increase in forest damage from pests and fires is likely; probable negative impact on winter logging operations due to warmer, wetter winters in northern areas.

- **Environment Canada (1992), *Global Warming: Implications for Canadian Policy*, Climate Change Digest, CCD 92-01.**

A recent Environment Canada study suggests that ecoclimatic conditions favouring the boreal forest may be virtually eliminated west of Quebec by 2050. Fire is likely to be a major factor for change and may be uncontrollable throughout much of the present boreal forest zone. Meanwhile, burned areas have shown a marked increase during the 1980s.

- **Cornelis van Kooten, G., (1995) *"Climate Change and Canada's Boreal Forest: Socio-economic Issues and Implications for Land Use,"* Canadian Journal of Agricultural Economics 43, 133-148.**

The paper reviews the effect of climate change and policies to sequester carbon on forest land use. Efficient mitigation strategies often require the conversion of agricultural land to forestry in order to sequester carbon, but such strategies could be wrong for Canada's boreal forest region if global warming is inevitable. It is argued that, from both an economic and a social perspective, conversion of the southern boreal forest to grassland or agriculture might be a better policy.

- **Armstrong, G. W.(1994), "*Timber Supply Impacts of Climate Change in the Mackenzie Basin,*" in Cohen, S.J. (ed.), Mackenzie Basin Impact Study (MBIS): Interim Report #2, Environment Canada, November 1994. [Also see Environment Canada (1995), *Mackenzie Basin Impact Study: Summary of Interim Report #2*, Climate Change Digest, CCD 95-01.]**

The Mackenzie Basin is an important timber producing region in Canada. About 90 percent of Alberta's annual allowable cut (AAC) comes from the region. Armstrong (University of Alberta) provides information on a methodology for assessing potential impacts on timber supply, drawing upon results obtained from the forestry studies.

Recreation/Tourism

- **Lamothe and Périard Ltée. (1987), *Implications of Climate Change for Downhill Skiing in Quebec*, Montreal, Quebec, May 1987. A summary appeared in "*Implications of Climate Change for Downhill Skiing in Quebec,*" Climate Change Digest, Environment Canada ,1988, CCD 88-03.**

A potential reduction of 67%-87% in the number of ski-days for resorts without artificial snow-making equipment; a potential reduction of 40-50% in the number of ski-days for resorts with artificial snow-making equipment; economic impact on ski resorts not likely to be proportional to the reduction in ski-days, as the number of skiers could be expected to increase on days remaining in the shortened ski season.

- **Environment Canada (1988), *Implications of Climatic Change for Tourism and Recreation in Ontario*, Climate Change Digest, CCD 88-05.[Also see "*Impact of Climate Change on Ontario Tourism and Recreation,*" University of Waterloo, Department of Geography, Waterloo, Ontario, 1985.]**

The length of ski seasons will be reduced at the Lakehead but the key holiday periods, when a large proportion of business in conducted, will still fall within the reliable ski season; The downhill ski season in the South Georgian Bay region could be eliminated with an associated loss of $36.55 million per annum in skier spending at the resorts and a $ 12.8 million (in 1985 dollars) reduction in the trade of Collingwood; summer recreational activities are likely to have extended seasons and the viability of summer recreational enterprises may increase with associated positive benefits to neighbouring economics.

• **Environment Canada (1988),** ***Socio-Economic Assessment of the Physical and Ecological Impacts of Climate Change on the Marine Environment of the Atlantic Region of Canada - Phase 1*****, Climate Change Digest, CCD 88-07.**

A milder climate would lead to an extension of summer recreation and tourism activities and a corresponding reduction in winter recreation activities. This could increase non-resident travel expenditures in the Region and decrease resident travel expenditures outside the Region; both effects would be beneficial for the balance of payment in the Region's travel account.

• **Environment Canada (1989),** ***Implications of Climatic Change for Prince Albert National Park, Saskatchewan*****, Climate Change Digest, CCD 89-03.**

Increased land use pressures brought on by more frequent drought might result in a desire to convert currently marginal lands to agricultural uses. Such pressures may be manifest in increased conflicts between parks and use of land for other purposes. Climate change also has implications for the land devoted to parks, the size of each individual park, park selection and designation, and boundary delineation.

• **Environment Canada (1989),** ***Implications of Climate Change on Municipal Water Use and the Golfing Industry in Quebec*****, Climate Change Digest, CCD 89-04.**

Climatic conditions influence both the beginning and the end of the golfing season; the actual average length of the golfing season is 171, 187 and 206 days for Quebec City, Sherbrooke and Montreal respectively;

With climate change, the number of days suitable for golfing could increase by 20 to 50 percent, thus significantly affecting the golfing industry which has current gross revenues of $245 million (1987 dollars).

• **Environment Canada (1989),** ***The Effects of Climate Change of the Economy of Alberta*****, Climate Change Digest, CCD 89-05. [Also see Acres International Limited (1989) "*****The Environment/Economy Link in Alberta and the Implications under Climate Change Report,*****" P08725.00, Calgary, Alberta.]**

[In Alberta] general results suggest climate change would extend the seasonal and geographical range suitable for many summer activities while the effects on winter activities are more uncertain.

• **The U.S. National Climate Program Office and the Canadian Climate Centre (1989),** ***Impacts of Climate Change on the Great Lakes basin*****, Symposium 1988 conducted on September 27-29, 1988 at Oak Brook, IL.**

In Great Lakes Basin, there will be both positive and negative impacts in recreation. As a result we should identify the opportunities and also our vulnerabilities to this change.

- **Environment Canada (1990), *Implications of Climate Change for Small Coastal Communities in Atlantic Canada*, Climate Change Digest, CCD 90-01.**

Some communities could benefit from increased opportunities for aquaculture; some could benefit from more tourism over a longer summer tourist season.

- **Environment Canada (1991), *Climate Change and Canadian impacts: The Scientific Perspective*, Climate Change Digest, CCD 91-01.**

Effects are generally positive for summer activities but negative for winter activities in southern regions (e.g., southern Ontario skiing); no consensus exists on impacts in the Rockies due to uncertainties regarding precipitation.

- **Environment Canada (1994), *A Regional Response to Global Climate Change: New England and Eastern Canada*, Climate Change Digest, CCD 94-03.**

A changing climate can affect tourist behavior and industry costs in both summer and winter seasons. In New England, the total direct impact of tourist spending is over $18 billion (U.S.) per year, while in Eastern Canada it is approximately $6.5 billion (Can.).

- **Environment Canada (1995), *Mackenzie Basin Impact Study: Summary of Interim Report #2*, Climate Change Digest, CCD 95-01. [Also see Staple, T. and G. Wall (1994), "*Implications of Climate Change for Water-Based Recreation Activities in Nahanni National Park Reserve*," in Cohen, S.J. (ed.), Mackenzie Basin Impact Study (MBIS): Interim Report #2, Environment Canada, November 1994.**

Staple and Wall (University of Waterloo) present a case study of Nahanni National Park Reserve, and conclude that in a scenario of warmer climate, tourism impacts would be mixed. Hydrologic changes would not be large enough to affect white water rafting. A warmer climate would extend the visitor season by four weeks in the fall, providing traditional economic benefits for the Nahanni region. However, projected increases in fire frequency could affect visitor safety, and subsequent change in the landscape could alter the hydrologic regime.

Focus On the Transportation Sector

- **Great Lakes Institute *Implications of Climate Change for Navigation and Power Generation in the Great Lakes*, University of Windsor, Windsor, Ontario (Phase I Report, March 1985; Phase II Report, March 1986). A summary is appeared in *Implications of Climate Change for Navigation and Power Generation in the Great Lakes, Climate Change Digest*, Environment Canada, 1987, CCD 87-03.**

Climate change will likely allow year-round shipping in the Great Lakes, with a subsequent 15 to 30% increase in shipping volumes. However, a 20% decrease in Great Lakes water supply, could result in a 6% loss in shipping capacity.

• **Environment Canada (1987),** ***Implications of Climate Change for Navigation and Power Generation in the Great Lakes,*** **Climate Change Digest, CCD 87-03.**

Maximum ice cover on the Lake may decline from 72% to 0% for Lake Superior, 38% to 0% for Michigan, 65% to 0% for Huron, 90% to 50% for Erie and 33% to 0% for Ontario, permitting an 11 month ice-free shipping season. Average annual costs to Canadian Great Lakes shipping companies for the four principal cargoes, (iron ore, grain, coal and limestone), may increase approximately 30%. The frequency of years when shipping costs equal or exceed those of the period of low lake levels (1963-1965) could occur in 9 years out of 10.

• **Environment Canada (1987),** ***Effect of a One Meter Rise in Mean Sea-Level at Saint John, New Brunswick, and the Lower Reaches of the Saint John,*** **Climate Change Digest, CCD 87-04.**

In Saint John (New Brunswick), road and rail transportation system could be heavily affected by coastal inundation. This inundation could also result in extensive disruption, and possibly even isolation, of communities to the east of Saint John. Increased flooding in the Jemseg-Maugerville section of the Trans-Canada Highway could severely disrupt road transportation between Atlantic and Central Canada.

• **Environment Canada (1988),** ***A Preliminary Study of the Possible Impacts of a One Meter Rise in Sea level at Charlottetown, Prince Edward Island,*** **Climate Change Digest, CCD 88-02.**

This work focused on waterfront disruption, industrial, housing and landmark displacement, and the detrimental effects to public property, sewers and *transportation* within and outside the city of Charlottetown.

• **Environment Canada (1988),** ***Socio-Economic Assessment of the Physical and Ecological Impacts of Climate Change on the Marine Environment of the Atlantic Region of Canada - Phase 1,*** **Climate Change Digest, CCD 88-07.**

Climate change may prevent the formation of sea ice, which in turn, could reduce costs for ferry services and marine transportation in the Atlantic Region, and permit extended seasons for some routes. However, some loss of winter marine traffic to Churchill, Montreal, and Saint Lawrence Seaway ports could occur as these ports become ice-free and accessible practically year-round. A one metre rise in sea level could result in damage to and loss of coastal infrastructure, which in a worst case scenario, could add up to several billion dollars in costs.

• **Lonergan, S. (1989), "*An overview of potential effects of rapid warming on the Canadian Arctic,*" in Topping Jr., J.C. (ed.), *Coping with Climate Change.* Climate Institute, Washington, D.C. pp. 464-468.**

While the title of this paper refers to the Canadian Arctic as a whole, the author focuses on the Mackenzie River Valley and the Mackenzie Delta, areas where most of the Arctic's population and economic activity are concentrated. Lonergan's results point to an extended shipping season (by about 6-8 weeks), and reduced ice flows for marine transportation. However, at the same time, the authors point out that rougher seas could cause iceberg calving which may result in negative impacts on marine shipping. A longer season is also projected for barge traffic on the Mackenzie River. Winter roads, on the other hand, could be negatively impacted by climate warming due to greater snowfall and shorter season. Finally, air shipments could be delayed due to storms.

- **Lonergan, S. and M.K. Woo (1989), "*The impacts of climate warming on transportation in the Canadian Arctic*," At: *Climate Institute Symposium on the Arctic and Global Change*, Ottawa, Ont., Oct. 26, 1989. pp. 81-95.**

Lonergan and Woo examine the physical and socio-economic effects of climate warming on transportation in the Canadian Arctic. The authors suggest that the ice-free season on the Mackenzie River will increase by as much as 40%, resulting in a longer shipping season for barges. A shorter operating season for roads is projected (due to melting of stream ice). Also, a small modal shift to air is predicted. Few benefits, however, are predicted to trickle down to the local economy, despite the potentially longer shipping season, owing to monopolistic competition and surplus capacity in the transportation industry.

- **Smith, J.P. (1989), "*An overview of EPA studies of the potential impacts of climate change on the Great Lakes Region*," in Topping Jr., J.C. (ed.), *Coping with Climate Change.* Climate Institute, Washington, D.C. pp. 532-541.**

Based on an assumption of a doubling of current carbon dioxide levels in the atmosphere; impacts on Great Lakes' transportation are predicted. A projected reduction in the ice cover could allow for a longer shipping season. However, the shipping industry is expected to experience a parallel negative impact, in that projected lower water levels in the Great Lakes will in turn force commercial ships to lower cargo loads. Maintenance costs may rise with climate warming, since dredging may be required to keep channels open.

- **Stokoe, P. K. (1989), "*Strategies to respond to climate change and sea-level rise in Atlantic Canada*," in Topping Jr., J.C. (ed.), *Coping with Climate Change.* Climate Institute, Washington, D.C. pp. 521-525.**

Stokoe predicts flooding of coastal areas due to sea level rise, and offers the recommendation that engineering standards (for infrastructure) should accommodate this trend to higher sea levels. He also predicts new infrastructure development in areas that become more attractive due to climate warming.

- **The U.S. National Climate Program Office and the Canadian Climate Centre (1989), *Impacts of Climate Change on the Great Lakes Basin, Symposium 1988,* conducted on September 27-29, 1988 at Oak Brook, IL.**

Several conference papers examined the impacts of climate change on the transportation sector. Possible consequences of climate warming include: reductions in cargo size, higher operating costs, restricted access to ports, and increased dredging on a regular basis.

- **Environment Canada (1990), *The Implications of Long-Term Climatic Changes on Transportation in Canada*, Climate Change Digest, CCD 90-02.**

This study is the most comprehensive effort examining the effect of climate change on the Canadian transportation sector as a whole. However, it is largely an integration of previous studies, as opposed to a primary research effort. In scope, the study is very broad, and its assessments are preliminary.

There is a possibility of a significant northward expansion of settlement and related activities in Canada. This would affect all four transportation modes - marine, roads, rail and air - and lead to substantial northward extension of facilities and services. Such a migration could, in turn, result in major socio-economic impacts on Canada's north.

Modest to moderate capital costs may be incurred to maintain/restore transportation facilities affected by flooding and other climate impacts. A possible exception could be major public works to control the water level in the Great Lakes system. Major capital costs would be required to expand transportation systems/services into northern areas, particularly for the road and rail modes. Significant or major capital costs would also be likely for an expansion of the ocean marine mode (depending on whether Canada decides to expand its own merchant marine fleet), specifically for increased coastal trade, and for increased coast guard and defence activity.

Increased coast guard, search and rescue, and defence activity would also contribute to significant increases in operating costs. These, however, would be partially offset by significant decreases in unit operating costs, owing to extended ice-free navigation in northern waters.

The preliminary assessment, presented in this study, suggests that on balance, long-term climate impacts on the Canadian transportation sector will have a net beneficial effect. While some potential impacts are expected to lead to an increase in costs, the more important ones are seen as having net benefit, with increased revenues more than making up for increased costs.

- **Environment Canada (1991), *Climate Change and Canadian Impacts: The Scientific Perspective*, Climate Change Digest, CCD 91-01.**

An increase in the ice-free shipping season could occur in Canada's Arctic and Great Lakes, providing an economic benefit. However, higher operating costs may result in the Great Lakes due to projected lower lake levels. A shorter season for winter ice and snow roads in high latitudes could also occur.

- **Environment Canada (1992), *Global Warming: Implications for Canadian Policy*, Climate Change Digest, CCD 92-01.**

Studies of the effects of global warming on transportation in Canada have been limited and largely superficial up to the present, possibly because of an instinctive feeling that the effects of global warming will be mainly beneficial. Further research is recommended to investigate the costs and benefits of climate change in major urban areas, and the impact of climate change on Arctic marine transportation.

- **Cohen, S.J. (ed.) (1993), *Mackenzie Basin Impact Study: Interim Report # 1.* Environment Canada.**

An interim report, on a six year study, which is assessing the potential impacts of global warming on the Mackenzie Basin Region and its inhabitants. The study framework, structure, organization, methods, data, and participants are presented. The transportation sector is highlighted in the report.

- **Lonergan, S.; DiFrancesco, R. and M.K. Woo (1993), "*Climate change and transportation in Northern Canada: an integrated impact assessment,*" In: *Climatic Change.* Vol. 24, 1993, pp. 331-351.**

Results of a two-year study to assess the impacts of climate change on the transportation system (barge, truck, air) in the Mackenzie River Valley, Northwest Territories. The physical and economic impacts of global warming are estimated using a combination of modelling techniques. These estimated impacts are then related to potential changes in the transportation infrastructure. While significant warming is forecast for the region, economic impacts from changes in transport are predicted to be minor. The greatest economic impact of climate change is projected to occur in the service sector.

- **University of British Columbia Disaster Preparedness Resources Centre and British Columbia Provincial Emergency Program (1993), *British Columbia Hazard, Risk and Vulnerability Analysis.* Vancouver, B.C.**

A risk assessment of various types of hazards found in British Columbia, including global warming. Specifically, the report predicts that global warming could cause a 1m rise in sea levels which would, in turn, affect the coastline of British Columbia. For instance, the report predicts that a lower causeway in Victoria, along with beaches on Dallas Road, could be flooded. Also, the Island Highway, along Qualicum Beach may have to be relocated. Low-lying Duncan would be particularly vulnerable to flooding. While most of downtown Vancouver is high enough to avoid any flooding, the Fraser Delta area could be in danger. Other negative consequences could include problems for bridge builders, port, and marine operations.

- **DiFrancesco, R.J. and S.C. Lonergan (1994), "Examining regional sensitivity to climate change using aggregate input-output data: the case of transportation in the Northwest Territories," *Canadian Journal of Regional Science,* 17(2), Summer 1994, pp. 233-257.**

A macro study of the Northwest Territories' economy. An evaluation of two scenarios leads the authors to conclude that climate warming would have direct effects on water and land-based shipping systems. Since the barge system is the primary freight mover (and the cheapest/ton) in the region, followed by trucking, the authors assume that the net effect of a significant ice-free period (due to climate warming) would be positive. This is because freight that could no longer be shipped by truck, would instead be shipped by barge (cheaper/ton).

- **Transportation and Climate Change Collaborative (TCCC) and Ontario Round Table on Environment and Economy (1995), A Strategy for Sustainable Transportation in Ontario: Report.**

A strategy for sustainable transportation in Ontario. The report begins with a review of climate change impacts on Ontario. Impacts predicted for the transportation sector are: a decrease (by as much as 50%) in the net supply of surface water to the Great Lakes basin; a fall in mean lake levels from 0.5 to 2.5 metres in the Great Lakes, and more frequent dredging of shipping channels. Proposed mitigative actions are aimed at stabilizing greenhouse gas emissions through reducing transportation energy demand and CO2 emissions, while at the same time, maintaining essential services and economic competitiveness of the transportation sector.

Survey of Non-Governmental Organizations

A survey of non-governmental organizations (see Appendix A-3) yielded little in the way of in-house research, except for a study (currently in progress) by the International Institute for Sustainable Development (IISD). While it is known that the IISD study deals broadly with transportation and climate change, no details were available as to whether there was any particular emphasis on the *Canadian* transportation sector.

Water Resources

- **The U.S. National Climate Program Office and the Canadian Climate Centre (1989), *Impacts of Climate Change on the Great Lakes basin*, Symposium 1988 conducted on September 27-29, 1988 at Oak Brook, IL.**

Water supply in the Great Lakes Basin will likely be decreased because of increased evaporation and decreased precipitation. We will likely experience an increased consumption of water.

- **Environment Canada (1989), *Implications of Climate Change on Municipal Water Use and the Golfing Industry in Quebec*, Climate Change Digest, CCD 89-04.**

The use of municipal water supplies for residential watering of lawns has been a significant concern in Quebec communities since the early 1970's and has lead to periodic restrictions against such use; one hour of watering lawn consumed the same quantity of water as a family of five would use in one day; climate warming is expected to increase water demand for lawn maintenance by 20 to 30%; to meet the demand, new and costly infrastructure would be required.

- **Environment Canada (1990), *Implications of Climate Change for Small Coastal Communities in Atlantic Canada*, Climate Change Digest, CCD 90-01.**

The climate model scenarios suggest less precipitation and more evaporation. This may result in local reduction in fresh water supply.

- **Environment Canada (1988), *Economic Perspectives on the Impact of Climate Variability and Change: A Summary Report*, Climate Change Digest, CCD 88-04.**

The issues of future water supply and demand are central to climate impact assessment; and of particular concern to Canada. The challenge is to consider "adaptive management" strategies that enhance the resilience of the regional ecosystem and that would make sense whether climate changes or not. This approach applies particularly to the Great Lakes, where the impacts of climate change may be amplified by increased consumptive water uses and large-scale diversions.

- **Environment Canada (1991), *Climate Change and Canadian impacts: The Scientific Perspective*, Climate Change Digest, CCD 91-01.**

Most scenarios of climate warming lead to a net basin runoff decrease of 25-50% in the Great Lakes-St. Lawrence System resulting in lower lake levels and less hydropower production; high-latitude watersheds would probably exhibit higher streamflow and floods during the snowmelt season.

- **Environment Canada (1993), *Adaptation to Climate Change and Variability in Canadian Water Resources*, Climate Change Digest, CCD 93-02.**

Based on what we now know about global warming, significant changes in climate and hydrology are plausible within a time period that matters for managers of water resources. Global warming will tend to exacerbate existing water resources problems in the southern Prairies and the Great Lakes. The Prairies can expect increased drought during the summer growing season, and the Great Lakes can expect a decline in mean lake levels to historic low levels.

Economic Impacts for Canada

- **Environment Canada (1988), *Economic Perspectives on the Impact of Climate Variability and Change: A Summary Report*, Climate Change Digest, CCD 88-04.**

This report summarizes a collection of papers on economic methodologies and applications assessing the impacts of climate variability and change. The authors of the papers are members of the Inter-University Working Group of Economics and Climate Change based at the Institute of Environmental Studies, University of Toronto and the Department of Economics, University of Waterloo; and supported in its research by the Canadian Climate Program.

- **Environment Canada (1992), *Global Warming: Implications for Canadian Policy*, Climate Change Digest, CCD 92-01.**

The effects of global warming on specific regions of Canada, or on individual sectors of economy or society, are much more uncertain at present. Sectors with long future time-frames, such as forestry and major construction, may need to develop and adopt adaptation policies immediately. In other sectors, however, proposal for policies and action to assist adaptation to the anticipated effects of global warming may be premature.

CONCLUSION: EVALUATION OF THE SEARCH

Literature pertaining to the impact of climate change on the Canadian agriculture, energy, fishery, forestry, recreation/tourism, transportation, water resources sectors as they affect the domestic flows of goods and services was obtained through several avenues, including:

- commercial databases;
- learned literature;
- internet;
- government organizations;
- non-governmental organizations (NGOs).

Results from the literature search indicate that there are five main organizations/projects where research has been undertaken relating climate change to the seven key sectors of the Canadian economy, namely:

1. The Environment/Economic Link in Alberta and the Implications under Climate Change;
2. Environment Canada (Climate Change Digest Series);
3. Impacts of Climate Change on the Great Lake Basin (Symposium);
4. Mackenzie Basin Study; and,
5. Ontario Round Table on the Economy and Environment.

The Environment/Economic Link in Alberta (1989)

The two principal objectives of this study were to compare recent climatic anomalies in Alberta with the simulated 2xCO_2 conditions tracked by global circulation models (GCMs), and to identify and, where possible, quantify the principal climate-economic linkages in the Alberta economy. The study was conducted by Acres International Limited and sponsored by Environment Canada.

Environment Canada's Climate Change Digest Series

The first issue of the Climate Change Digest identified the major socio-economic impact studies undertaken since 1984. This series includes studies that investigate the potential impacts of climate warming on Canada.

Focusing on the transportation sector, *The Implications of Long-Term Climatic Changes on Transportation in Canada: a Summary of a Report*, prepared by the IBI Group in 1990, represents by far the most comprehensive effort (uncovered in this search) dealing with Canada as a whole and all transportation modes. It is largely a synthesis of previous impact studies, as opposed to a primary research effort.

Impacts of Climate Change on the Great Lakes Basin (1989)

This symposium was held in the Chicago area on September 27-29, 1988. A select audience of 120 persons representing a wide variety of climate-sensitive interests attended the three-day symposium. Attendees came from municipal, state, provincial, and federal government agencies and universities concerned with natural hazards, agriculture, water resources, climate, transportation, conservation, natural resources, and policy. Private sector representatives were from the transportation industry, electrical utilities, business and commerce, news media, and agriculture.

The Mackenzie Basin Study (1993-94)

The Mackenzie Basin Study, (Interim Reports No. 1-2, 1993-94), edited by S.J. Cohen, is a large multi-disciplinary project being conducted into the impact of global warming on the Mackenzie Valley (NWT) and on its inhabitants. This study investigates the impact of climate change on the key economic sectors of the Mackenzie River Valley. The Valley encompasses northeast British Columbia, northern Alberta, northwest Saskatchewan, western Northwest Territories, and portions of southeast and northern Yukon Territory.

Ontario Round Table on the Economy and Environment

The Ontario Round Table on the Economy and Environment (ORTEE), formed in 1989, has produced several reports investigating the impact of climate change on Ontario’s economy. Between 1989 and 1992, a series of taskforces on key sectors (agriculture and food, energy and minerals, forestry, manufacturing, transportation, urban development and commerce) of the province’s economy were formed and a report was produced for each sector.

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Appendix A-1: Description of Commercial Databases

Database & Author	Time Span	Media Type	Description
Government Documents:			
Canadian Research Index-MicroLog (Micromedia Ltd.)	1982-Dec. 1996	CD-ROM	**Federal, provincial, and municipal documents.** An index of titles and abstracts of federal, provincial, and municipal government publications. Includes scientific and technical research papers in physical, natural, and social sciences. Also covers policy papers, statistical publications, and annual reports.
Learned Literature:			
Compendex	1987-Jan. 1997	Polaris (Univ. of Ottawa)	**Engineering literature.** This database covers worldwide engineering and technical literature from all engineering disciplines, as well as from related fields in science and management. Records are drawn from over 2,600 published journals, conference proceedings, conference papers, technical reports, monographs, and other materials.
Econlit (American Economic Association)	1969-Sept. 1996	CD-ROM	**Economics literature.** Indexed bibliography with selected abstracts of the world's economic literature. It covers over 400 major journals as well as articles in collective volumes (essays, proceedings, etc.), books, book reviews, dissertations, and selected working papers.
Geography (Elsevier/Geo Abstracts)	1990-Nov. 1996	CD-ROM	**Geography literature.** Covers the international literature in physical and human geography from over 2000 journals, monographs, books, conference proceedings reports, and theses.

Appendix A-2: Transportation Journals:

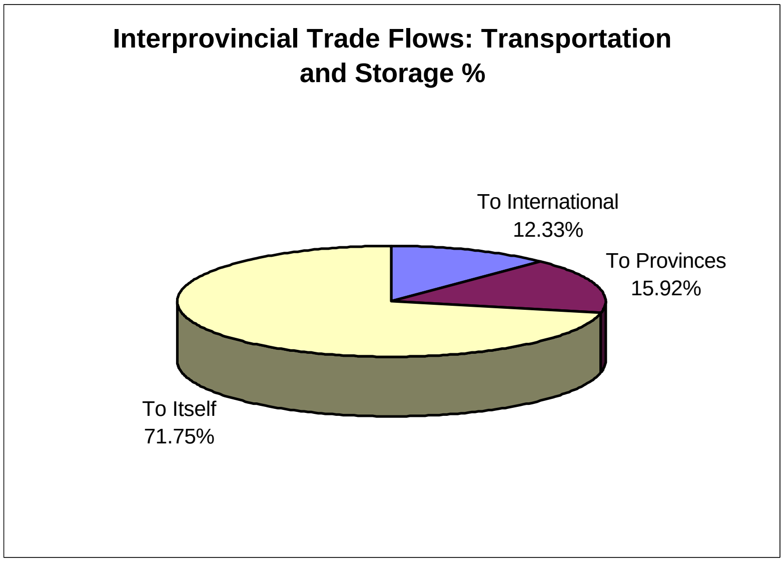
Several transportation journals were also searched for articles examining climate change and the Canadian transportation sector. While several articles dealt with the topics of global warming and CO_2 emissions, none specifically looked at the *Canadian* transportation sector.

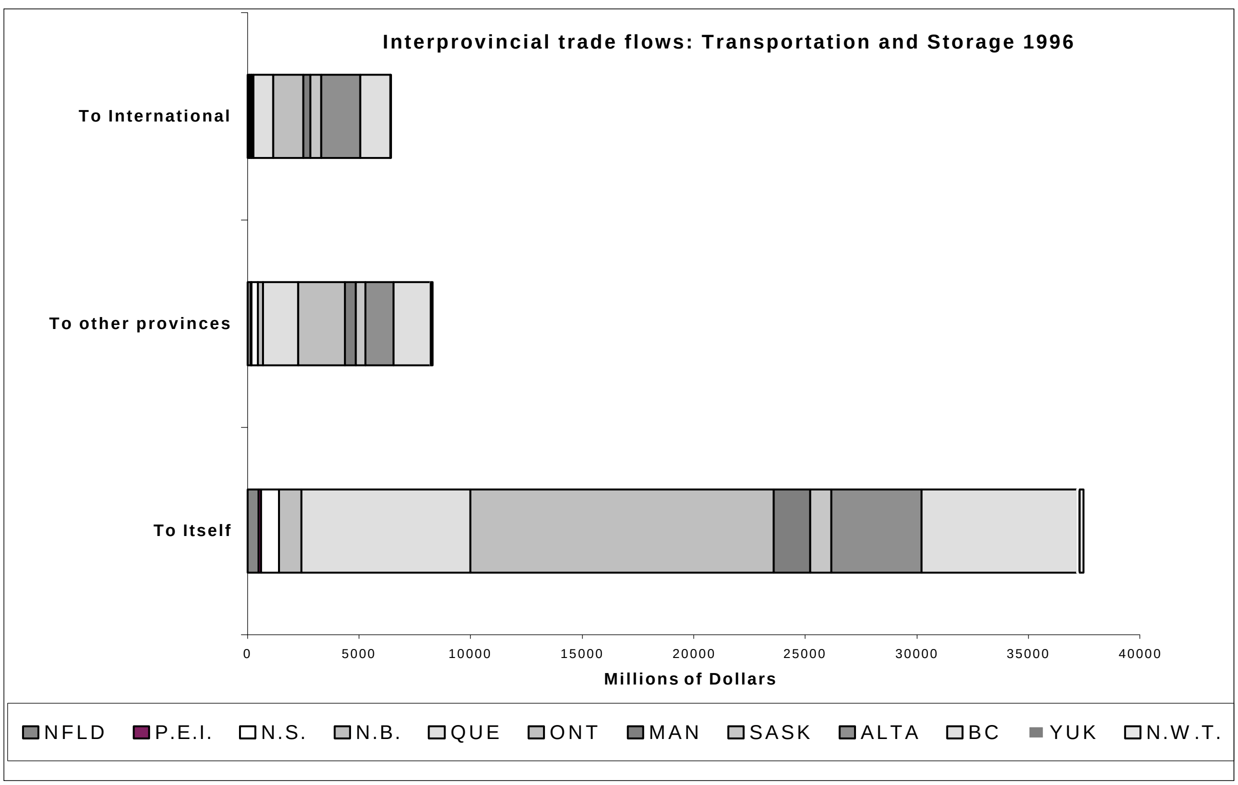
Journal Name	Time Span	Publisher
Transportation	1983-1995	Kluwer Academic Publishers
Transportation Research A & B	1983-1994	Pergamon Press
Transportation Journal	1983-1995	American Society of Transportation and Logistics
Transportation Planning and Technology	1983-1996	Gordon and Breach Science Publishers, SA.
Journal of Transport Economics and Policy	1983-1995	The London School of Economics and Political Science and the University of Bath

Appendix A-3: Non-Governmental Organizations

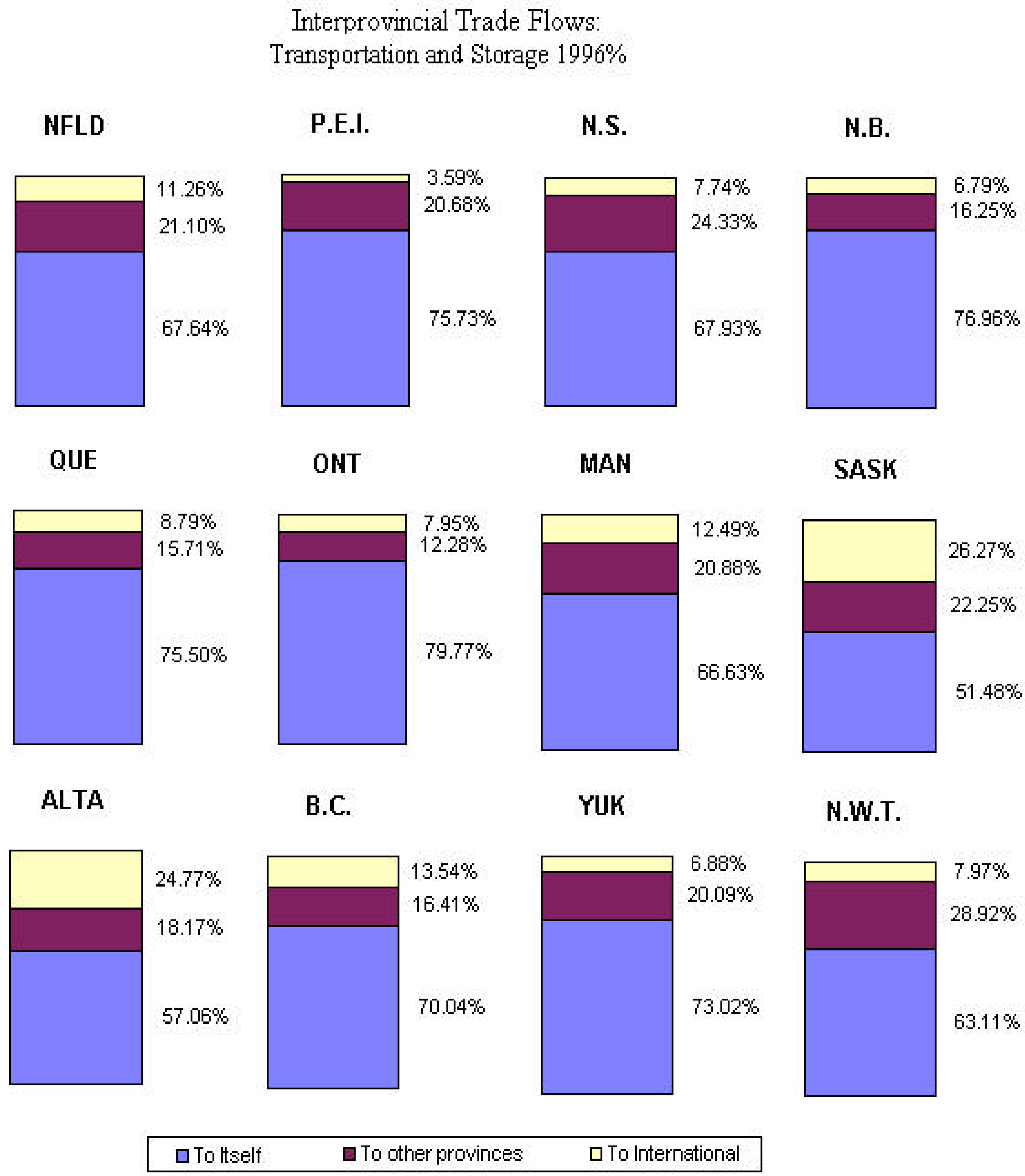
Organization	Phone Contact	Internet Contact	Results
Friends of the Earth	✓	✓	In 1988-1989, Friends of the Earth assembled 'fact sheets' from secondary sources on transportation and climate change. However, since that initial effort, the 'fact sheets' have not been updated with current information or in-house studies.
Greenpeace		✓	No documentation, yet on the internet site, specifically looking at the effect of climate change on the transportation sector in Canada. Greenpeace does, however, have an extensive on-line database of articles and press releases on climate change. They also have information on "greening" transportation.
International Institute for Sustainable Development (IISD)	✓	✓	According to Marlene Roy (Information Officer), a report is currently being completed on Transportation and Climate Change. Whether the report is to be released to the public is still to be decided.
Pembina	✓	✓	Little information available on the Internet site. Did place a phone call to Robert Hornung (Director), but no call returned yet.
Pollution Probe	✓	✓	No publications directly related to climate change and the transportation sector in Canada. Other publications available are: "*The Costs of the Car*", "*Greening Canada's Passenger Transportation Systems*", and "*Trade and the Environment*". Pollution Probe does provide mail-out information packages on various issues including "*Climate Change*".
Sierra Club	✓	✓	The Sierra Club has developed a 'fact sheet' on "*Cars and Climate Change*". According to the 'fact sheet', the Sierra Club completed a study in September 1996 called the '*Rational energy program: analysis of rational measures to the year 2010'* on fuel economy standards and carbon dioxide emissions.
World Wildlife Fund		✓	The World Wildlife Fund is currently conducting a "Climate Change Campaign". Their website (http://www.panda.org) has information on climate change and links to other sites dealing with climate change. However, the website does not list any specific reports dealing with the effect of climate change on the transportation sector in Canada.

Appendix B-1: Graphs of Interprovincial Trade Flows: Transportation and Storage 1996





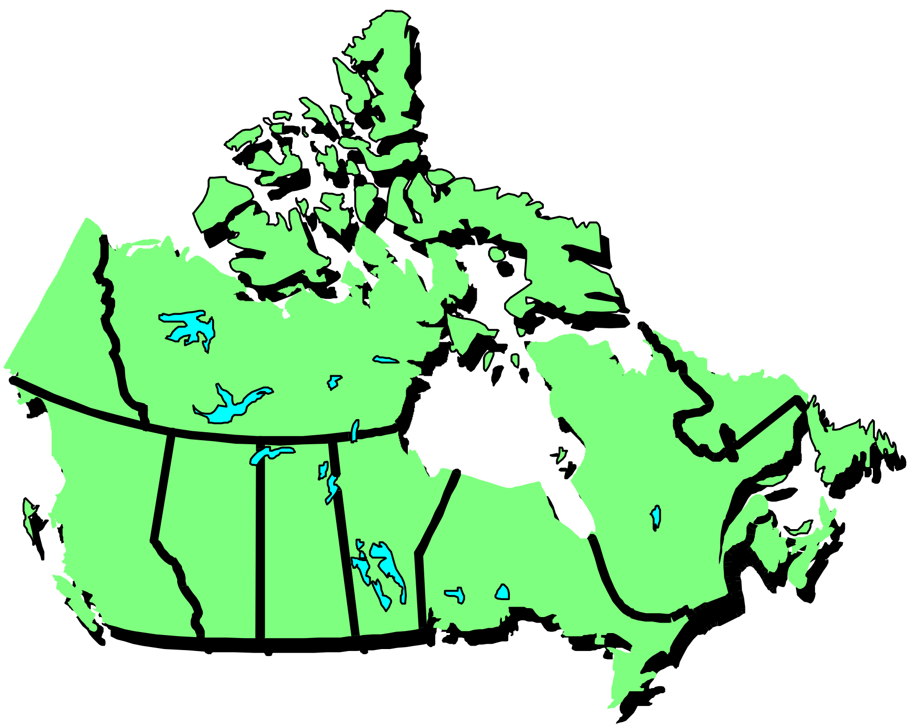
Appendix B-2: Interprovincial Trade Flows by Province: Transportation and Storage 1996



CHAPTER SIX

CHANGING LANDSCAPES: A SYNTHESIS OF SELECTED ASPECTS OF THE CANADA COUNTRY STUDY

Hague H. Vaughan[1]



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EXECUTIVE SUMMARY

We are threatening our ecosystems and all of their interacting environmental, social and economic aspects with probable rates and severities of change in climate which are likely in many cases to exceed their ability to adapt, to overwhelm their integrity and to degrade those attributes upon which we have come to depend. Should this occur, it will affect not only our own personal well being but also that of future generations, thereby compromising any commitment it is possible to make to sustainability. The identification of probable effects at the landscape level of ecosystem organization is alarming but also informative in terms of identifying priority areas where action based on risk is most urgently required and will perhaps be of greatest benefit.

Effects will vary in the various regions of Canada as will the pattern of changing climate. Not all of the effects of probable climate change will be negative. Warmer climates will bring longer ice-free seasons for water-borne transportation, reduced snow clearance and highway salting costs, reduced heating, new agricultural crops and lands, CO_2 'fertilization' of plant growth and may have beneficial effects on marine fish distributions amongst other things. Further, there will be winners and losers as suitable areas for specific economic activities shift. This could include effects on agriculture, aquaculture, outdoor recreation, commercial and recreational fisheries, ski areas, and shoreline developments. The rate of change compared to the rate of adaptation will greatly affect the palatability of outcomes.

Projected changes in climate will alter many of the fundamental variables which define existing landscapes particularly:

1. Temperature increases which will result in more benevolent winters; a greater number of growing season degree-days; increased evapotranspiration; reduced ice cover on lakes, rivers and oceans; reduced areas of permafrost; reduced snowpack and associated spring runoff;
2. Precipitation which will be generally greater, decreasingly fall as snow and likely be more variable;
3. Sea level which will steadily rise inundating low-lying areas and increasing coastal erosion;
4. Temperature and precipitation changes interacting so as to reduce summer water levels and flows; alter wetland water balances; lengthen water renewal times in lakes; threaten seasonal and semi-permanent wetlands; reduce habitat for cold water fish; and alter patterns of sea surface temperature and salinity. Summers may be locally wetter but increased evapotranspiration will commonly result in less available water, decreased soil moisture and higher water demand.
5. An increased number and severity of extreme events would destabilize existing landscapes and ecosystems

Broad landscape changes would result driven by the forces of:

- shifting ranges and altering ecozones
- altered and more variable hydrology;
- melting of permafrost, and
- rising sea levels.

1. The Taiga and Boreal forest belts are projected to shift northward by about 500 Km. under anticipated $2xCO_2$ conditions. As CO_2 levels continues to increase, but hopefully at a decreasing

rate, vegetation will only begin to approach a state of stability in relation to local climate when the rate of climate change falls to far less than rates being anticipated in the near future. Under the projected conditions, it will not be the Taiga or Boreal Forest as we know it that will move northward but rather the more fast-moving flexible species such as those with wider seed dispersal, faster growth and early maturation. Vegetation is therefore more likely to resemble early successional stages. Some wildlife species, desired ecosystem attributes and socio-economic aspects will benefit but others will suffer. For example, the traditional knowledge of aboriginal peoples in the areas affected will become less relevant or useful as landscapes and wildlife communities alter.

2. The Southern Arctic Ecozone is projected to all but disappear from mainland North America under a climate brought about with CO_2 doubling. It presently includes the major summer range and calving grounds for Canada's largest caribou herds as well as habitat for bear, wolf, moose, arctic ground squirrels and lemmings. It is a major breeding and nesting ground for a variety of migratory birds including the yellow-billed, arctic and red-throated loon, whistling swan, snow goose, oldsquaw, gyrfalcon, ptarmigan and snowy owl. It is home to Canada's Inuit.

3. The probable climate trends will result in generally less water availability and greater variability of levels and flows. The pattern of water availability is a fundamental variable defining landscape pattern and processes as well as the interacting economic and social geography. Much of existing industry, built environments, and transportation/distribution systems are not particularly resilient to changes of the type and magnitude projected especially when destabilized by a greater number and severity of extreme events. Positive aspects are few and impacts are likely to significantly affect aquatic ecosystems, wildlife, tourism, recreation, property values, transportation, power generation, fisheries, effluent and drinking water treatment, channel dredging, infilling of impoundments and the local availability of water for agriculture, industry and urban areas.

4. The anticipated northward shift in permafrost areas is estimated to be about 500 Km under a $2xCO_2$ climate. This will have serious implications for hydrology, wildlife, biodiversity, cultural values and lifestyles. Massive terrain slumping will occur as will increases in sediment loads to rivers and lakes. A deeper active layer will reduce overland flow as both infiltration and active layer storage capacity increase. [Regional hydrology will be fundamentally altered as water in lakes, ponds and wetlands perched on permafrost or with permafrost cored boundaries increasingly flows overland or to the groundwater systems.]

   The effects will likely extend to infrastructure and transportation including the integrity of foundations (pipelines, bridges and buildings), water control structures, ice-roads and the melting of the assumed impermeable permafrost beds of mine tailings ponds. Altered flooding patterns and sediment loadings will impact internationally significant wetland habitat such as the Peace-Athabasca-Slave Delta, the Mackenzie Delta and that associated with the Hudson Bay and Queen Maud Gulf lowlands.

5. Coastal economic landscapes and natural areas will be affected profoundly as rising sea levels and storm surges result in shoreline erosion, sediment redistribution, loss of habitat, salinization of water supplies and increased coastal flooding. Many beaches and coastal wetlands would be squeezed between advancing seas and engineering structures. Innumerable coastal communities are

vulnerable to inundation or storm flooding especially Charlottetown with some of the highest-valued property in the downtown core and significant parts of the sewage systems at risk. Possible responses to sea level rise include erecting walls to hold back the sea, raising the land to compensate for rising sea level, and allowing the sea to advance and adapting. Each has advantages and disadvantages.

While there may be some positive aspects, most of the impacts of anticipated changes in climate on Canadian landscapes would be severe, widespread and long-lasting. Such effects therefore present serious risks to the well-being of Canadians and their minimization should be a serious concern. It is therefore recommended that:

- the accurate assessment and communication of these risks be vigorously pursued
- the identification and implementation of least-cost options to increase the ability of related ecosystems (including their environmental, social and economic aspects) to accommodate variability be accelerated
- serious attention be given to opportunities identified in the Canada Country Study for adapting to these and other potential impacts of changing climate.
- the nature and degree of these risks be given due consideration in the development of national strategies on GHG emissions.

INTRODUCTION

The late Edward S. Deevey (1914-1988) used to remark on the eminent suitability of freshwater as an area of study for an ecologist, in particular its usefulness as a medium for the understanding and management of ecosystems (personal communication). His point was that air is overly responsive, too responsive in effect to allow for the development of insights into ecosystems unless sampled and studied to excess in order to compensate for its characteristic inability to integrate events and conditions at suitable time-scales. Land was the opposite: slow to change so that any feedbacks to events or interventions were too gradual to allow effective ecosystem assessment or management. Freshwater seemed made for the purpose, integrating and expressing ecosystem conditions at a handy rate and even providing a repository of data about past conditions within associated sediments. I sometimes wonder what he would think now as we contemplate how we might best cope with atmospheric changes of such magnitude and consistent direction as to alter and degrade highly inertial landscapes.

The changes to the atmosphere induced by human activities are so great as to be discernible against the high background noise of normal variability and their probable future trends pose severe risks to human well being. Freshwater, in the words of John Pomeroy (1997):

> . . . has three important roles in ecosystem response and interaction with atmospheric change. Freshwater is a
>
> 1. **transmitter** of atmospheric change to Canada's environment,
> 2. **mediator** of this change., and
> 3. **host** for aquatic ecosystems that are affected by this change.

> As a transmitter, water is a flow of mass, energy and biochemical constituents through and between ecosystems and between the surface and the atmosphere, as water, water vapor, snow and ice; hence it transmits climate change impacts across the country and across ecological and jurisdictional boundaries. It transmits the effect of drought to soils as soil water and the effects of heavy precipitation downstream as floods. Freshwater can mediate climate change to some degree because it is stored on the landscape as lakes, snowcovers, glaciers, wetlands, rivers, and is a store of latent energy.

In this role, freshwater moves beyond being possibly the most suitable medium for detecting ecosystem change to being a means of delivering change as well as severe stress to ecosystems at a landscape level. That is somewhat new to common experience. In the past we could think of landscape, including the dispersion of human settlements and activities, as a reflection of underlying consistencies in geology and topography (and arguably soil) in a relatively consistent climate. Geologists and paleoecologists amongst others know that those consistencies are to varying extents an illusion and that landscape never truly catches up to long term variation but is in fact constantly altering so as to track local patterns at a number of scales. This results inter alia in a balance between specialization and adaptability which best suits the rate, degree and type of change encountered. This is equally true for the nature and spatial patterns of human activities.

We are now threatening our ecosystems and all of their interacting environmental, social and economic aspects with probable rates and severities of change in climate which are likely in many cases to exceed their ability to adapt, to overwhelm their integrity and to degrade those attributes upon which we have come to depend. Should this occur, it will affect not only our own personal well being but also that of future generations, thereby compromising any commitment it is possible to make to sustainability.

The Canada Country Study adds significantly to the already strong case that Canada and the well being of Canadians are at risk. Sensible decisions and policies depend upon an accurate assessment and appreciation of the threats presented. By addressing a landscape level of integration, this chapter attempts to summarize some of those threats as described elsewhere in the Canada Country Study. The probability of effects at this level of ecosystem organization is indeed alarming but also informative in terms of identifying priority areas where action based on risk is most urgently required and will perhaps be of greatest benefit.

Risk is a product of both the probability and the severity of an event. As probabilities with regard to the changes in those climatic variables of greatest significance to ecosystems remain at present uncertain, particularly at a local level, assessment of effects always involves a level of conjecture. Despite this, the severity of those effects is sufficient to motivate the early identification of any opportunities to minimize or adapt to impacts.

Not all the effects of probable climate change are negative. Warmer climates will bring longer ice-free seasons for water-borne transportation, reduced snow clearance and highway salting costs, reduced heating, new agricultural crops and lands, CO_2 'fertilization' of plant growth and may have beneficial effects on marine fish distributions amongst other things. Further, there will be winners and losers as suitable areas for specific economic activities shift. This could include effects on agriculture, aquaculture, outdoor recreation, commercial and recreational fisheries, ski areas, and shoreline developments. The rate of change compared to the rate of adaptation will greatly affect the palatability of outcomes.

This chapter is intended as neither an exhaustive review of the material covered elsewhere in the Canada Country Study nor a repetition of the extensive scientific literature reviewed there. It is rather a synthesis of the resulting information aimed at drawing attention to risks posed by large scale ecosystem effects.

PATTERNS OF CHANGING CLIMATE

General Circulation Models (GCMs) describe with increasing elegance and detail the expected climate averages to be anticipated upon the doubling of CO_2 in approximately 50 years. While different models give different results, the differences are small compared to the overall climatic alterations upon which they agree. Results from earlier 'Equilibrium Models' were based on a doubling of CO_2 followed by a period during which stable climatic conditions were achieved in a world model with a commonly underrepresented ocean influence. The more recent 'Transient Models' improve on both aspects by incorporating coupled complex oceans and incremental CO_2 increases while also allowing for the local cooling effects of aerosols. Probable future patterns of human populations and economic development are also considered. The Canada Country Study (CCS) uses these descriptions as a basis for assessing the probable vulnerabilities of, and effects on, Canada and Canadians. Three issues arise from this:

- There is no reason to suppose that the upward trend in atmospheric CO_2 will even pause when it reaches the doubling point: Canada and the world's lack of progress on achieving a balance between economic growth and greenhouse gas (GHG) emissions virtually ensures that 3x and possibly even 4x CO_2 will become a reality. The CCS assessments are therefore at best highly conservative.

- The pattern of changing climate will vary locally or regionally and existing GCMs outputs are too coarse to allow for much detail at this level. Further, the progression of change in climate variables of importance to ecosystems is largely unknown (see Table 6.1) though interpolations are emerging from the transient models.

- One aspect of climate which is of critical importance to ecosystems is that of within- and between-year variability particularly when expressed as extreme climatic events (see Chapter 2). GCMs were never intended to focus on variability, though there is increasing confidence amongst practitioners that extreme events (droughts, floods, storms, fires, winter thaws, spring/fall freezes, etc.) will increase in severity and number.

Based on what we presently know, the process of climate change induced by natural and anthropogenic factors in Canada is likely to have a number of interacting aspects over coming years:

- systematic change towards warmer longer summers, and shorter wetter winters with less precipitation falling as snow (high confidence)
- increased number and severity of extreme events including droughts, storms and floods (medium confidence); and

Table 6.1: Critical variables needed to improve prediction of climate change impacts on regional ecosystems

The progression, on a Regional basis, of seasonal averages and of the degree of between-year variability in:
• temperature, precipitation, wind and radiation; • the intensity and probability of extreme events including drought, storms and floods; • snowcover distribution, depth, extent and duration; • precipitation at varying elevations; • the probability of short-term anomalies such as late spring/summer frosts, mid-winter temperature or rain events and intense spring storms; • surface heat fluxes and UV-B radiation • sea-level pressures
This would allow better estimations of important ecosystem variables including:
• glacial mass balance; • evaporation; • temperature, precipitation and wind patterns at various elevations; • snowmelt and runoff; • evapotranspiration; • wetland water balance; • wave height and air-water mass transfer; • water renewal times of lakes • length and variability of growing season; • number and variability of growing degree-days; • ice cover extent, thickness and duration; • between-year and within-year variability of water levels and stream flows; • degradation of deltas and estuarine areas; • rates of sea-level rise; • delivery of freshwater to N. Pacific as direct precipitation and river discharge; • DOC trends in lakes and UV-B exposures; • disappearance of lakes, ponds, and wetlands; • loss of cold water fish habitat; • water supply variability; • sea surface temperature and salinity; • ocean mixing, stratification and circulation

With these, ecosystem responses and effects can be assessed.

Source: Ecological Effects of Atmospheric Change. National Water Research Institute, Environment Canada, 1997

- increased between-year variability (modest confidence)

Pending an acceptable and effective means of limiting worldwide GHG emissions, there is at present no suggestion of a point at which these trends will stop.

Any such general pattern of changing climate will vary regionally. Already we see the greatest degree of warming in the northwest while the Atlantic region is cooling as a result of the presence of sulphate aerosols, the future trends for which are conjectural.

The result of such change is the altering of many of the fundamental variables which define existing landscapes particularly:

1. Temperature increases which will result in more benevolent winters; a greater number of growing season degree-days; increased evapotranspiration; reduced ice cover on lakes, rivers and oceans; reduced areas of permafrost; reduced snowpack and associated spring runoff;
2. Precipitation which will be generally greater, decreasingly fall as snow and likely be more variable ;
3. Sea level which will steadily rise inundating low-lying areas and increasing coastal erosion;
4. Temperature and precipitation changes interacting so as to reduce summer water levels and flows; alter wetland water balances; lengthen water renewal times in lakes; threaten seasonal and semi-permanent wetlands; reduce habitat for cold water fish; and alter patterns of sea surface temperature and salinity. Summers may be locally wetter but increased evapotranspiration will commonly result in less available water, decreased soil moisture and higher water demand.
5. An increased number and severity of extreme events would destabilize existing landscapes and ecosystems

EFFECTS ON LANDSCAPES

As described in the CCS chapters and volumes, the majority of anticipated broad landscape changes are driven by the forces of:

- shifting ranges and altering ecozones
- altered and more variable hydrology;
- melting of permafrost, and
- rising sea levels.

Shifting Ranges and Ecozones

Almost all CCS chapters describe how anticipated climate change will cause geographic shifts in species ranges, ecosystem boundaries and the location of socio-economic activities and interests. Perhaps the most dramatic are the projected shifts in Canadian ecozones. The USDA Forest Service MAPSS (Mapped Atmosphere-Plant-Soil System) biome model describes the distribution of vegetation under a climate brought about with CO_2 doubling (Neilson, 1995; VEMAP Members, 1995). It couples the outputs of GCMs models to a complex model of vegetation and the various factors affecting its distribution. Highly respected in the literature, the model and the maps of vegetation it produces are extensively used in IPCC assessments of climate change effects. Using the older 2xCO_2 equilibrium GCMs from the IPCC First Assessment Report, the 1995 results indicate that the implications for Canada would be the disappearance of the Southern Arctic Ecozone from the mainland and a northward shift of the Taiga and Boreal forest belts by about 500 Km. Shifts in other vegetation types also are indicated though the exact result varies with the GCMs model used. More recent results using the Transient Models confirm these earlier findings and are the basis for the IPCC Regional Impacts of Climate Change report presently being finalized.

A point which must be thoroughly appreciated is that this represents the equilibrium vegetation that would be supported under that averaged climate. In order for this to come about, climate must remain relatively consistent while species migrate to new locations. As discussed above, there is no reason to suppose that the increase in atmospheric CO_2 concentrations will stop at the doubling or even tripling of present levels nor can we suppose that migration rates will keep pace with changes in climate. Estimates of tree species migration are largely based on vegetational responses to climate changes over the past 10,000 years as inferred from palynology. Rates are observed to vary with species and be in the range of 10 to 200 Km per century (e.g., Davis and Botkin 1985, Gear and Huntley 1991). These may not be maximal rates but rather a reflection of the rate of climate change driving the response. On the other hand, past migrations would not be hindered by the many barriers human activities impose particularly fragmentation of landscapes by farmland, urbanization and infrastructure. It seems unlikely that tree species would be able to keep up migration rates of 150 to 550 Km per century as would be required under the projected climate (Kirschbaum and Fischlin, 1996). This has some clear implications including:

- that the disappearance of vegetation and its associated wildlife, attributes and socio-economic benefits will occur far more rapidly through dieback than the establishment at the same location of new vegetation which resembles any of our present species assemblages.
- that the use of GCMs outputs in this manner does not allow for any effects of increased number and severity of extreme events. These would be likely to accelerate dieback though they may also facilitate migration.
- that vegetation will only begin to approach a state of stability in relation to local climate when the rate of climate change falls to far less than that projected.

The probable result is that, under the projected conditions, it will not be the Taiga or Boreal Forest as we know it that will move northward but rather the more fast-moving flexible species such as those with wider seed dispersal, faster growth and early maturation. Vegetation is therefore more likely to resemble early successional stages with advantages to some wildlife species, desired attributes and socio-economic benefits but not to others. For example, deer and other browsers as well as raptors are likely to be more prevalent with associated benefits to hunters and birdwatchers but habitat for wildlife of closed forest will be reduced.

Shifting ranges and ecozones can also be considered as affecting economic activities. Optimum locations for facilities and enterprises will shift from present distributions as a consequence of changing climate. There will as a result be individual winners and losers though a sector as a whole may benefit.

The tourism and outdoor recreation industry may be strongly affected with extended seasons for warm-weather recreational activities offering extensive opportunities to the industry while winter outdoor recreation activities will have a shorter season, especially in more southerly latitudes. Decreased reliability of ski conditions may, for example, require that existing ski resorts have to rely increasingly on artificial snow-making to maintain the season.

While changing climate will affect the Canadian recreation and tourism industry, it can adapt through the relocation of facilities, application and improvement of technology and the development of multi-season recreational centres. These are all occurring to varying degrees at present.

Water Resources and Altered Hydrology

Regional volumes and the water resources chapter emphasize the critical importance of freshwater in the assessment of ecosystem effects of changing climate. The probable trends will result in generally less water availability and greater variability of levels and flows.

It is probably impossible to overemphasize the implications of the projected changes in hydrology for the structure and functioning of Canadian ecosystems including all their environmental, social and economic aspects. The pattern of water availability is a fundamental variable defining landscape pattern and processes as well as the interacting economic and social geography. Much of existing industry, built environments, and transportation/distribution systems are not particularly resilient to changes of the type and magnitude projected especially when destabilized by a greater number and severity of extreme events. Their persistence is therefore at risk.

Among other points made elsewhere in the CCS which bear upon landscapes:

- Canada's lakes and rivers are likely to suffer major disruptions, the exact nature and extent of which will vary regionally. Flow patterns and levels may alter on average, seasonally, or between years with an increased variability and probability of extreme events. This would degrade ecosystem integrity and constrain uses including transportation, power generation, drinking water quality and quantity, waste dilution, swimming, fishing and contact recreation.

- Declining snowpack will reduce spring freshet and associated recharge of wetlands, deltas, drinking water supplies, impoundments and riparian environments. Aquatic ecosystem habitats will be reduced in volume and area. In relatively arid areas of the Prairies, NHRI's Dr Raoul Granger has demonstrated how this might be compounded by further reductions in freshet resulting from flow over unfrozen ground (Pomeroy, 1997)

- Water availability for dilution of point sources will be more irregular resulting in occasional high concentrations of contaminants and apparent eutrophication requiring some adjustment in release protocols. Typically shallow waters may be expected to 'heat-up' significantly with consequences for food-chain dynamics, populations, and species diversity. Lower summer flows are likely to result in weed growth, fish kills and constraints on use including taste and odour problems.

- Critical impacts on wetlands are likely in the Prairie Pothole Region. Occupying depressions in the landscape in a dry climate with small watershed areas, Prairie Pothole wetlands are highly susceptible to a lack of moisture occurring through the effects of decreased snowpack and associated spring recharge, droughts and increased climatic variability. Already strained by losses of 71% in Canada (Environment Canada 1986, 1988) and 50-60% in the US (Leitch, 1981), this area is still described as one of the most important wetland regions in the world (Weller, 1981) yielding 50 to 75% of all the waterfowl produced in any year in North America (Leitch and Danielson, 1979). Trends in duck abundance already reflect the interactions between changing wetness regimes and landscape alterations (Bethke and Nudds, 1995). Any additional stress would be of great concern and could be accommodated only through active programs to protect, enhance and increase wetland areas in this region.

- Temperature changes would alter lake structure and increase the probability of hypolimnetic anoxia. Valued cold-water species such as salmonids would encounter restricted habitat and food sources. Established bio-geochemical cycles, predator-prey relations and food-webs will be destabilized. Changed flow and runoff patterns will result in altered concentrations of major ions, nutrients, contaminants, suspended solids and dissolved organic carbon.

- In the Great Lakes and elsewhere, water level changes and variation can be expected to threaten valued littoral and wetland habitat and impact both recreational and commercial fisheries as well as wildlife habitat. Shoreline properties, infrastructure (docks, wharves, pipe locations, breakwaters, etc.) and shipping channels will be affected.

- Socio-economic effects are likely to include impacts on tourism, recreation, property values, transportation, power generation, fisheries, effluent and drinking water treatment, channel dredging, infilling of impoundments and the local availability of water for agriculture, industry and urban areas.

Without detailed regional descriptions of how climate will alter, accurate prediction of local consequences and costs is impossible as is the identification of specific opportunities to modify or mediate local impacts. All of these effects could occur to a degree in any area of Canada. That the socio-economic aspects of landscapes are likely to be particularly affected suggests that the identification of least-cost opportunities to increase the ability to tolerate increased variation should be a priority.

Melting Permafrost and Other Cryospheric Effects

As described in the CCS sections on the North and elsewhere, the melting of permafrost in large areas of Canada will have a major effect on northern landscapes with little or no opportunity to minimize the impacts.

The anticipated northward shift in permafrost areas is estimated to be about 500 Km under a 2xCO_2 climate (Prowse, 1997, Anisimov and Nelson 1995, Fitzharris, 1996). This will have profound effects on these areas as summarized in Prowse, 1997. The melting of widespread ground ice will result in massive terrain slumping and increases in sediment loads to rivers and lakes. A deeper active layer will reduce overland flow as both infiltration and active layer storage capacity increase. Peatlands are projected to disappear from south of 60/ N in the Mackenzie Basin though they may well increase in area further north (Cohen, S.J (ed), 1997) while patchy arctic wetlands currently supported by surface flow would not persist. Peatlands and wetlands would become sources for atmospheric carbon rather than sinks (Oquist and Svensson, 1996). Lakes and ponds which have permafrost hydrologic divides are more likely to drain laterally or to the groundwater systems.

Landscape alteration on this scale has serious implications for hydrology, wildlife, biodiversity, cultural values and lifestyles. The effects will likely extend to infrastructure and transportation including the integrity of foundations (pipelines, bridges and buildings), water control structures, ice-roads and the melting of the assumed impermeable permafrost beds of mine tailings ponds. Altered flooding patterns and sediment loadings will impact internationally significant wetland habitat such as the Peace-Athabasca-Slave Delta, the Mackenzie Delta and that associated with the Hudson Bay and Queen Maud Gulf lowlands.

The Queen Maud Gulf lowlands are part of the Southern Arctic Ecozone, a transitional area between the taiga forest to the south and the treeless arctic tundra to the north which includes the major summer range and calving grounds for Canada's largest caribou herds as well as habitat for bear, wolf, moose, arctic ground squirrels and lemmings. It is a major breeding and nesting ground for a variety of migratory birds including the yellow-billed, arctic and red-throated loon, whistling swan, snow goose, oldsquaw, gyrfalcon, ptarmigan and snowy owl (Ecological Stratification Working Group 1995). It is home to Canada's Inuit. According to the USDA Forest Service MAPSS biome model mentioned above, the Southern Arctic Ecozone will all but disappear from mainland North America under a climate brought about with CO2 doubling (Neilson, 1995, VEMAP Members, 1995). There appears to be little which can be undertaken to minimize or adapt to the effect of such change on wildlife, biodiversity and culture.

Other cryospheric effects altering landscapes described in CCS chapters include the retreat of mountain glaciers, declining snowpacks, longer ice-free periods in lakes and altering probabilities of ice-jam flooding:

- A steady pattern of glacial retreat is apparent in the Canadian Rockies and worldwide. For Canada, this will eventually result in diminished late season streamflows in B.C. and Alberta. This will threaten water supplies in small communities, irrigation, and fish habitat as well as the viability of the Alberta cattle industry.

- Warmer temperatures will affect the extent, duration and depth of the snow cover in Canada, with possibly a 40% decrease in snow cover duration over the Canadian Prairies. The seasonal distribution of river flow and water supply will be altered with adverse consequences for hydroelectric power, aquatic life and agriculture.

- In the Atlantic provinces, southern Ontario and northern regions susceptible to spring flooding, changes in late winter-early spring precipitation patterns could result in altered frequency of ice jams and flooding. Damages caused by these events are currently estimated to cost Canadians $60M annually, though ice-jam floods are an integral part of riparian ecology, northern deltas and wetlands being particularly dependent on the resulting periodic recharge. Depending on the specific pattern of altering climate, areas where ice jams are presently rare may suffer from an increase in frequency and/or severity whereas areas where they are common may see fewer.

The most sensitive areas are likely to be in the moderately cold regions where mid-winter break-ups might begin to occur.

Rising Sea Levels

CCS volumes from the coastal regions describe the expected rise in sea levels which will accompany global temperature changes. Coastal economic landscapes and natural areas will be affected profoundly as rising sea levels and storm surges result in shoreline erosion, sediment redistribution, loss of habitat, salinization of water supplies and increased coastal flooding.

Many beaches and coastal wetlands would be squeezed between advancing seas and engineering structures including manmade dikes which will become more common as a result of efforts to protect shoreline properties The maintenance of existing recreational beaches will require increasing costs. In many areas, development will prevent the wetland migration or creation that would otherwise result from the gradual inundation of areas that are barely above today's high water level. Loss of coastal wetlands would affect fisheries and wildlife as well as the nutrient status of nearshore waters.

Rising sea level enables saltwater to penetrate farther inland and upstream in rivers, bays, wetlands, and aquifers. Saltwater intrusion into surface waters would harm some aquatic plants and animals and would threaten human uses of water. Salt water intrusion into aquifers will affect wells and reduce agricultural productivity in low-lying areas due to soil salinization. Groundwater levels will rise resulting in increased pumping costs to maintain infrastructure.

Storm surge flooding, overtopping of dikes, increased erosion and sediment redistribution will greatly increase the costs of protecting and maintaining coastal infrastructure including homes, roads, railroads, sewage systems, docks and port facilities. Reduced extent and duration of sea ice would increase open water fetch and the contribution made by wave energy to coastal erosion during winter storms.

Major Canadian deltas such as the Fraser and Mackenzie are particularly vulnerable to rising sea levels and associated impacts on the sustainability of the deltaic ecosystem. Vulnerable coastal areas in the Atlantic region include the salt marshes of the Bay of Fundy and the narrow barrier islands and spits along the Gulf of St. Lawrence coast of New Brunswick which protect important recreational areas on the mainland as well as environmentally sensitive freshwater bogs and woodlands. Prince Edward Island is highly susceptible to erosion of its sandy barriers, coastal dunes, salt marshes, and intertidal flats. Increased beach erosion would threaten the Island's tourist industry as well as shorefront buildings, roads and sewage systems. Charlottetown appears to be especially vulnerable with some of the highest-valued property in the downtown core and significant parts of the sewage systems at risk.

Innumerable other coastal communities including Placentia (Newfoundland) and the lower Fraser Valley (B.C.) are vulnerable to inundation or storm flooding. While many coastal areas are currently protected with levees and seawalls, these structures have been designed for current sea level: higher storm surges might overtop them, and erosion could undermine them from below.

Possible responses to sea level rise fall into three broad categories: erecting walls to hold back the sea; raising the land to compensate for rising sea level; and allowing the sea to advance and adapting. Each has advantages and disadvantages.

Structural measures can protect property from rising water levels but the resulting loss of natural shorelines may have adverse environmental, recreational, and aesthetic effects. Wetland and shallow water habitats are already being lost because the structures prevent these systems from migrating inland.

Elevating land surfaces is expensive and open-ended. Long-term cost-benefit studies which include property values and shore-protection costs as well as environmental and aesthetic factors may sometimes justify such action.

Economics would appear to favour planning measures which whenever possible enable shorelines to remain in roughly their natural state as sea level rises, rather than be replaced with structures. Such measures would best apply to areas that are not yet developed. They broadly fall into two categories: (1) setbacks, which are regulations that prevent development of areas likely to be inundated; and (2) rolling easements, which allow development today but only with the explicit condition that the property will not be protected from rising water levels (Titus, 1997).

Several nationwide assessments have been conducted in the United States focusing on the potential loss of wet and dry land and the cost of holding back the sea recognizing that the impact of sea level rise ultimately depends on whether and how the latter is pursued. Assuming alternative policies for protecting coastal land, estimates for the cumulative cost of a 50 cm rise in sea level in the U.S. through the year 2100 would be between $20 and 200 billion. (Titus *et al.*, 1991)

KNOWLEDGE GAPS AND CHALLENGES

Summary and analysis of the Canada Country Study results which describe changes to landscapes leads to the recognition of a number of knowledge gaps and challenges which restrict analysis or the proper application of findings. These include:

- an inability to set values on ecosystems and their attributes which would facilitate appropriate consideration in decision-making;
- the lack of credible regional scenarios of changing climate over the coming decades which sharply restricts the ability to assess effects, identify opportunities to minimize impacts or evaluate the benefits of adaptation measures.
- the need for specific research into the response of landscapes and ecosystems to probable patterns of changing climate such as the response of wetlands to altered hydroperiods, successional patterns at Boreal forest and Tundra ecotones, landscape responses to altering permafrost, effects of altering northern hydrology, linkages with other atmospheric issues and ecosystem responses in multiple stressor conditions.
- the lack of integrating mechanisms to project effects and plan or implement appropriate responses in the often interjurisdictional and/or interdisciplinary areas which are emerging as significant such as:
    - water management in conditions of scarcity and competing interests;
    - the sensitivity of existing dams and basin management to shifts in hydrology

- the protection against or adaptation to sea level rise;
- strategies for increasing the resilience of vulnerable industries, urban areas and infrastructure;
- enhanced protection where possible for valued and sensitive habitats such as prairie and northern wetlands, littoral areas, cold water fish habitat, large tracts of Boreal forest and Taiga in the north-central portions of their ranges, etc.

CONCLUSIONS

The Canada Country Study regional and sectoral chapters identify a number of areas where broad landscape-scale effects of climate change can be anticipated. While there may be some positive aspects, most of the resulting impacts would be severe, widespread and long-lasting. Such effects therefore present serious risks to the well-being of Canadians and their minimization should be a serious concern. It is therefore recommended that:

- the accurate assessment and communication of these risks be vigorously pursued
- the identification and implementation of least-cost options to increase the ability of related ecosystems (including their environmental, social and economic aspects) to accommodate variability be accelerated
- serious attention be given to opportunities identified in the Canada Country Study for adapting to these and other potential impacts of changing climate.
- the nature and degree of these risks be given due consideration in the development of national strategies on GHG emissions.

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CHAPTER SEVEN

CLIMATE CHANGE AND SUSTAINABLE DEVELOPMENT: RESEARCH HIGHWAYS IN NEED OF A MERGING LANE

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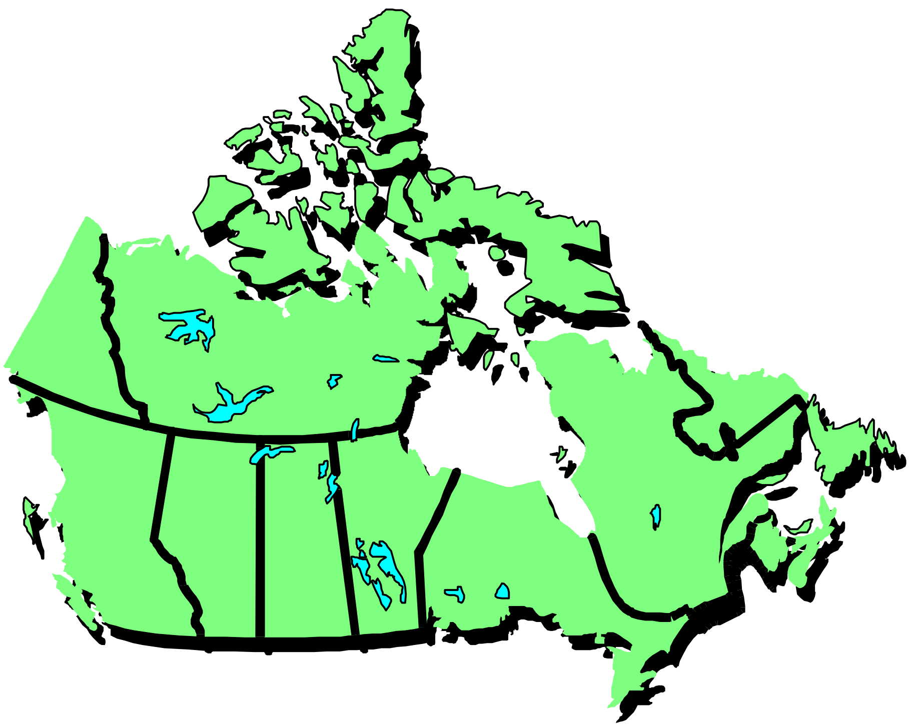

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EXECUTIVE SUMMARY AND RECOMMENDATIONS

The consequences of climate change and sustainable development remaining as separate discourses are explored, both in general and in the Canadian context. One of these consequences is the difference in emission and economic development scenarios generated by the two groups. A second is that strategies to reduce greenhouse gas emissions are designed and assessed in a narrow technical context, divorced from the economic and social forces that underlie them. We identify the need for climate change and sustainable development to be represented in a more explicit manner in each other's research agendas, and for integrated assessment of climate change to incorporate alternative methodologies that complement global scale integrated assessment models. These methodologies should include greater involvement of stakeholders as partners with researchers in a shared learning experience.

THE ISSUE

In a thought-provoking paper, Newby (1993) has argued that recent attempts to develop an international human dimensions of global change program have fallen prey to what he calls the 'IPCC fallacy'. This is the tendency, exemplified by the Intergovernmental Panel on Climate Change's (IPCC hereafter) First and Second Assessment Reports, to deal with the human or social dimensions of global change by attaching some social science analysis, virtually as an appendage, to a body of work that defines the problem in terms of natural science approaches. From this perspective, the social science contribution (the humanities are rarely invoked) is to analyze the 'driving forces', 'impacts' and 'adaptive capabilities' relative to the biophysical phenomenon of global climate change, largely divorced from their social context.

Newby's paper brings to the surface an important difference in approach among the different groups and individuals studying global environmental change. In particular, it points to a difference between a natural science approach to environmental problems that defines them in terms of physical flows of matter and energy and a social science approach, which tends to define them in terms of human behaviour. Associated with each approach are typical problem definitions, types of methods, standards of validation and credibility, and definitions of key concepts like data, testing, models, and so forth.

Of course this description oversimplifies the picture. The relationship among the various fields and disciplines within the global change arena is characterized by great complexity and conceptual and methodological disagreements both among and within those fields and disciplines.[1] Nevertheless, the broad distinction sketched out here is visible in the products, actions, and debates of the two international program of research in the global change field: the International Geosphere-Biosphere Program (IGBP) and the newly renamed and relocated International Human Dimensions Program (IHDP). Even their institutional affiliations reflect this distinction. The IGBP was set up by member unions of the International Council of Scientific Unions (ICSU), and the IHDP, then named the Human Dimensions of Global Change (HDGC) Program, was co-sponsored by the International Social Sciences Council.

[1] For a slightly more nuanced view of this relationship than the one presented here, see Robinson and Timmerman (1993).

In this paper we contend that the distinction between these two approaches to environmental problems explains the otherwise puzzling lack of interaction between two fields of research and activity, associated respectively with climate change (CC) and with sustainable development (SD). The purpose of this paper is to describe these alternate approaches to global environmental change and to suggest how they might be reformulated more fruitfully.

Although climate change is one of the most important symptoms of 'unsustainability', it is remarkable how little the discussion of CC has influenced that of SD, and vice versa. The SD research community has not generally considered how the impacts of a changing climate may affect efforts to develop more sustainable societies. Global warming is acknowledged as a problem, but is typically leaped over in an effort to push governments towards specific policy responses (*e.g.,* reduce energy and materials consumption, resolve North-South inequities, etc.). Conversely, the concept of SD and the methodological and substantive arguments associated with it are notably absent in the CC literature. A striking example of this was the third volume of the IPCC's Second Assessment report. Although Working Group III had been explicitly asked at its opening plenary to address sustainable development issues, the actual discussion of SD in the report is almost non-existent.

The reason for this, we suggest, is rooted in the very different approaches to science, politics and practice associated with the separate discourses and research cultures of CC and SD. While the reductionism of the dominant natural science approach to CC has constructed it as an environmental problem amenable to scientific analysis, this formulation has not been especially helpful in figuring out how to respond politically because it ignores the human dimensions of the problem and the difficult and locally differentiated politics of responding to it. As a result of this political detachment, the questions posed by the science of CC have not proven terribly relevant for policy making, despite the ambitions of making science policy-relevant. Even in the meetings that led to the Kyoto Protocol, the rhetoric of a debate on the science of climate change was often overshadowed by the reality of debates over economics. By contrast, the human-centered SD approach to environmental problems is more politically and geographically sensitive, but it is analytically vague. This makes it difficult to define or implement in practice, and therefore vulnerable to being co-opted by those seeking to cloak their activities in the green mantle of sustainability (Eden, 1994).

In response to these challenges, we argue that the solution is not to subsume one approach to the other, but to reformulate them both, recognizing their complementary strengths in addressing environmental problems. We concur with Rayner and Malone (1998), who call for a greater partnership between the natural and social sciences, the humanities, and the expertise of stakeholders in decision making.

THE TWO DISCOURSES

At first glance it might seem odd to suggest that CC and SD represent very different ways to think about global environmental problems. Central to both concepts are human impacts on the environment, particularly the global dimensions of environmental problems. Moreover, both CC and SD are terms that came into prominence in the late 1980s. In the case of CC, a major conference in 1988 (WMO, 1988) brought this issue to the attention of policy-makers in a way that was hard to ignore, and that sparked a whole series of subsequent scientific and political activities. In the case of SD, the concept was brought to popular attention by the activities of the World Commission on Environment and Development (WCED), and the publication of their report, *Our Common Future*, in 1987. And certainly, CC is one of the major problems of SD cited in the Brundtland report and in other SD writings, while the topic of SD was part of the mandate of the IPCC's Second Assessment report.

Despite these similarities, there exist significant differences in the way these two concepts have played out, both as research questions and as policy issues. As the following discussion will make clear, part of the reason for this has been the science-driven nature of the CC debate - characterized by a form of physical reductionism - and the problem-driven nature of the SD field - characterized by a more human behaviour-centred approach.

The Discourse of Global Climate Change

Although theories about anthropogenic climate change have a long history, dating as far back as ancient Greece (Glacken, 1967), the contemporary concern with global climate change is strikingly new. In the short space of a decade or so, the so-called enhanced greenhouse effect, caused by changes in the earth's radiation balance due to the accumulation in the atmosphere of carbon dioxide (CO_2) and other radiatively sensitive gases, has gone from being a little-known technical concern of a few atmospheric scientists to a subject of widespread public anxiety and international regulatory interest. Indeed, global climate change is now widely regarded as the "the most important problem facing mankind over the next fifty years" (Gribbin, 1990 quoted in Buttel *et al,* 1990: 57). Rallying behind this banner of a scientifically determined threat to the planet and to humanity as a whole, an international network of scientists, government bureaucrats, environmental activists, and other interests has succeeded in propelling the problem of global climate change to the top of the international agenda.

Three features of the current scientific and political discourse on climate change are noteworthy: its reductionism, its technical and instrumental rationality, and its alliance to both moral-liberal and rational-technocratic politics. The IPCC and the other national and international scientific bodies studying climate change have tended to focus on it as a global **environmental** crisis, to the exclusion of its social, cultural, moral, and political dimensions and their connections to other pressing social and environmental problems such as hunger, poverty, and North-South inequities. As a result of this narrow, natural science based formulation of the problem, the question of global environmental change has been reduced from a wide-ranging one about the uneven political economy of modern capitalist development and underdevelopment to a narrowly defined problem of global atmospheric emissions. By constructing climate change as a matter of simple physics and thereby largely excluding from their analyses the underlying social factors causing the problem, scientists have been able to model it mathematically. Their computer visualizations represent the facts of future climate change in alarming hues of red and orange, making the problem 'real' for policy-makers and the public at large. But the exclusively scientific basis of the call for action and the moral-liberal and the rational-technocratic politics to which it appeals have proven insufficient, if not, in fact, actually counter-productive, for constructing an effective response to global climate change. A closer examination of these three problems follows.

Reductionism

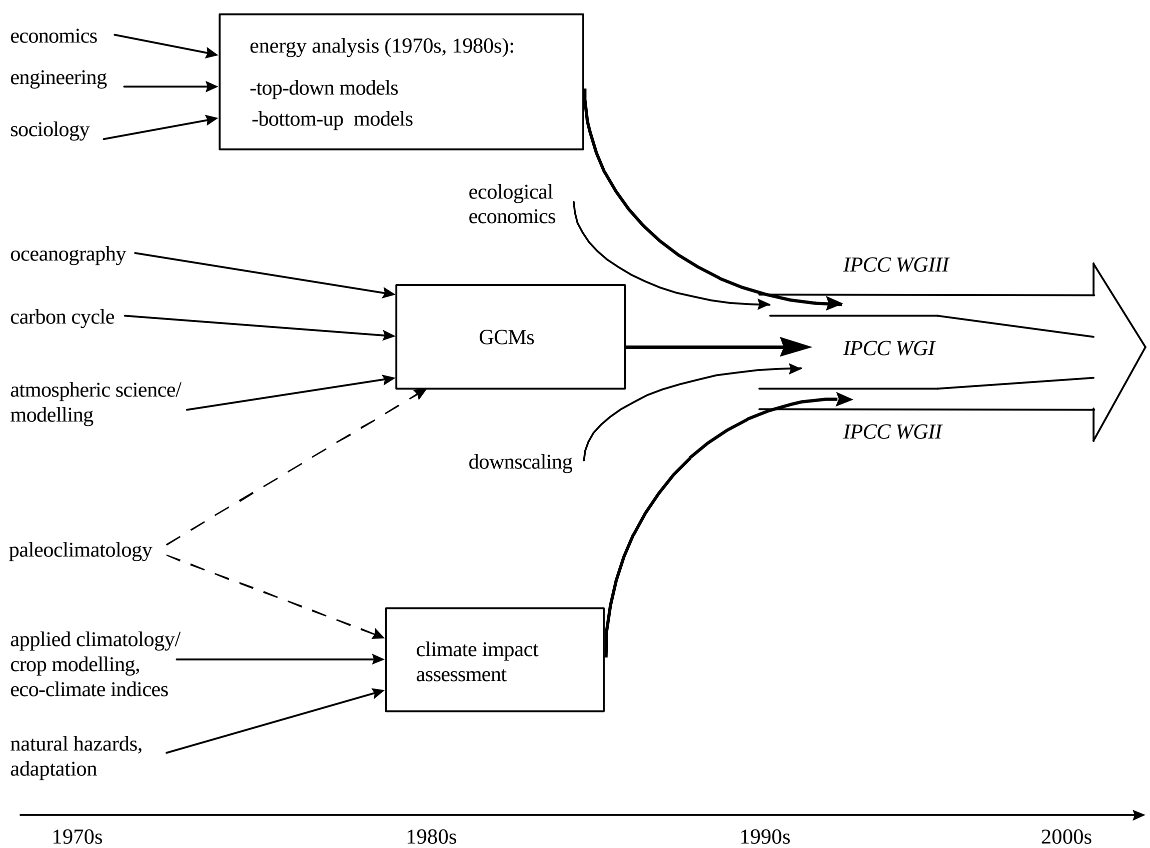
The reductionist formulation of CC is a legacy of the way in which it was initially conceived as an object of scientific knowledge and then brought to widespread public attention. Although the modern theory of global climate change brought on by an enhanced greenhouse effect has been debated since the late nineteenth century, the early work of Aarhenius (1898) and others left no institutional and programmatic legacy. Instead, the present discourse about global climate change owes its shape to the coalescence of two separate scientific research programs, the first, based in oceanography and concerned with the global carbon cycle and fluxes between the earth, ocean, and atmosphere, the second, founded in atmospheric science and concerned with numerical modelling of atmospheric behavior (Hart and Victor, 1993). The fruit of their union is the general circulation model (GCM), which mathematically models the flows of matter and energy within and between coupled global ocean and atmospheric systems. The complexity, computational demands, and costs of developing and running these models are such that there are only a handful worldwide.

The GCMs provide just one of many possible approaches to studying climate change, but they have become far and away the most authoritative. They are now widely celebrated as the best tool for understanding and, thereby, protecting and managing the global atmosphere. Although GCMs are now widely celebrated as the best tool for understanding and, thereby, protecting and managing the global atmosphere, the initial justification for such basic research was military. At least in the United States, where many of the first GCMs were developed, atmospheric modeling and oceanographic research into the carbon cycle were both heavily dependent on Cold War military research funds, rather than, as is now the case, being justified in terms of their applications for environmental protection. This rhetorical shift began in the 1970s as scientists exploited the nascent concern with the environment, which lay behind the 1972 Stockholm conference on the human environment, to forge international research connections and secure increased funding for global monitoring and research. This new interest in anthropogenic environmental atmospheric change, sparked in part by public fears about air pollution and the effects of supersonic jet transportation, not only helped bring atmospheric chemistry into the fold, as it became clear that CFCs and other gases were radiatively significant, it also marked a shift in the modeling community away from an interest in equilibria to the potential threat of anthropogenic climate change. As atmospheric scientists began to sound the alarm about the dangers of an enhanced greenhouse effect in the 1980s, their construction of the problem of a question of carbon dioxide emissions appealed to a variety of other powerful interests and allies. National and international government bureaucracies and western environmental lobby groups seized upon the issue as an organizing rationale for a wide range of environmental protection and pollution control policies. The scientific construction of climate change as a problem of carbon emissions was also tailor-made for the promoters of so-called alternative energy sources such as nuclear and hydro-electricity, which were struggling in the cheap energy markets of the 1980s (Boehmer-Christiansen, 1994). Together, they helped bring the problem to the attention of national and international policy makers and the public at large.

The hegemony of GCMs has served to marginalize other, less reductionist ways of understanding global climate change, most notably paleo-climatic and other analogue methods. Critical to the authority of the GCMs, as Shackley and Wynne (1995b) note, is that, in the absence of definitive proof of anthropogenic climate change in the observational record, they not only provide the best evidence of the fact of global climate change but also hold out the seductive promise of detailed predictions necessary to manage the problem (on their own, or through downscaling exercises, *e.g.*, Giorgi *et al*, 1994). It was the predictions of the GCMs that first caught the attention of policy-makers and the public at large at the Toronto Conference in 1988 (WMO, 1988). The GCMs provided the foundation for the first assessment by the IPCC in 1990 (Houghton *et al*, 1990), as well as subsequent IPCC reviews.

Scientific reductionism and the associated reliance on physical process modeling has had a number of effects on the way in which the problem of climate change is studied and understood. In Figure 7.1, we have tried to map out the relations between the various domains of the climate change research community.

Figure 7.1 The climate change discourse, 1970s to present



Analysis of CC has been divided into three distinct research components, which are held together by their dependence on the GCMs, either as research tools or sources of input data. First there is the largely GCM-based research on the impacts of trace gas emissions on the climate. This became the focus of IPCC working group I. Working group II was assigned the task of assessing the impacts of the CC predicted by the GCMs on ecosystems and human activities (*e.g.*, agriculture, biogeoclimatic zones, sea level, etc.). Because of the involvement in this research of the natural hazards research community, which historically had focused on both the impacts of natural hazards and adaptation to them, Working Group II was also charged with considering the issue of adaptation to CC. Working Group III dealt with policy response options. Although its mandate for the Second Assessment Report was expanded to encompass the broad human dimensions of CC, it remained largely focused on the politically controversial question of mitigation. As a result, it was dominated by participants (both individual and institutional) in the 1970s debate about how to respond to the (apparently) imminent depletion of fossil fuels whose energy models are now being applied to study the economics of CC mitigation. As we discuss in 'The Separation of Mitigation from Impacts and Adaptation' pg 18, this institutional division of labor between adaptation and mitigation has had important research and policy implications. This organizational structure has been repeated by a number of nationally based CC assessment studies (*e.g.*, Smith and Tirpak, 1989; Nishioka *et al*, 1993; UKCCIRG, 1996; Canada Country Study, Volume VII). Facilitated by a number of international initiatives, this research model is being gradually extended to developing countries (*e.g.*, Strzepek and Smith, 1995). There, as elsewhere, the approach remains resolutely reductionist: driven by and dependent upon the GCMs and other physical processes modeling.

Thus, the relationships between these knowledge domains - atmospheric science, physical impacts, and policy options- are hierarchical. The analysis of biophysical impacts relies on CC scenarios, usually derived from GCMs, and in turn, the study of response options depends upon the output of the same GCMs and biophysical impacts work. This way of organizing research has tended to produce a 'certainty trough', in which consumers of model output from one research field accord it greater confidence and certainty than practitioners in the originating discipline (Shackley and Wynne, 1995a). More troubling, the hierarchical structure constitutes an environmental and technological determinism: the physics of climate change, as represented in the GCMs, set the environmental parameters to which societies must adjust and adapt (Taylor and Buttel, 1992). It is closely associated with a misleading baseline mentality in which discussion of the range of potential futures is artificially constrained by undue focus on the social and environmental parameters set by the 'business-as-usual' case (see 'Scenarios of the Future', pg. 16).

More recently attempts have been made to combine these different research clusters in a process of so-called Integrated Assessment (IA). Although not restricted to these, the most visible outputs to date have been a number of large-scale Integrated Assessment Models (IAMs). IAMs have been heralded by IPCC Working Group III as the main tool for providing analyses of abatement options. Typically, an IAM consists of a series of linked models across a 3-4 step continuum from trace gas emissions to changes in atmospheric composition to changes in climate and sea level, *i.e.*, first-order impacts, and, possibly, to higher-order impacts affecting emissions (*e.g.*, Alcamo *et al*, 1995, 1996; Matsuoka *et al*, 1995). Response options are normally considered outside of the models and treated as exogenous inputs, making it difficult to model tradeoffs between various adaptation and abatement options. Furthermore, because of their large, often global scale, IAMs rely on a considerable degree of aggregation and abstraction. As a result, many important regional scale environmental and social processes, such as population growth and economic development, can be missed, or worse, assumed to continue on a so-called business-as-usual trajectory (‘The Separation of Mitigation from Impacts and Adaptation’ pg 18). The inevitably uneven distribution of impacts, especially to the most vulnerable, is concealed by a focus on the aggregate. So too is the multi-objective and polyvalent nature of places, which embody a wealth and richness of meanings not easily captured by aggregating individual preferences or by focusing exclusively on the impacts of CC to the exclusion of other economic and environmental changes. The response from the IA-modelling community has been to press tirelessly onwards trying to include more variables and achieve greater resolution.

We suggest, however, that the problem goes much deeper than simply the spatial scale of resolution or level of abstraction. It is fundamentally one of values. Models ‘see’ the world through complex algorithms. Analytical choices about what to represent and how to represent it necessarily involve making value-laden judgments. Thus modeling, particularly (though by no means exclusively, cf. Wynne, 1996) social and economic modeling, is a deeply political practice. But the reductionism of the IAMs encourages modellers to treat representation simply as a technical question of proper parameterization, to be decided in private by experts, rather than a political question to debated publicly.

Technical and instrumental rationality

These aspects of IA modeling point to a second feature of CC discourse: its narrow scientific and technical bent. CC science is a classic example of what Weber and other sociologists call instrumental, or means-end rationality: technical knowledge applied to the most efficient achievement of some, unquestioned end (Brubaker, 1984). In the case of CC, the social context under which greenhouse gases are produced has been largely ignored, except as technical questions about rates and physical processes. Luxury emissions of greenhouse gases from fossil fuel use in developed countries are analyzed in the same universal, scientific terms as survival emissions from agriculture in developing countries. Though the political importance of these differences may have been recognized in the international debate leading to the 1997 Kyoto Protocol, they are disregarded for the purposes of analysis, which, through the GCMs and the Global Warming Potential index (Shackley and Wynne, 1997), has sought to unify the very different qualities of greenhouse gas emissions into a system of global scientific equivalence. Thus, CC science is predicated on the idea that the objective of properties of greenhouse gases can and should be distinguished from their human meanings or any social objectives in managing them.

This effort to detach scientific and technical understanding of the phenomena of CC from an appreciation of their value and social meaning is reflected in the way in which research has been funded. The vast majority of research funds have been devoted to reducing scientific uncertainties about the physical processes, rather than exploring the social context in which they will be understood and experienced. This allocation of funding serves to reinforce the hierarchical relations among the three domains of CC research. Far more importantly, such an approach tends to discount the fact that over the long term, the climate will be one among many social, economic, and environmental factors shaping the world. IAMs were developed to help understand the complex relationships between climate changes, physical impacts, and possible policy-responses, but, as we noted above, the general approach remains resolutely reductionist and technical. This tends to leave CC scientists and the policy-makers who depend on their technical expertise blind to the diverse social meanings (and political economy) of the entities that have been analytically united through the GCMs, IAMs, and the Global Warming Potential Index into a global economy of greenhouse gas exchange (Demeritt, forthcoming).

Because of the overwhelmingly instrumental character of the CC discourse, the national and international politics of global climate change have not only been driven by the claims of science, but founded upon them. At the 1988 Toronto conference, which first brought CC to widespread public attention, the appeals for action were based on objective science, rather than the basis of equity or some other normative criteria (WMO, 1988). As such, they denied any normative or political content, at the same time that a particular political agenda was being advanced as a logical response to an objective and unbiased assessment of the facts of science. This is quite different from previous ideas about CC, which, though certainly concerned with careful observation of environmental change, were connected to and explicitly grounded in a normative evaluation of society, whose moral value was thought to be reflected in human induced environmental changes. Thus, while French philosophers saw the corruption of colonialism both reflected in and confirmed by the climate changes they measured in eighteenth century Mauritius (Grove, 1995), early nineteenth century American moralists celebrated the warming that they saw accompanying the clearing of the forest as divine confirmation of American efforts to civilize the wilderness (Demeritt, 1991). By contrast, contemporary scientific discourse on CC disavows such moralism or, for that matter, much interest in human society as an object of study, except as an exogenous source of atmospheric emissions driving CC.

Perversely, in fact, the objectivist cast of CC discourse and the sharp disjuncture it has made between science and policy (usually a euphemism for politics) has tended to reinforce its scientific reductionism and its marginalization of any broadly cultural and social consideration of CC. These much more obviously value-laden dimensions of the CC problem have been regarded as political and thus, by definition, unscientific (Newby, 1993). It is no coincidence that neo-classical economics, the most reductionist and instrumental of the social sciences, has come to dominate the study of what now passes for the human dimensions of CC. By denying the epistemic legitimacy and scientific value of anything that appears remotely political, CC discourse has tended to turn its attention away from those dimensions of the problem that are most important for policy purposes.

Moral-liberal and rational-technocratic politics

The reductionism and instrumentally rational tone of CC discourse are closely related to a third feature: its alliance to both a moral-liberal and a rational-technocratic view of politics and science (Taylor and Buttel, 1992). In either case, the reductionist conception of global warming as an exogenous environmental force affecting humanity as a whole appeals to the common and undifferentiated interests of a global citizenry. It by-passes the complex, locally specific problems of SD, reducing them to the single imperative of controlling global greenhouse gas emissions. The only difference is how emission reductions are to be achieved. The moral-liberal formulation depends on communicating scientific knowledge of the objective risks of CC to sway self-serving, naive, or scientifically ignorant behavior contributing to global warming, while the rational-technocratic relies on science to identify the optimal policy to which individuals must then submit. Both assume that the proper role for science is to provide certain knowledge on which to found political decisions and that therefore the first obstacle to addressing CC is scientific uncertainty, which impedes the formation of democratic consensus (moral-liberal) and the optimization of policy (rational-technocratic).

This formulation of the relationship between science and politics provides a weak foundation for responding effectively to CC. The moral-liberal politics of global citizenship and public education to convince individuals to change their lifestyles to avert global climate change has run afoul of public apathy and mistrust (Hinchliffe, 1996), while the rational-technocratic is vulnerable to being discredited, when, as is almost inevitable, the social and political commitments of its science-driven agenda become apparent. Thus, social critics complain that the narrow focus on greenhouse gas emissions, whose effects will not be felt for a generation or more, divorces them from their social context and displaces attention from far more pressing and immediate concerns, such as poverty and hunger. Developing countries are resisting pressure to reduce their greenhouse emissions as a new form of environmental colonialism, designed to keep them poor and underdeveloped (Parikh, 1992; Parikh and Painuly, 1994). What is worse, perhaps, is that continued scientific uncertainty has become the principal rationale for continued political inaction in the face of CC. It has allowed the fossil fuel industry in the United States to dress up its selfish and steadfast opposition to any policy of mitigation as a principled defense of scientific standards. To the extent that the narrowly scientific focus on global CC addresses itself to an undifferentiated global ‘we’ and relies exclusively on the authority of science to create this sense of global citizenship, ‘we’ are likely to act more as spectators than participants in the shaping of our related, but different futures (Taylor and Buttel, 1992: 406).

The SD Discourse

While the term sustainable development was probably coined during the 1980s[2], its intellectual pedigree goes back much further. Concern with the environmental impacts of human activities in Western history goes back at least to the Greeks (Wall, 1994). More recently, the emergence of modern industrial society in Europe gave rise to a series of influential critiques on the part of the Romantics, who were appalled at what they saw as the soulless mechanism of the new age and the concomitant denigration of external and internal nature. A quite different critique was presented by the early social critics, who were dismayed at the human consequences of industrialization. At the end of the nineteenth century, these two strands of thought were influential in the development of two prominent schools of environmental thought in the US: the preservationists associated with Muir (1901 by way of Thoreau and Emerson), and the conservationists associated

[2] As noted above, the term was popularized by the Brundtland Commission in 1987, but had been used before (see Clark and Munn, 1986). The term ‘sustainable society’ had been used by Brown at the beginning of the decade (Brown, 1981).

with Gifford Pinchot (1910).[3] The preservationist tradition was transcendentalist in nature, arguing for the preservation of nature as a moral and ethical imperative, linked to the spiritual development of humankind. The conservationists were explicitly utilitarian, arguing that conservation of nature was needed to ensure the continued availability of natural resources for human use in the future.

In the twentieth century, these two strands of thought tended to be submerged by other concerns during the Great Depression, the Second World War, and the post-War boom. They began to re-emerge in a new form in the 1960s, with the rise of protests over nuclear power and various forms of air and water pollution.[4] Thus was born the 'environmental movement' of the 1970s and 80s.

As the name suggests, the environmental movement of this period was primarily concerned with biophysical questions of environmental impact, resource depletion, and nature preservation[5]. A strong apocalyptic tone was expressed in major statements such as *Limits to Growth* (Meadows et al, 1972) or *A Blueprint for Survival* (Goldsmith *et al*, 1972). These tendencies were reinforced by the energy crisis of 1973/4, which was interpreted by many as the first indication that the world would soon run out of non-renewable resources, or pollute and/or overpopulate itself to the point of collapse. The 'energy crisis' of 1973/4 and its successor in 1979, became a central focus of environmental concern. Billions of dollars of research into energy efficiency and alternative forms of energy was undertaken during the late 1970s and early 1980s, governments instituted energy conservation programs, and the electric power industry, in North America in particular, began a much publicized series of demand-side management and alternative energy programs (Buttel *et al*, 1990).

On the international front, although the more narrow focus on local problems characteristic of environmental arguments of the 1960s had begun to be replaced by a more explicitly global focus during the 1970s, the environmental argument was still primarily being made within industrialized countries. The reaction in developing countries was often skeptical. In a famous statement at the UN Stockholm Environment Conference in 1972, the Brazilian Minister of the Environment is reported to have said, "If it is a choice between pollution and industry, or no pollution and no industry, give us your pollution".

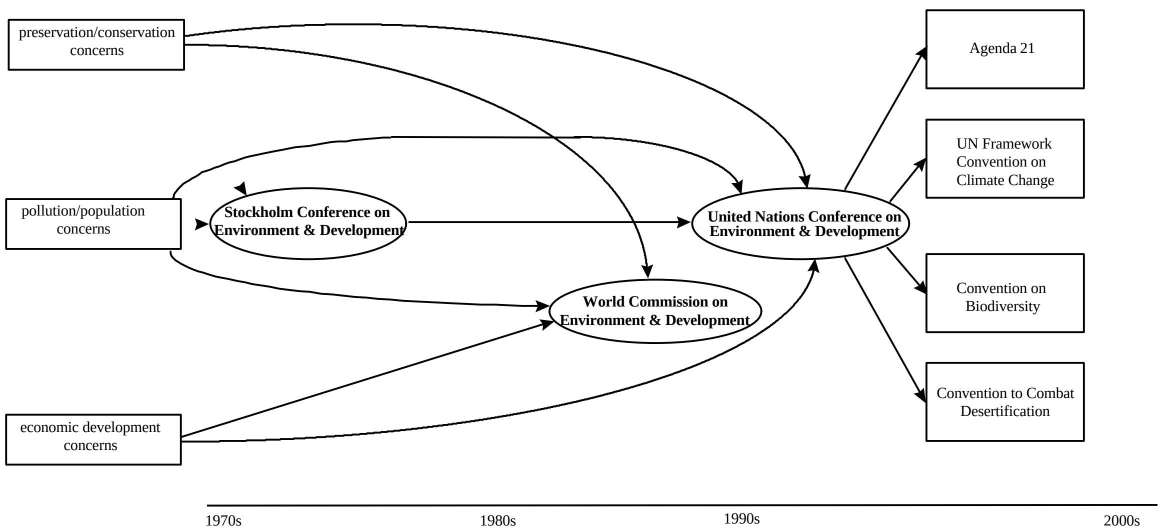
[3] This is of course the American history. The emergence of modern environmental concern took a somewhat different form in other countries. For example, in Britain, it was closely connected with a peculiarly English sense of Tory noblesse oblige, while in Canada early nature preservation was strongly associated with economic nation-building. The point here is simply that early modern concerns with the impacts of modern industrial society on both nature and humans played a role in the development of modern environmental concern in this century.

[4] These concerns represented the emergence of a new form of 'urban' environmental concern, focusing on pollution and resource depletion issues, rather than on wilderness preservation. In North America, at least, this gave rise to a new set of environmental groups, like Pollution Probe in Canada, in addition to the already-existing groups like the Sierra Club, that focused more on wilderness issues. The former groups tended to adopt a more conservationist approach, with a strong focus on questions of efficiency of use, while the wilderness groups were the heirs of the preservationist tradition.

[5] European environmentalism, with stronger roots in social and political criticism, tended to exhibit a greater focus on social issues (e.g. Green Party, Germany).

During the 1980s, these disparate strands (nature preservation, concern with pollution and resources, an increasingly global focus, inclusion of the concerns of developing countries) began to come together (see Figure 7.2). A major catalyst was the emergence of the world oil glut of the mid-1980s, which simultaneously removed fears concerning resource depletion, drastically reduced research and investment into energy efficiency and alternative energy sources. This coincided with the emergence of CC onto the scientific, and then, political agendas in the late 1980s. One result was the almost total conversion of the 'energy problem' into the 'climate problem', which had the effect of providing a much more explicitly environmental and global context to the energy debate.

Figure 7.2 A brief look at the sustainable development discourse, 1970s to present



With regard to international issues, the creation of the World Commission on Environment and Development (WCED) by the UN in 1985 represented a turning point in the sophistication of the debate and the incorporation of the concerns of developing countries. Insofar as it had addressed issues of international development at all, much of the environmental literature produced in industrialized countries had tended to focus on the need for population control in the developing world. For almost the first time, the Brundtland Commission provided an internationally prominent forum for the presentation of the position of developing countries. In so doing, the Commission brought together two previously separate literatures: the literature on environmental sustainability and the literature on social and economic development.

In adopting the term 'sustainable development', the Commission argued that problems of human development (poverty, inequity, basic human needs) could not be separated from, indeed were causally connected with environmental problems of resource depletion, biodiversity, pollution and life support systems. The fact that this concept was articulated by a UN Commission headed up by a Head of State of an industrialized country gave it much greater visibility and impact than would have otherwise been the case. It also parachuted SD onto the political agenda, both in the international arena and also, in many countries, domestically. Finally, the explicit linkage of the population and development 'problem' in developing countries with the 'consumption' problem in industrialized countries meant that SD was inherently a global concept.

This is not to say that the concept of SD was universally popular, or even acceptable among all the relevant constituencies. Many environmentalists, for example, viewed it with suspicion, not least because of its apparent popularity with politicians and large corporations. Concerns were also raised about its analytical vagueness, and the degree to which it provided a veneer of environmental respectability for continued economic growth (Redclift, 1996).

Yet it was precisely this prospect of reconciling concerns for improved material standards of living, social well-being, and environmental sustainability that arguably underlay a whole series of local, national, and international policy initiatives in support of sustainable development. These initiatives reached their peak at the United Nation's Conference on Environment and Development, held at Rio in 1992. The Rio conference was attended by more Heads of State than any previous conference and led directly to the development of a number of international conventions, statements, national policies, and local Agenda 21 initiatives.

However, this apparent political strength of the concept of SD also points to its major weakness in practice. Despite a plethora of policies, conventions, statements, and programs, it is not clear that substantial progress is currently being made in achieving the goals of SD. In the CC arena, for example, the key element that emerged from Rio was the UN Framework Convention on Climate Change and a welter of accompanying national policies. The most noticeable result, to date, is the recognition that most industrialized countries will not come close to meeting the very limited targets for emission reduction articulated in the Convention, targets that are nowhere near the level required to stabilize atmospheric concentrations of greenhouse gases.

Concerns about the fruitfulness and utility of the concept of sustainable development have been aptly summarized by Gibson (1990) who suggests that the concept is vague, attractive to hypocrites and conducive to fostering illusions. A brief glance at these concerns helps to reveal the strengths and weaknesses of sustainable development literature and practice.

Before doing so, we should note, without taking a position on these issues, it is clear that their existence confirms the general point made earlier: SD is a not a scientific concept but a contested term in an essentially political discourse about human activities and behaviour. Driven by a set of ecological and social concerns which in turn are based in part on scientific research findings, the SD discourse is nevertheless more of an arena within which the practical implications of those concerns are debated, and various policies and decisions proposed and evaluated. It is perhaps not surprising that the weaknesses of the idea of SD are a function of these same characteristics. Because it is seen as a win-win strategy, the real social, political, and environmental trade-offs involved in achieving sustainability over the long term are often ignored. A large part of its political popularity stems precisely from this lack of facing up to hard decisions. And in turn, the ability to do so is enhanced by the lack of conceptual rigour about what SD actually means in any particular context, and what those trade-offs and hard decisions are likely to be.

Vagueness

The most prominent definition of sustainable development is that provided by the Brundtland Commission (1987: 8):

> Humanity has the ability to make development sustainable-to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs.

Some elaboration is provided on the next page:

> . . . sustainable development is not a fixed state of harmony, but rather a process of change in which the exploitation of resources, the direction of investments, the orientation of technological development, and institutional change are made consistent with future as well as present needs.

The clear focus in these and other formulations is upon the ability to continue to meet human needs in the future while reducing impacts on the environment. This is combined with a strong emphasis upon the need to increase material standards of living in large parts of the world. The stage is set for the term sustainable development to mean rather different things to different groups and interests. To industry spokespeople, sustainable development may mean recognizing that continued economic growth is essential to increases in environmental protection. To environmentalists, the message may be the need for a fundamental reformulation of the nature of economic activity, and the need for significant redistribution of wealth.

The very term sustainable development itself illustrates this problem. The meaning of the words 'sustainable' and 'development' are themselves controversial. Is 'development' synonymous with economic growth or does it imply something more (or less) than that? Over what time frame is such development to be sustained? Are some activities (*e.g.*, mining) inherently unsustainable because the resource is finite?

The result of this situation is that no specific or operational definition of sustainable development has been generally accepted. However, while this is a continuing source of frustration from the point of view of analysis and research, it is arguably a source of strength in the political arena. The very vagueness of the term sustainable development allows different interests, with quite different views about SD issues, to engage in political dialogue about SD policy. The emergence of SD 'round tables' and local agenda 21 organizations around the world illustrate this point, as does the presence of hundreds of heads of state at the Earth Summit in 1992. In other words, the vagueness of the concept of SD, while an analytical weakness, can be a political strength. While such constructive ambiguity does not of course mean that fruitful policy decisions will be made, it allows the formation of political discourse and coalitions that offer that possibility.

Hypocrisy

A major concern among environmentalists is that the frequent use of the sustainable development discourse by government and industry represents cosmetic environmentalism, a rhetorical cover for continued business as usual policies. Examples commonly cited are the labeling of commodities ranging from saltless soda crackers to ethanol-spiked gasoline as green products.

Of course, this issue is closely tied to the problem of vagueness mentioned above. Without clear definitions and criteria for SD policies and practices, it is difficult to prevent, or even recognize, unjustified claims. Moreover, legitimate debate exists about the relative environmental merits of alternative consumer products or production processes.

Once again, this problem illustrates the political and social nature of the concept of SD. And again this more political character has practical consequences. One result of the prevalence of SD policies and rhetoric in government and business circles has been the emergence, and rapid growth, of the fields of green labeling and certification, and sustainability indicators. This development has begun to allow claims about environmental impact to be tested and monitored.

The recent emergence of the ISO 14000 standard illustrates exactly this phenomenon. Widely seen as relatively weak in terms of specific content - since it requires the existence of an environmental management system but says nothing about its contents, the apparent popularity of this standard has the potential to have a significant impact on business practice around the world (Begley, 1996).

Delusions

Perhaps the most fundamental critique of the SD concept is that it fosters delusions, that it encourages the view that we can have our cake and eat it too from the point of view of ecological sustainability. There are two issues of concern here. First is the question of whether the very idea of SD is an oxymoron. In this connection, the argument by the Brundtland Commission that we need a five to ten-fold increase in global economic activity in order to address the problem of widespread poverty and material deprivation is often seen to be incompatible with the requirements for global ecological sustainability (Duchin and Lange, 1994). Second is the suggestion that the strongly anthropocentric focus of the concept of SD, centred as it is on human needs, is incompatible with a need to move to more ecocentric or biocentric approaches to environmental problems, with their associated emphasis upon a philosophical and spiritually-based rethinking of the relationship between humanity and nature, coupled with a fairly radical modification of human behaviours and activities (Sagoff, 1995). Common to both of these views is the belief that the concept of SD may be actively unhelpful in addressing environmental problems, distracting attention from the fundamental changes needed and fostering the illusion that cosmetic SD policies will be sufficient to avert environmental collapse.

This is not to say that the concept of SD is empty. Indeed, it can be argued that it represents a potential breakthrough in thinking about the linkage between environmental and social issues. It allows, even requires, a recognition of the globally interconnected nature of environment and development questions. In so doing, it points to the need to reconcile the interests of different regions of the world, and the need to explore ways of reducing global environmental impacts while simultaneously increasing human well-being. This has found expression primarily in the political arena as a policy and behavioural issue, not a scientific one, thus proving popular with government and business, as well as local groups such as the Local Agenda 21 movement in Europe. It is deeply rooted in the real political and decision-making processes that will be a principal means through which the ideals of sustainability is achieved.

The Institutional Context—Convergence and Divergence

So far we have presented the discourses of CC and SD as if they were completely unconnected. In fact, there have occurred various attempts to combine them in research and policy initiatives. A brief glance at how these have played out internationally and in Canada, an industrialized country that has played an active role in promoting action on both CC and SD, will illustrate the degree to which such attempts have been unsuccessful.

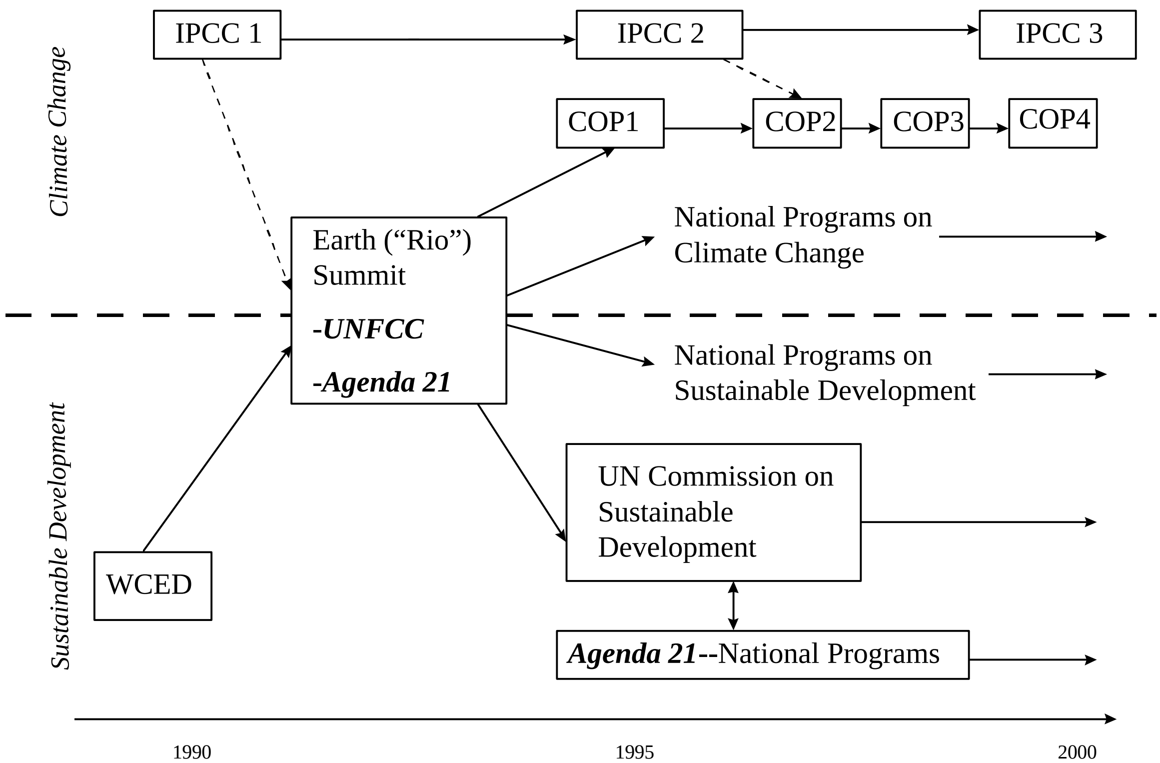
International institutions and initiatives

Figure 7.3 illustrates the separate paths that CC and SD programs have taken in the international arena during the last 10 years. While the IPCC and the WCED were quite separate activities, there was a brief period of coalescence around the Earth Summit in 1992, when both issues were discussed under the same framework of global environmental concerns. Indeed, at Rio, CC was seen as one of the key issues of SD, and discussion began on some of the key ethical and political issues surrounding it. After Rio, however, discussion of CC and SD resumed their separate paths. The CC path includes the IPCC reviews in various areas of scientific inquiry, including atmospheric science, impacts (agriculture, forestry, water resources, health, etc.), economics, and IAMs. There is no comparable research effort within the SD path. Nor is there any direct link between the IPCC and SD activities. However, in the SD arena, Rio was followed by a series of policy initiatives in various countries, including a rash of national SD strategies and a series of local Agenda 21 programs at the community level.

The policy component of CC that grew out of Rio has focused on the international arena, specifically the Framework Convention on Climate Change (UNFCCC) and the ensuing Conferences of the Parties (COP). This process has not, to date, succeeded in getting countries to slow their increases in global emissions of greenhouse gases. Although some developed countries have provided targets for emission reductions (usually reduction to 1990 levels by 2005), most will not achieve them (IEA, 1995).

During 1997, the Rio +5 conference provided a venue for simultaneous consideration of CC and SD issues. As of this date however, it does not appear that this will lead to a combined effort on CC and SD. Indeed plans are well underway for a Third Assessment Report of the IPCC that will once again not place CC into the broader discussion of SD.

Figure 7.3 International climate change and sustainable development programs, 1980s-present



Institutions within Canada

The Government of Canada has been one of the most active promoters of both the international Framework Convention on Climate Change and of the concept of sustainable development. Just as the SD and CC paths diverged at the international level after the Earth Summit, however, a similar divergence appears to have taken place in Canada after a brief period in the early 1990s when it seemed that they were being brought together.

When the CC issue became more visible as a policy concern in the late 1980s, Canada's strategy was to place substantial emphasis on climate research. This became a component of the Government of Canada's Green Plan, which was announced in 1990. The 'Global Warming Science' component, led by Environment Canada, was designed to provide better information on climate trends, processes and potential changes. The latter would be approached through continued investment in climate modelling (GCMs). A small portion was also earmarked for impact assessment.

The Green Plan itself was a much broader and more ambitious document, in which CC and SD were considered together (Canada, 1993). The Plan also had a major goal of attempting to develop a sense of environmental citizenship among Canadians by promoting new environmental values (*e.g.,* through support of environmental non-government organizations (ENGO) and the Eco-Logo program). Darier (1996) concluded that this was an example of 'environmental governmentality' in which a policy of research and education was established to 'teach' environmental values to Canadians.

Canada's actual experience with the Green Plan, however, suggests that CC and SD continue to remain separate discourses. Most of the natural science programs were directed at the CC issue, including major efforts on climate change detection, climate modelling, and research on climate-related processes. There was a vision of strong policy initiatives directed at CC, including emission agreements, energy efficiency and tree planting, all under the rubric of 'Global Environmental Security'. However, the National Action Program on Climate Change (NAPCC), a response to the UNFCCC, has centered on the Voluntary Challenge and Registry Program (VCR) to encourage industry to find greater efficiencies in the production and consumption of energy. There is also a national communications program for public education, programs to encourage the development of alternative fuels and 'green' industry, and to promote enhancement of carbon sinks in agriculture and forestry. There has been no explicit linkage made, however, to the sustainable renewable resources programs or Agenda 21 (Canada, 1995).

While the CC issue was defined as a 'natural science' problem, in which GHG emissions were leading to a warming which would harm Canadians, the SD debate was addressing a wide range of cultural and economic aspects of environmental problems. Several policy initiatives within the Green Plan addressed SD, including sustainable forestry initiatives, 12% set-aside of land as protected space, and waste clean-ups. There were no research programs on the underlying causes of unsustainability, though.

The separation of CC and SD discourses within Canada may be narrowing again, as evidenced by recent discussions related to Canada's 'National Circumstance'. The Delphi Group (1997) defines this as "the study of how the climate change convention will impact on the economic output and environmental conditions of countries". A 'National Circumstances Framework' has been proposed, which should include factors that relate to both CC itself and the climate change convention. However, in its proposed negotiating strategies, this report recommends that adaptation, a key aspect of SD, not be part of any climate change strategy. Trade is narrowly defined in terms of carbon content of fossil fuels and embodied energy exports (*e.g.,* energy associated with exports of processed minerals, electricity, etc.), and does not include renewables (*e.g.,* forest and agricultural products). Although regional CC impacts are acknowledged, including those non-market concerns that may lead to an underestimation of impacts on Canada, it still isn't clear how this will play in the negotiations at the international scale in the long term.

The debate within Canada leading up to the 1997 Kyoto Protocol focused on Canada's ability to meet greenhouse gas emission targets through technological change alone. Energy prices, lifestyle issues and adaptation were not part of this. Concerns over targets and commitments from developing countries led to conflicts with some fossil fuel interests who were worried about economic impacts of policy measures. As a result, federal and provincial/territorial government representatives worked out a compromise target of stabilization at 1990 levels by 2012, and this became Canada's opening position at COP3. The acceptance of a more stringent reduction of 6% was unanticipated. Perhaps there is still an expectation that low emission cars and other technological changes will be the main (or only?) options available. Sink enhancement (*e.g.,* reforestation) is also being considered.

Within the Kyoto agreement, a variety of financial and technological measures are being encouraged (*e.g.,* Clean Development Mechanism, Joint Implementation, emissions trading). These are measures with implications for economic development, and monitoring of performance will depend on our ability to assess how well engineering and biological innovations alter both energy consumption and GHG emission rates, and vulnerabilities to changing temperature and precipitation patterns. When the Green Plan was established in Canada, SD activities had been located in various programs (*e.g.,* sustainable forestry, agriculture, fisheries) with no explicit linkage to climate change. As Canada adjusts to the challenges of the post-Kyoto policy environment, it is important to note that this separation continues to be evident.

CONSEQUENCES OF THE SEPARATION OF CLIMATE CHANGE AND SUSTAINABLE DEVELOPMENT

There are a number of consequences of the separation of the CC and SD discourses. Here we want to focus on three issues: (i) the implications for scenario analysis; (ii) the separation of mitigation and adaptation in CC research and policy-making; and (iii) the relationship between science and policy.

Scenarios of the Future

Any attempt to discuss CC or SD requires consideration of possible future conditions, impacts, trade-offs, consequences and policy options. However, this has taken quite a different form in the two sets of literature.

In the SD field, reflecting its more political and qualitative focus, much of the literature is concerned with description of environmental problems, evaluation of existing or prospective policy approaches or instruments, theoretical or conceptual analysis of concepts like 'natural capital', examination of public attitudes of behaviour in specific settings, development of sustainability indicators, discussion of ethical and distributional issues, etc. There is also tradition of quantitative scenario analysis dating back to *The Limits to Growth* in the early 1970s (Meadows et al, 1972). The strong focus on energy issues in the 1970s and 1980s gave rise to a series of 'soft energy path' studies inspired by Lovins (1976). By the late 1980s, the focus began to shift to a more general analysis of 'sustainable futures' (*e.g.,* Svedin and Aniansson, 1987; Robinson, 1996).

More recently, the Global Scenarios Group (Gallopin *et al*, 1997) has analyzed several widely diverging scenarios, including two 'Barbarization' - 'Breakdown' and 'Fortress World') and two 'Great Transition' - 'Eco-communalism' and 'New Sustainability Paradigm' scenarios. The former incorporate increasing conflict, which could result in high short term population and economic growth (Fortress World) or short-term growth and long term decline (Breakdown). The latter project strong improvement in technology and environment, with high total economic and population growth short term, followed either by a leveling off (New Sustainability Paradigm) or a long term decline (Eco-communalism). In these scenarios, compared with more conventional development scenarios, regional shares of global markets for food and other goods change markedly, with a shift towards greater equity.

Two points need to be considered about these scenarios, though. First, these and previous attempts to analyze futures quite different than current trends imply have had little impact on SD policy-making (Baumgartner and Midttun, 1987). Second, and more directly relevant to this paper, the potentially dramatic regional changes in greenhouse gas emission trends, as well as in impact and adaptation costs of CC have not received much explicit attention (Langeweg and van Woerden, 1997; Tol, Fankhauser, and Smith, forthcoming).

In the CC field, the use of scenario analysis is much more central to the exercise since the whole modelling approach depends upon underlying scenarios of the key socio-economic 'drivers' of climate change. The IPCC has created six emissions scenarios (Alcamo *et al*, 1995), IS92a-f, including the well known IS92a, a business as usual case that postulates global annual growth of 1.68% for 1990-2020. The most optimistic scenario in terms of reducing emission rates is IS92c, with a low economic growth rate of 0.56%, while the most pessimistic, IS92e, presents a 2.39% growth rate. All six scenarios assume improved efficiency (*i.e.,* energy/unit GDP declines), but this does not offset the emissions effects of growth in population and GDP. IS92c reflects relatively slower population, GDP/capita, and GDP growth rates. The IPCC scenarios also incorporate land use emissions, based primarily on assumed rates of tropical deforestation and agriculture expansion.

However, despite the explicit mandate to include SD in its evaluation, the IPCC scenarios represent variants of conventional 'business as usual' views of the future. They do not consider alternative patterns of development, such as those contained in the SD analyses mentioned above. Moreover, by presenting scenarios in this fashion, the IPCC analysis, and indeed virtually the whole of the CC literature, presents a misleadingly narrow picture of the potential for quite different sets of future conditions.

Despite these limitations, the IPCC scenarios underlie virtually all of the analysis of the costs of greenhouse gas mitigation, impacts, and adaptation. In turn, these cost estimates form a large part of the political debate over mitigation and adaptation strategies and climate policy responses. This means that that debate is constrained by an artificially narrow, and therefore misleading, view of the options available, and of the importance of the socio-political and 'cultural' context within which decisions, including climate policy decision, will be made.

The resultant situation is ironic. The factors that make the IPCC CC scenarios politically palatable - a 'scientistic' view of human 'driving forces' and 'business as usual' futures - also makes them ultimately less politically useful. They, nevertheless, appear to be more politically influential than a wider range of SD scenarios that address the SD issues that the IPCC failed to incorporate in its analysis. Addressing such issues (*e.g.,* the existence of multiple baselines, or alternative social and technological development paths) would require incorporating more of a social science, even humanities-oriented perspective in the analysis.

To be fair, these concerns have not gone unnoticed, even within the IPCC. As noted by Working Group III report:

> The point is not that individual base case forecasts or scenarios are uncertain with regard to exogenous parameters such as economic or population growth rates. It is that there exists a range of quite different underlying socio-economic development paths that would give rise to different emission scenarios and costs of mitigation … it seems clear that we need to improve our ability to explore long-term development paths or configurations of technology that are very different than those typical of experience in past decades (Hourcade *et al*, 1996: 279, 289).

Although alternative development paths and trade globalization were not part of its emission scenario exercise, the IPCC has noted that new emission scenarios should be in the form of integrated scenarios of global change (Alcamo *et al*, 1995). They have concluded that the assumptions about population and economic growth, energy costs, and technological improvements made by the IS92 scenarios, which were used in both the First and Second Assessment Reports, result in a smaller range of emission estimates than the range of other published scenarios. It may be that the same could be said for impacts costs, regional vulnerabilities, and adaptation, but this is not yet known.[6]

The Separation of Mitigation from Impacts and Adaptation

An important characteristic of the CC literature is the strong separation between the analysis of mitigation and the analysis of impacts and adaptation. The emphasis, in both research funding and policy attention, has been upon the former category.[7] This distinction was enshrined in the first IPCC assessment report, was unsuccessfully bridged in the second assessment report, and will again apparently be reflected in the basic structure of the third report. It is also reproduced in many government policy-making structures, where climate change mitigation is addressed by different agencies than is impact assessment and adaptation. In Canada, for example, mitigation is primarily the province of Natural Resources Canada, which has responsibility for energy policy, while impact and adaptation issues are handled by Environment Canada.

Much of the reason for this distinction has to do with the way that the CC problem has been defined. As noted above, CC has traditionally been conceptualized in terms of a chain of causes and effects from socio-economic driving forces through to impacts, with a strong emphasis upon the science of atmospheric processes. This leads naturally to a conceptual separation of mitigation issues from those of impacts and adaptation. In turn this leads to an institutional separation, with important socio-political implications. Mitigation issues have mainly to do with energy policy and the energy industry. Impacts and adaptation concerns connect to a much broader spectrum of actors and interests (*e.g.,* Cohen, 1997a, 1997b). With by far the most attention being focused on

[6] Rob Swart (1997), coincidentally the only member of both the Global Scenario Group and the IPCC scenario group has informed us that the IPCC is currently working on producing a much broader range of scenarios to be explored in its Third Assessment Report.

[7] It should also be noted that, in the latter, impacts have been heavily emphasized over adaptation, although this is changing as the potential for adaptation to reduce impacts gains more recognition.

mitigation, the public policy debate over CC has turned almost entirely on energy policy and emission reduction issues, despite the fact that in terms of value of information, we stand to gain a much larger 'bang for the buck' by investing more in the impacts component of CC assessments (Nordhaus and Popp, 1997).[8]

Mitigation and adaptation policies will, of course, form part of a spectrum of measures adopted in response to any number of issues. Climate change policy cannot be treated in isolation. Many mitigation measures, such as certain energy efficiency programs, can reduce impacts and thus represent adaptive strategies in their own right. More importantly, many mitigation and adaptation measures will be adopted for reasons that have nothing to do with climate change per se. Arguably, the restructuring of the energy industry, driven by economic factors virtually unconnected to climate change will have much more significant implications for climate mitigation and adaptation than any single policy designed specifically to address these issues.

All this suggests that it may be more fruitful to think of mitigation and impact response as components of a larger process of adaptation that is continually going on in human societies, with or without climate change. Climate change itself can then be seen as a potentially critical factor in this larger process of adaptive response to changing conditions. This approach allows impacts, mitigation, and adaptation, as traditionally constructed, to be combined in a much richer consideration of social change.

Such an approach to adaptation also provides a means to connect the CC and SD discussions. By adding human purpose to this larger picture of adaptive behaviour (*i.e.*, by recognizing that human activity is always guided by some degree of conscious purpose) then it is possible to recognize the growing prominence of the goal of sustainable development or sustainability in public policy discourse. That is, increasingly, at least at the rhetorical level, SD is an important goal to which this adaptive behaviour is directed. From this point of view, CC is seen as an important, potentially crucial, problem (but also opportunity) that will affect the ability of human societies to achieve SD.

The Relationship Between Science and Policy

As suggested above, the approaches to policy, and the use of science in formulating policy, have also been influenced by the current separation of the CC and SD discourses. This goes beyond the institutional separation of responsibilities outlined above.

In whatever institutional context it has been addressed, CC has been constructed in narrowly scientific terms as a problem of atmospheric emissions largely divorced from their social context. This has provided a tight analytical focus to the study of CC, something that has eluded SD, where the intensely politicized debates have addressed fundamental issues but have been so heated as to make it difficult to reach closure about even such apparently straight-forward issues as a

[8] Others have gone so far as to argue against significant attention being paid to impact and adaptation issues. In an influential editorial, Glantz (1990) pointed out that many CC researchers expressed concern because the analysis of impacts issues might demonstrate that some jurisdictions might gain from climate change, thus weakening any potential political consensus in favour of mitigation actions.

definition of SD. By excluding any obviously social or political matters, the scientific reductionism of CC makes consensus possible, but the result is, in some sense, irrelevant. The things that can be known with scientific certainty are not necessarily the most important to know. So, for example the science of CC can agree about the physical sources of carbon emissions, but only by refusing to consider the far more important and deeply political question of why they are increasing and how (or if) they should curtailed. But even within the relatively narrow ambit of atmospheric science, reductionism can hinder understanding. There are a number of other atmospheric issues interacting with the carbon-driven CC issue (*e.g.*, ozone depletion, acid rain, etc.). This realization has led to some rethinking of how atmospheric science can contribute to the integration of air issues (Maarouf and Smith, 1997; Munn and Maarouf, 1997).

As long as CC is seen primarily through the lens of climate science, the contribution of science to policy will be funneled through climate models and research. Reducing uncertainties in climate science will not, however, reduce uncertainties in impacts and response strategies. These have complex physical, biological, economic and social components, far outside of the expertise of atmospheric sciences. The restructuring of IPCC Working Group III in 1992 from a response strategies focus to a broader assessment of 'cross-cutting issues' (including emissions scenarios, equity and social considerations, IA and decision making frameworks) was a step towards placing "the socio-economic perspectives in the context of sustainable development" (Bruce *et al*, 1996). This represented progress, but as we pointed out earlier the goals laid out in this area were not reached in practice in the Second Assessment Report. Moreover, initial plans indicate that the Third Assessment Report is going back to the old separation of impacts/adaptation and mitigation.

If good (atmospheric) science is not enough to encapsulate the relevant CC issues, could it be because CC is too narrow a framework to focus on? The policy debate in North America turns on balancing the economic benefits of continued greenhouse gas emissions against their potential costs, in terms of GDP impacts to the economy, and the potential risks of catastrophic global environmental change. But what about renewable resources, non-market effects, regional development, trade, aid, North-South equity, responsibility to future generations, etc.? The science-driven focus on emissions themselves has made it difficult to pose these questions. They are at the centre of SD, but without the analytical rigor of CC science it is difficult to focus attention upon them, or, indeed, even to define them unambiguously as problems that we might all agree to address.

These matters are complicated by the question of the role and status of scientific knowledge within the policy process. By remaining firmly within a 'scientistic' mode of discourse, which strongly separates science from values or policy issues, the CC field has attempted to profit from the high status accorded to natural and physical science understandings of the world.[9] However,

[9] The explicit attempt to separate science and value questions in the activities of the IPCC has not prevented it from becoming mired in controversy over the ethical values and equity issues embedded in its analysis of the 'value of a statistical life'. Ironically, the attempt by the relevant authors to defend their analysis on the grounds of value-neutrality may have made the problem worse (Pearce, 1996). This suggests that, even if it were desirable, the separation of science and value cannot easily be maintained in the analysis of impact and mitigation issues associated with climate change.

as suggested above, this has come at the cost of addressing the social, political, cultural, ethical, and other questions that are critical in order to address CC issues in a meaningful way, but are the province of the messier social sciences and humanities. Conversely, the SD literature is rife with extended treatment of such issues but the lack of clear consensus and the much more obviously political nature of the debate have greatly weakened its ability to provide authoritative policy advice.

The pre-Kyoto debate provides an important example of what can happen when science-driven policy issues reach the stage when decisions may be taken. In Canada and elsewhere, arguments about the costs of policy measures became quite heated, with dire predictions of substantial economic losses, accompanied by attacks on the science (especially atmospheric science) as a means of discrediting the foundation for taking such measures (*e.g.*, Jones, 1997). While uncertainties in science were characterized as a reason for delaying action, opponents of such actions were more than willing to assign high levels of certainty to projections of the consequences of (premature) action.

But how certain is certain enough? The answer to this question must necessarily be a value-laden judgment. This suggests the impossibility of making any absolute distinction between science and objectivity on the one hand and politics and values on the other. Since the interpretation of evidence, which determines the ‘factness’ of any scientific fact, must always involve some element of human judgment, the entire science-politics dualism is a false one (Demeritt, 1996). The discourse of CC has involved scientists and policy-makers in deeply political negotiations over the interpretation of data, as in the IPCC’s infamous ‘preponderance of evidence’ declaration, the meaning of scientific uncertainty, and the allocation of responsibility for determining these matters(Shackley and Wynne, 1996, 1997). It could hardly be any other way. The difficulty is not so much that adjudicating these questions is political in trivial ways, but rather that we have pretended that somehow it might not be. This problematic science-politics dualism has served to disqualify the more human centered discussions in the field of SD from informing policy debates, despite their relevance to pressing policy issues, because their (self-evidently) value laden nature is not regarded as scientifically credible. Its effects on CC science have been no less destructive. While the illusion that science might provide an objective foundation for CC policy has won it great political authority, it has also invited the kind of bitter partisan attacks on CC science that characterize the present debate in the US and Canada, where individual scientists, such as Ben Santer, lead author of chapter 8 of the IPCC’s Working Group I Second Assessment Report on the *Science of Climate Change*, have been subjected to personal attack (Feder, 1996).

Rayner and Malone (1998) propose that CC issues be joined to issues of societal resilience, including economic development, institutional restructuring, and provision of multiple strategies for response. This would enable CC to be integrated into the routine decision making frameworks of governments. How can research help to make this happen? Given the complexity of the global problems at hand, there is no question of doing with the expertise of natural science. The challenge is to make this knowledge more politically relevant to human problems, like SD, while still remaining credible, like CC. Rather than trying to isolate science still farther from the political process, we suggest that the way forward lies in involving more meaningfully the uses of scientific knowledge as well as those affected by scientific informed policy decisions into the practice of science: hypothesis formulation, data gathering, analysis, and interpretation.

RESEARCH NEEDS: NEW CONCEPTUAL FRAMEWORKS

Given the concerns noted above, how might we go about bringing together the current chiefly disjoint discourses surrounding CC and SD? Will it be possible to bridge the gap between the more global, 'objective', and science driven approach to climate change with the more local, normative, and problem-driven approach to sustainable development? And can we assure that this is done in a manner that emphasizes the strengths of each rather than exacerbating their deficiencies.

For the discourses on CC and SD to become more closely integrated, it is necessary to appreciate how the CC and SD research efforts have contributed to their separation. In defining CC and other global environmental stresses as natural science problems, this strong focus on natural science has hindered the development of new tools and approaches to assessing the economic and social components of these issues. The social science research community has not been engaged to the same extent as its physical and biological scientist cousins. This has been recognized at the international level, and the attempted revitalization of the Human Dimensions of Global Environmental Change Programme (HDP) is a positive sign. CC and SD have been explicit components of IHDP, and this platform should be further explored.

If we are to integrate research on CC and SD, the place to begin may be in the way the way the future scenarios that underlie both CC and SD analysis are generated and used. It seems clear that it would be desirable to broader the CC scenario analyses to include a much richer picture of the socio-economic, political, historical and cultural dimensions of human behaviour and choices. What we are eventually after are integrated pictures or visions of the future that include a wider spectrum of possible future conditions, including conditions that represent quite different development paths than are traditionally considered most likely. It is not surprising that both Schneider (1989) and Oppenheimer and Boyle (1990) both begin their texts on CC by weaving a story of what the world might look like in the middle of the next century under a scenario of a changed climate. These provided a context in which they could proceed to discuss many of the more technical aspects of the CC issue.

To accomplish this goal, we find ourselves initially looking at the growing field of IA. This field has made advances in the development of an interdisciplinary science and in trying to provide policy relevance to scientific research. However, in actual practice, the field has taken a fairly narrow approach, emphasizing in most cases the development of large, quantitative IAMs (Parson, 1995; Risbey *et al*, 1996). Only one of these, the (Netherlands) RIVM's Tool to Assess Global Environmental and Health Targets (TARGETS) model has consciously broadened its focus beyond the issue of climate change (Rotmans and de Vries, 1997). Also, there has been some movement towards bringing these models into a broader form of analysis. One example is the Urban Lifestyles, Sustainability, and Integrated Environmental Assessment (ULYSSES) project in Western Europe and North America, which is using IAMs together with focus group and policy exercises (Jaeger *et al*, 1995). Another is the application of an IAM in a series of workshops on climate negotiations in the Netherlands (Van Daalen and Grunfeld, 1996). However, these efforts are in the early stages and the outcomes of this approach remain to be seen.

Elsewhere, we have presented a framework that addresses both the integrative nature of IAs and their policy usefulness, including a self-awareness of their role and capabilities (Rothman and Robinson, 1997). We propose an ‘ideal’ form of IA that goes beyond what is typically seen in existing analyses. This includes moving from linear to more complex chains of analysis, from non-adaptive to perfectly-adaptive to realistically-adaptive agents, from simplistic to sophisticated to pluralistic consideration of alternative underlying development paths, from strictly quantitative to quantitative and qualitative analyses, from science-driven to policy-driven, and from analyses that dictate to users to those that involve those users in the actual assessment process. By doing so, we argue for both a richer form and a richer process of IA.

A few points need to be emphasized in implementing a study following the kind of framework we propose:

- It is easier and perhaps necessary to do in the context of places: many of the key relationships and potential conflicts that must be understood to get a good sense of the implications of changing climate and other important environmental, social, and economic changes will be played out in particular geographic areas
- It requires local knowledge/understanding/visions: this follows from the previous point. There will be many particulars that can only be understood with a detailed understanding of the region being considered. Much of this knowledge will fall outside of traditional ‘scientific’ understanding and within the areas of ‘folk wisdom’, ‘traditional environmental knowledge’, etc.
- While the preceding two points suggest a regional scale of analysis, such research must be placed in a global context: no geographic region is truly isolated and many of the forces/changes will be occurring in many places. Thus, what is occurring ‘extra-territorially’ will also have a large influence.
- It must also include broader social issues, without neglecting important environmental aspects, *e.g.,* climate change and energy issues: this is important for a sense of completeness and consistency that is necessary for exercises of the type proposed. Trying to understand the impacts of climate change without considering what else might be happening will provide a very incomplete picture that may have no relationship to reality. At the same time, neglecting important environmental aspects/feedbacks leads to a highly inconsistent picture of the future.
- It cannot be done solely with models, particularly a single, integrated model: the issues and relationships are simply too complex. Also, models tend to have two principle biases: 1) an ‘exclusionary’ bias, whereby information and insights are excluded, not because they are not important, but rather because they are difficult or impossible to include in formal, quantitative models, and 2) a bias of ‘misplaced concreteness’ in which the seeming objective, scientific nature of models lends excessive legitimacy to their results. These reiterate the concerns

expressed earlier in this chapter on the imbalances between previous work on mitigation versus impacts and adaptation.

Beyond the work of Schneider (1989), Oppenheimer and Boyle (1990), and the Global Scenarios Group (Gallopin *et al*, 1997), there are other examples that we can consider in developing this new framework for analysis. Robinson, *et al* (1996) did use a large input-output model of the Canadian economy to assist in the construction of a scenario of a sustainable Canada in the year 2030, but this was done in conjunction with a great amount of other quantitative and qualitative analysis. As part of the 2050 Project-Transitions to Sustainability, Nagpal and Foltz (1995) collected a series of essays and interviews, written by persons primarily in developing countries, on their hopes and dreams for their region and their children in the middle of the next century. Yergin and Gustafson (1993) have explored possible mid-term futures for Russia and the other former Soviet countries. This work is interesting in that it started out as a traditional energy study, but they soon realized that it was not possible to say anything about the future of energy in this region without addressing the broader social context. In the late 1980s, an exercise in creative scenario analysis (Svedin and Aniansson, 1987) resulted in the development of a set of 'surprising futures'. Finally, the scenario group within Royal Dutch/Shell and its spin-off - The Global Business Network - have explored various scenarios related to sustainability (Tibbs, 1996).[10]

We do not wish to argue that IAMs are an inappropriate way to explore many of the issues related to CC and SD. However, if they are going to continue to contribute to these dialogues, and help to bring them together, it is necessary that they evolve to become less truth machines and more heuristic tools that engage users. Two current modelling efforts provide examples of this new approach. The first, mentioned above, is TARGETS being developed at the RIVM in the Netherlands. The second is QUEST, or Quite Useful Ecosystem Scenario Tool, being developed at the Sustainable Development Research Institute at the University of British Columbia (Rothman *et al*, 1996). Rather than attempting to forecast or predict, these tools are designed to help users to explore different possible futures. They both emphasize the uncertainties in our understanding of the behavior of the underlying complex dynamic systems that they represent. Furthermore, they are both designed to be used interactively by laypersons, with minimal assistance from 'experts'.

Currently, these tools are being used in exercises examining the possibilities of bringing together researchers and stakeholders. Existing projects include ULYSSES, the Climate, Energy, and Alpine Regions (CLEAR) project in Switzerland, and Integrated Visions for a Sustainable Europe (VISIONS) (Pahl-Wostl, 1997; VISIONS, 1997).

It is important to recognize, though, that using models, even in broader contexts, is not the only possible, or even the best way to address long-term social, economic, and environmental issues. The Mackenzie Basin Impact Study (MBIS) and the Great Lakes-St. Lawrence Basin (GLSLB) studies represent two Canadian integrated assessment studies of CC impacts that did not rely exclusively on IAMs, and in neither case was a large-scale model the focus of the integration effort. Integration was done instead by attempting to link individual researchers to each other

[10] Members of the scenario group within Royal Dutch/Shell have also been involved in the development of the IPCC scenarios for its Third Assessment Report discussed in Section 3.2 (Swart, 1997).

(using small models and other methods), as well as by trying to build links between researchers and various stakeholders (Cohen, 1997b; Mortsch and Mills, 1996). This can include methods of 'storytelling' or more narrative approaches to performing integration in the context of CC and SD.

Thus, while we share many of the goals of Integrated Assessment Modellers, we argue for greater methodological pluralism when it comes to the tools used to address issues such as climate change and sustainable development. It is unfortunate that, particularly within the climate change discourse, there exists a strong tendency to treat IAs and IAMs as if they were equivalent (Frederick, 1994; Mendelsohn and Rosenberg, 1994; Toth, 1995; Dowlatabadi, 1995). Even where acknowledgment is made of the distinction between IAMs and IAs, the discussion often devolves into a discussion of IAMs (*e.g.*, Weyent *et al*, 1995; Tol, forthcoming; Parson, 1995 Rotmans *et al*, 1995: 6).

CONCLUSION

Climate change and sustainable development have been pursued as largely separate discourses. This has led to difficulties in establishing strong working linkages between the research and policy communities. This is true at both the international level and within individual nations.

CC has been characterized by considerable research efforts, particularly in the natural sciences, while the SD research effort has been relatively weak. On the other hand, policy actions directed at SD have attracted widespread support around the world (although SD may mean different things to different stakeholders), while the main CC policy instruments, the UNFCCC and the Kyoto Protocol, continue to be resisted by many countries.

The resolution of this problem will not come by excluding values from the analysis of CC and SD in order to increase its rigour, and thus its policy impact. This would simply be to mask the value issues at the heart of the CC and SD debates. Conversely, the solution does not lie in the continuous deconstruction of all CC and SD research and policy, and the associated assertion that they can all be reduced to debates over fundamental value questions. This is a recipe for inaction.

Part of the answer may lie in recognizing that it is inappropriate to apply natural science standards of analysis, verification, and proof to questions that are properly the province of the social sciences and humanities, and vice versa. That is, there is no point in expecting the analysis of the ethics, or even the costs, of climate change mitigation to be susceptible to the same standards of analysis and evaluation that apply to measurements of mean global temperature. Both qualitative and quantitative, 'representational' and 'discursive'[11] approaches to understanding CC and SD are required, and it serves no useful purpose to try and conflate them.[12]

The disjunction between these two important and intricately related issues need not and should not be the case. Hopefully the ideas expressed in this article will aid in bringing the currently

[11] We owe this formulation of this distinction to a conversation with Ted Parsons.
[12] For a longer treatment of this issue, see Robinson and Timmerman (1993).

separate discourses closer together. Three main points with which we would like to leave the reader are as follows:

a) Science is political in non-trivial ways. Climate change is a hybrid between interdisciplinary science and science-policy bridge building. We need to be aware of the social and political implications of scientific constructions of climate change (*i.e.*, when problems are defined). Science is a social process, yet scientists often pretend that it is not.

b) Sustainable development has incorporated differences in values into debates about future directions, but it needs greater analytical and intellectual rigour (methods, indicators, etc.) to make this concept advance from theory to practice.

c) Integrated assessment, especially integrated assessment models, have been and will continue to be highly visible manifestations of our desire to find powerful analytical tools that will provide scientific advice on climate change and sustainable development to decision makers. However, integrated assessment cannot simply be about making models relevant to decision makers. Integrated assessment has to go beyond models to embrace the larger goal of facilitating consensus among a broad range of researchers and stakeholders.

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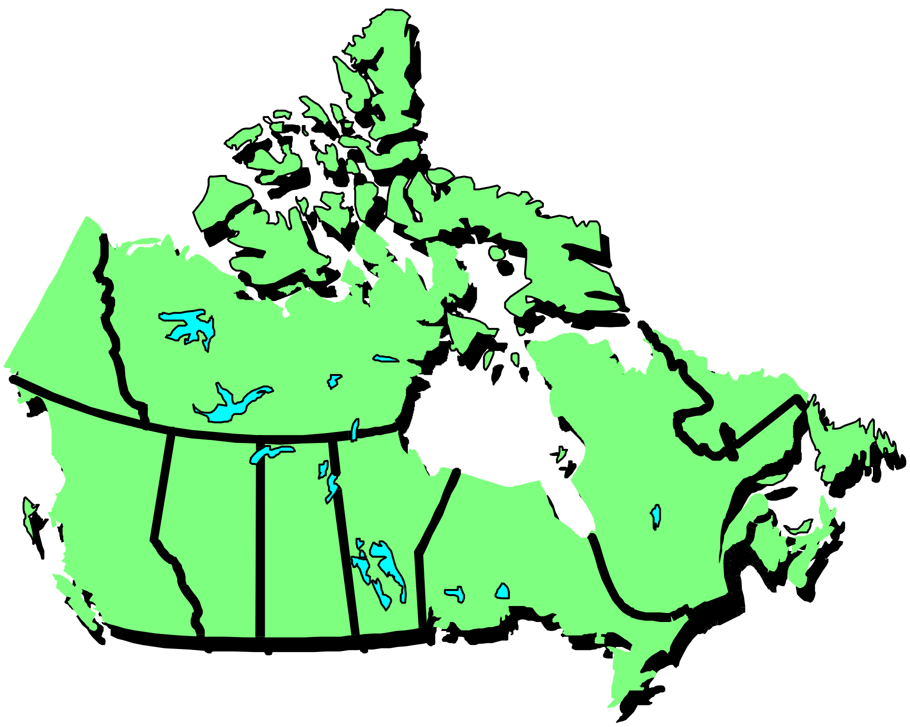
CHAPTER EIGHT

CLIMATE CHANGE, NORTHERN SUBSISTENCE AND LAND BASED ECONOMIES

Helen Fast[1] *and Fikret Berkes*[2]



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EXECUTIVE SUMMARY AND RECOMMENDATIONS

This discussion of climate change and northern subsistence societies starts from the premise that there is a distinct land-based subsistence and commercial economy in the Canadian North, that this economy has continued to be important, and that there are no short-term prospects of replacing the subsistence sector by the wage sector and industrial economy. Major issues and findings can be grouped into three categories: (1) *climate change may affect the distribution of animals and other resources on which the subsistence economy is based;* (2) *climate change may affect the use of traditional knowledge and local adaptations;* (3) *climate change may affect the health of northern populations through dietary dislocations and epidemiological changes.*

Research should be undertaken in three areas: (1) to link available biological/ecological information on the impacts climate change to local resource use and the northern economy; (2) to develop adaptive management strategies with emphasis on the resilience of social and ecological systems, and on flexibility to respond to uncertainty and largely unpredictable climate change; and (3) to study the issue of the health of northern populations relative to the potentially significant implications climate change has for the long-term availability of this country food. The analysis leads to the following recommendations:

1. More specifically targeted research is needed on impacts of climate change on resource availability.
2. More work should be encouraged to link available ecological information on resources to economic impacts.
3. Methodology needs to be developed to sort out the effects of climate change from the cumulative impacts of large-scale development, such as those of hydroelectric projects.
4. What are the limits to adaptability in northern subsistence economies?
5. A better understanding of non-linear, discontinuous (non-gradual), unexpected effects of climate change on northern regions is needed.
6. Develop adaptive management strategies which rely on feedback learning and on policies designed as experiments from which resource managers can learn.
7. Develop policies to implement ways in which flexibility is built into resource management systems and institutions.
8. Develop policies to implement ways in which rapid response can be initiated more effectively, as in the case of extreme events and emergencies.
9. Build flexibility into management systems and institutions by delegating more responsibility to the local level.
10. Recognize the importance of local sources of protein for the overall well-being of northern populations.
11. Recognize that the mixed economy of northern aboriginal communities is not a transition stage but an adaptive economic organization that enhances self-reliance. A full switch into a wage economy is, in any case, *not* an option.

12. Develop policies that encourage self-reliance while providing wage income opportunities for northern peoples.
13. More work is needed to draw together findings relating the consumption of country foods to various indices of health.
14. Little seems to be available on epidemiology of climate change for the north; this area needs more research.
15. Develop methodology to estimate the costs of increased dependence and the costs of facilitating potential adaptations.

ISSUE DEFINITION AND SCOPE

Northern indigenous peoples, already one of the more vulnerable segments of Canadian society, would be affected by ecosystem shifts that may be outside the limits of historical experience. If these shifts occur at a rapid pace, there may be difficulties in adapting. - *From the submission of the Canadian Global Change Program to Canadian energy and environment ministers.*

The focus of this paper is on the land-based economy of Canada's northern indigenous peoples. The subject cuts across regions, from Labrador across the Northern parts of Quebec, Ontario, Manitoba, Saskatchewan, Alberta, British Columbia, to the Northwest Territories and Yukon. It also cuts across resource types: wildlife, fisheries, forest resources and water. The area covered is vast, although indigenous populations in the Canadian North are small and no one lives entirely off the land. The issues discussed here may be applicable to some non-aboriginal populations elsewhere in Canada as well, especially to rural populations in the mid-north. However, there have been no studies to establish the degree of reliance of non-indigenous groups on a land-based economy.

In the case of indigenous communities, numerous studies have been carried out in all regions of the Canadian North since the 1970s on aboriginal land use, wildlife harvesting, and socio-economic change. These studies have been largely related to aboriginal land claims and to the environmental assessment of development projects. These studies have established that (1) the subsistence sector is worth about $15,000 per household per year in the Arctic and about half that in the Subarctic; (2) the subsistence economy often comprises one-quarter to one-half of the *total* local economy; (3) the subsistence economy is *not* disappearing and may even be becoming stronger; and (4) there are no short-term or medium-term prospects that the subsistence sector can be replaced by the wage sector and industrial economy—the jobs do not exist nor are they likely to be created (Berkes and Fast, 1996). As the Mackenzie Delta Beaufort Sea Regional Land Use Planning Commission (1988) concluded, "apart from the oil and gas potential, there are no easy opportunities for increased economic activity either through entrepreneurial activity or jobs". Tourism was identified as a potential source of jobs, but that also requires a local population which is active on and knowledgeable about the land.

Very little is known about the possible impacts climate change might have on the northern economy. On the one hand, environmental change is integral to the daily lives of northern peoples, and a capacity to adapt to change is part of their livelihood systems. On the other hand, extreme events and unusual fluctuations create safety hazards as well as adaptation problems, and little is known about their cultural, social and economic limits to adaptability. A case in point is the disappearance of Norse colonies in Greenland. Detailed archaeological work has revealed that cooler periods occurred from 1308-18, 1324-29, 1343-62, and 1380-84. The cold spell of 1343 corresponds with the abandonment of the Western settlement. A key factor seems to have been a reduced capacity among the Norse people to produce and store fodder for their farm animals. Historically they had been able to store enough fodder for one, and at most, two years. A cold spell that prevented fodder production for two years represented the limit of the resilience of the Norse farming economy and their livelihood system. Unable or unwilling to adapt to a marine mammal and fish diet like their Greenland Inuit neighbours, the Norse died off after eating the last of their starving animals (Pringle, 1997).

In a similar vein, the impact of climate change on Canada's contemporary northern peoples may be evaluated with special attention to limits of adaptability and resilience of northern economies. The literature emphasizes the importance of the adaptations of arctic and subarctic peoples to cope with fluctuations in resource availability. But the literature also points out that non-climate related changes have impacted these groups more than have climate changes in the last few decades (Langdon, 1995; Wenzel, 1995). In recent historical times, northern populations have been impacted by epidemics, acculturation and social and economic change, including for example the collapse of fur markets (Wenzel, 1995). By comparison, the impact of recent climate change on the welfare of northern peoples has been negligible. Based on studies in Aklavik and Fort Liard, Newton (1994) concludes that the sustainability of northern communities is impacted more by direct human-induced perturbations than slow changes to the natural environment; nevertheless, potential increases in the severity of extreme climatic events could influence losses. There is good evidence that northern peoples notice and respond more to *extreme events* than to changes in *mean conditions* (Aharonian, 1994), and that *unpredictable* changes are more important and potentially damaging than predictable extreme events (Berkes, 1988). The relevant body of theory that bears on these issues concerns the resilience of ecological and social systems and adaptive management (Holling,1986; Berkes and Folke, 1997).

The relationship between climate change and northern subsistence economies can be analyzed around three major issues, all related to adaptation, flexibility, resilience and unpredictable change:

1. Climate change may affect in unpredictable ways the distribution of animals and other resources on which the land-based economy depends;
2. Climate change may affect the use of traditional knowledge and local adaptations; and
3. Climate change may affect the health of northern populations through dietary dislocations and epidemiological changes.

HOW CLIMATE CHANGE MAY AFFECT NORTHERN SUBSISTENCE AND LAND-BASED ECONOMIES

The northern economy is comprised of three sectors: the wage sector, transfer payments, and subsistence harvesting. The largest source of cash in the north has for the past forty years been government expenditures. Other important sources of cash include the wild fur industry, tourism, and the sale of native handicrafts. Although there is a divergence of opinion concerning the accuracy of these figures, according to various studies since the 1970s, the northern subsistence or land-based sector is worth about $15,000 per household per year in the Arctic and about half that in the Subarctic (Table 8.1). A significant part of wage and transfer income goes into the production of country food for subsistence. This land-based economy is typically one-quarter to one-half of the *total* local economy (the rest being the wage and transfer sectors) (Table 8.2). The compilation of data from several dozen studies across the Hudson Bay Bioregion has produced a substantial body of evidence documenting the vigor with which subsistence activities continue to be practiced across Canada's Arctic and Subarctic regions. Despite the changing world in which subsistence societies live, and despite greater cash flows than in earlier times, there has not been a significant decline in subsistence activities in the Arctic and Subarctic.

Table 8.1 Imputed value of subsistence country meat

					Value per household per year	
Region	**Year**	**Potential edible weight (kg)**	**Imputed value ($)**	**No. Of households**	**Current $ (year of study)**	**Constant $ (1991)**
Keewatin	1981-2	829 440	7 879 680	665	11 849	17 892
	1982-3	793 003	7 533 529	685	10 998	15 727
	1984-5	895 298	8 505 331	705	12 064	15 925
Mushkegowuk	1990	686 713	7 846 155	1 116	7 031	7 453
Pinehouse	1983-4	84 455	451 307	98	4 605	6 290
Wemindiji	1975-6	67 636	372 000	117	3 180	8 459
	1976-7	79 272	436 000	121	3 603	8 863
Northern Manitoba	1983-4	355 529	1 462 931	1 238	1 167	1 594

Full references and explanatory notes may be found in Berkes and Fast, 1996.

Table 8.2 The land-based sector in the overall economy

	Total cash economy per year			Imputed value of Native traditional activities		
Region	**Year**	**Current $ (year of study)**	**Constant $ (1991)**	**Current $ |(year of study)**	**Constant $ (1991)**	**Cash economy to traditional economy**
Sanikiluaq	1984	2 155 000	2 952 350	2 946 515	4 036 726	1:1.37
Mushkegowuk	1990	25 370 880	26 893 133	8 372 400	8 874 744	1:0.33
Northern Manitoba	1985	178 827 600	236 052 430	22 367 500	29 525 100	1:0.13
Waswanipi	1968-70	251 315	774 050	209 665	645 768	1:0.83
	1982	1 814 451	2 739 821	684 667	1 033 847	1:0.38
Wemindji	1975-6	625,000	1 687 500	531 000	1 433 700	1:0.85
	1977-8	1 184 000	2 960 000	732 000	1 830 000	1:0.62
Pinehouse	1983-4	2 101 289	2 878 766	1 135 281	1 555 335	1:0.54

Full references and explanatory notes may be found in Berkes and Fast, 1996.

Climate change is likely to have dramatic impacts on these subsistence economies. Though some scientists are predicting cooling, most are anticipating a warming trend. Some are predicting a gradual period of transition, others a dramatic reversal. The study of ice cores supports the notion of dramatic climate change for the warmer; Beaulieu (1997) argues that natural and anthropogenic conditions are pushing the climate to the earth's limits of tolerance and will force it to 'flip' into very different conditions. Climate change, if it comes, is expected to have its greatest impact in arctic and sub-arctic latitudes (Roots, 1996). There is already evidence to suggest that change will not be uniform across the region. The western Arctic, for example, and particularly the Mackenzie Delta area, is expected to experience more seasonal variability and a more complex pattern of change than the eastern Arctic (Maxwell, 1987). Any of the projected scenarios, however, will directly and indirectly affect the health of the resources on which the subsistence economy is based, and the environment in which the harvesting occurs.

Climate Change May Affect the Distribution Of Animals And Other Resources On Which Northern Subsistence And Land-Based Economies Are Based.

Projected Effects of a Warmer Climate on the Subsistence Land Base

The climate warming scenario projected by computer models as well as by analysis of historical climate patterns suggests a warming in the Arctic of 8°C to 10°C in winter and 1°C to 2°C in summer. These predictions anticipate increased storm activity, moisture and windiness, with an average increase in precipitation of 20 to 30 percent. The number of days lakes will be ice-covered is expected to decline by 30 to 35 days according to one estimate (Maxwell, 1987) and by as much as 120 days in the fall and another 15 days in spring (DOE, 1991). Snow-cover days are projected to be reduced by 30, with a concomitant possible increase in spring run-off and flooding. Summers may become ice-free, and winter ice may become thinner (Maxwell, 1987).

Most primary productivity in the Arctic Ocean is the work of microscopic algae which use the bottom surface of the ice as initial habitat and later extend to the water surface. These algae are most active at the ice edge during the short time period during which the ice melts. Since the ice edge moves north as it melts, the season of highest growth in any area is limited to a few weeks, and in total covers an area of 5 to 10° latitude. This same small area attracts the larger animals who rely on these sources for food (PAME, no date). Plankton are either plants (phytoplankton) or animals (zooplankton). The latter includes a group called icthyoplankton—the drifting eggs and larvae of many fish species. Increases in ambient UVB could stress these species and cause their disappearance or adaptation to a different, potentially less nutritional, form (Diffey, 1991).

Under conditions of climate warming, multi-year ice and large areas of permafrost are expected to disappear. As the treeline moves northward by about 200 to 300 kilometres in response to warmer temperatures, and the tundra moves back to cover only the archipelago, the variety and volume of vegetation will increase in the region (Harris, 1987; Bregha, 1987). Such a movement of the tree-line will in turn have implications for the amount of snow cover. Increased snow-fall would result in later snow-melt which in turn would delay the flowering of vegetation which already has a very short period of productivity (Scott and Rouse, 1995).

Another effect of heavier snowfalls would be wetter and cooler springs and a shortening of the annual frost-free period. “Any change that promotes higher winter snowfall will have a pronounced effect on vegetation communities even if summer precipitation and temperature remain unchanged” (Scott and Rouse, 1995). Thawing of the permafrost would also result in ‘thaw lakes’ and subsidence on the land, disrupting natural drainage patterns, damaging forests and making travel much more difficult (Harris, 1987). In sum, such degradation of the permafrost will have serious ramifications for existing ecosystems and wildlife habitat (Canadian Climate Program Board, 1991), and so for the wildlife on which subsistence harvesting depends.

Forests, Wildlife and Waterfowl

One-third of Canada’s land area is boreal forest (Jackson, 1992). Some researchers predict the northward shift of the treeline at a rate of 100 to 250 km per decade (DOE 1991), or 25 times faster than under normal conditions. Pruitt (1993) and Jackson (1992), however, anticipate the loss of large areas of forest, particularly in the southwestern half of the taiga—“the northern (or boreal) coniferous forest”—first to insect invasions of budworms, sawflies and bark beetles, and then to massive forest fires. The northward movement of the forest, he suggests, will not occur until soil conditions become compatible with forest growth (Pruitt, 1993). Some researchers predict fewer forest fires overall, under conditions of climate warming, while recognizing there might also be periods of drought in the southeastern boreal forest which could lead to an increase in forest fires (Bergeron and Flannigan, 1995; Jackson, 1992).

Terrestrial, aquatic and marine animals in the Arctic and subarctic live in a marginally supportive physical environment at the best of times, and small changes in conditions can have major impacts on their health and survival. Roots (1996) concludes that the conditions of rapid warming suggested by climate models will lead to significant decreases in the productivity of both northern forests and to a reduction in the number of large animals in the forest and on the tundra: “During episodes of temperature change or other climate change, it is the animals and plants with short life cycles that can adapt most readily to take advantage of changed conditions. Thus, viruses, soil bacteria, parasites, insects and annual plants will respond more rapidly than long-lived plants such as lichens or sedge grasses, or long-lived animals like whitefish, caribou, wolves or geese”. The literature provides historical evidence that some animal population fluctuations can be correlated to temperature shifts. As the climate in Canada warmed during the 1920s to the 1940s, for example, lynx populations almost became extinct, partly because temperatures above –25°C create softer snow crusts and make travel impossible for lynx. As temperatures cooled over the next thirty years these populations recovered dramatically (Scott and Craine, 1993).

Winter caribou ranges will be reduced as palsas in the Hudson Bay Lowlands collapse over thawing permafrost. Both barren-ground caribou and woodland caribou will experience reduced habitat, due to fires and thicker, harder snow conditions. The movements of land animals—including caribou, moose, arctic fox and wolves—will be constrained by longer periods of open water over more extensive areas. Polar bear, ringed and bearded seal populations will likely decline as the extent of sea ice needed for habitat declines in extent. White-tailed deer, on the other hand, will be expected to increase their range northward, leading to an increase in wolf and coyote populations. Mink, otter, and likely beaver populations will decline, writes Pruitt (1993), in response to drier conditions which reduce their habitat and fragment ranges. Snowshoe hare and white-tailed jackrabbit and ground squirrel populations will increase, though tree squirrels will decline in number as forests are reduced. Thawing permafrost will impose major alterations on prime waterfowl and shorebird breeding and molting grounds along the coasts, resulting in sea level rises and saltwater intrusion (DOE, 1991). Maarouf and Boyd (1997) consider the northward shift of the treeline, and the destabilization of permafrost and vegetation in geese feeding areas to be detrimental to goose populations.

Long-term ecological studies at La Persouse Bay, Northern Manitoba, provide a striking example of how climate change can produce unpredictable effects through the loss of ecological resilience. Cold episodes and bad weather in spring has resulted in migrating lesser snow geese to remain longer in the Bay. Since the Bay already has a resident breeding population of lesser snow geese, the increased grubbing pressure on the roots and rhizomes of saltwater marsh graminoids results in the destruction of saltmarsh swards before the onset of above-ground growth. With the loss of the insulating mat of vegetation, the sediment surface becomes hypersaline as a result of increased evaporation, further reducing plant growth. This positive feedback relationship eventually exceeds the ability of the system to absorb perturbation and still maintain its ecological integrity, i.e., its resilience (Holling, 1986). The marsh, having lost its ecological resilience, becomes a desert, flipping into a different equilibrium, one that no longer supports geese (Srivastava and Jeffries, 1996).

Fish and Marine Mammals

Fish and marine mammals comprise an important component of the subsistence economy, accounting for as much as 20% of the subsistence harvest of the West Main Cree in Northern Ontario (Fast, 1996 after Berkes *et al.*, 1994). Climate change is expected to affect fish populations through changes in water temperature and circulation patterns (Jackson, 1992). The rate of metabolism of the fish and demand for food will increase with warmer temperatures. Under conditions of warmer temperatures spawning and hatching will occur earlier, while the incidence of bacterial disease is expected to increase. Other influencing factors include food availability and competition for these resources (Lin and Regier, 1995). Though the effects of climate change on fish populations in Northern Canada have not been the subject of much study (Reist, 1994; Jackson, 1992), it is known that their capacity to adapt to changed environments is very much species specific. Under conditions of rapid change fish will either move northwards, disappear from present ranges, or become genetically altered (Lehtonen, 1996). Reist (1994) has also noted that the effects of various events taken together can be cumulative, with the actual impact on fish being greater than the events taken singly would suggest. Some examples of such ‘various events’ include climate change, resource exploitation, contamination and changes in local habitat.

Coldwater fish species generally, and arctic char populations in particular, are expected to suffer a decline caused by decreases in the extent of summer habitat and reductions in oxygen concentrations. Their optimum temperature range for growth is 5 to 16°C, with lethal temperatures occurring between 22 and 27°C (Lehtonen, 1996). Arctic cisco, on the other hand, “one of the most abundant of the anadromous fishes and an important component of commercial and native subsistence fisheries” in the Beaufort Sea, seem to have a preference for warmer temperatures in test conditions, and can also tolerate high salinities typical of marine environments (Fechhelm *et al*., 1993).

In sub-arctic regions it is anticipated that significant changes in fish species will occur in waters presently populated with lake whitefish, walleye, northern pike and lake trout. The introduction of new species will have mixed effects ranging from negative to benign to positive. It has been suggested, however, that “the future prospect of extensive regional modifications of freshwater species distributions as a result of climate change should be greeted with alarm” (Minns and Moore, 1995; DOE, 1991). Implications for the future of subsistence and commercial arctic and sub-arctic fisheries are potential serious.

Under conditions of warming, marine mammals such as beluga, bowhead whales, harbour and harp seals and walrus are expected to increase in numbers, and to occupy a larger range as pack ice retreats (DOE, 1991). These increases in number may have positive effects on the Arctic subsistence economy and life-style,

Economic Impacts

Melting glaciers coupled with thermal expansion of the oceans are expected to raise mean sea levels 0.5 m or more, particularly in the Beaufort Sea region (Canadian Climate Program Board, 1991; DOE, 1991). Such changes in sea level are expected to have devastating effects on the Arctic’s coastal settlements, and costly measures will be needed to protect them from flood damage, if indeed they can even be protected.

An increase in activity in the permafrost would have mixed implications for the both the cash and the subsistence economies. Though onshore oil and gas development would become more expensive with softening permafrost, offshore hydrocarbon developments would benefit from more moderate conditions, and marine transportation would become viable for an additional six to eight weeks annually. A reduction in permafrost would also facilitate less costly mining operations (Maxwell, 1987), and the development of presently known reserves of oil, natural gas, lead, zinc and iron ore might become economically viable (Bregha, 1987). Benefits could be expected to accrue to the tourism, recreation and marine transport sectors (DOE, 1991). In the Western Arctic, which is drier and rockier than the eastern Arctic, however, rapid increases in the active layer of permafrost would exceed existing structural tolerances for movement (Harris, 1987). Similarly, winter and all-weather roads would become unstable and so would be available for shorter periods each year. Accessibility to fish and wildlife habitats would be affected, thereby altering subsistence and commercial harvesting patterns (DOE, 1991).

Influences of a Colder Climate

Ice cores can provide evidence of climate for the past 100 000 years, and some studies of arctic ice cores have suggested that climate trends are not toward warming, but rather a ‘return’ to the ice age (Koerner, 1987). The majority view is for a warming trend, within which some areas such as the Labrador coast, may be getting cooler (Cohen *et al*., 1994). The view that cooling is more likely than warming is espoused by Ball, a historical climatologist, who argues that cooling will be "much more devastating" for all Canadians, including northern populations, than would warming (pers. com., 1997). Historical records provide an indication of what the effects of cooling might be on vegetation and wildlife.

During the last major cooling of the Arctic around 1500 BC to 1700 AD the tree-line retreated as a consequence of massive fires in the dying forests (McGhee, 1987). Even monthly mean temperature changes of as little as 1°C during the warmest or coldest months of the year have been shown to alter the extent and type of vegetation found in these regions (Ball, 1986). It is conjectured that during that period of cooling the caribou for example, were forced to alter their migration routes in search of vegetation (McGhee, 1987). As temperatures dropped hunters had increasing difficulty securing food, as the caribou had moved inland, and whales could no longer summer in the estuaries where they had previously been hunted. The Inuit are thought to have adapted by hunting the growing number of ringed seal which became more plentiful as the sea ice extended (McGhee, 1987). The Inuit also began spending summers inland, relying on fish and hunting the caribou they found there. In this way they adapted to the suddenly altered and regionally variable conditions which occurred during the Little Ice Age (McGhee, 1987).

If the climate were to become cooler the current area of permafrost would be extended southward and some ground heaving could be expected. Overall the impacts on infrastructure should not be extensive, while the effects on winter roads would be such that they could be used for longer periods each year. Finding water supplies, however, could become more problematic, and might require the modification of systems used to transport water in order to keep them from freezing (Harris, 1987).

Communities around the Hudson Bay have experienced some cooling effects over the past several decades, thought to be caused by the melting of Greenland's ice cap and the cooling trend off Labrador. The changes which have been observed, however, are instructive in considering what the impacts of a cooling climate might be on the subsistence environment: shorter springs; less eel grass which is used by migrating geese as food; cooler temperatures; rapid and early passage of fall seasons; increased snowfall (resulting in fewer geese stopping over to feed along the coastal areas during their fall migration); a shift in wind direction from the north in spring and preventing the geese from landing in large flocks; a haze that seems to be blocking the sun's warmth; spring tides failing to prevent polynyas freezing over (Arragutainaq *et al.*,1995).

Climate Change May Affect the Use of Traditional Knowledge and Local Adaptations

Traditional ecological knowledge (TEK) represents experience acquired over thousands of years of direct contact with the environment. Berkes (1993) proposed a working definition of TEK as "a cumulative body of knowledge and beliefs handed down through generations by cultural transmission, about the relationship of living beings (including humans) with one another and with their environment". The term is, by necessity, ambiguous since the word 'traditional' itself is ambiguous. It usually refers to cultural continuity transmitted as conventions of behaviour and practice derived from historical experience. However, societies change through time, constantly adopting new practices and technologies, making it difficult to define just what is 'traditional'.

Because of this, some scholars avoid the term ‘traditional’ and prefer ‘indigenous knowledge’, which helps avoid the debate about tradition, and explicitly puts the emphasis on indigenous people.

‘Ecological knowledge’ poses definitional problems of its own. If ecology is defined narrowly as a branch of biology in the domain of Western science, then strictly speaking, there can be no TEK; most traditional peoples are not scientists. The alternative is to define ecological knowledge broadly to refer to the knowledge, however acquired, of relationships of living beings with one another and with their environment. In this regard, ‘ecological knowledge’, is not the term of choice for many indigenous peoples themselves. Many native peoples of the Canadian North refer to their ‘knowledge of the land’, rather than to ecological knowledge. In this sense, however, ‘land’ is more than the physical landscape; it includes the living environment. In recent years, many kinds of indigenous environmental knowledge and their uses, including the use of TEK for climate change research, have been acknowledged, but the relationship of TEK to science remains controversial (Berkes and Henley, 1997).

Hunter/fisher/trappers depend on detailed local knowledge of animal distributions and behaviour, snowfall patterns, and timing of freezeup and breakup. One of the earliest studies of climate change and traditional knowledge was carried out by Spink (1969) who showed the value of local Inuit knowledge in corroborating evidence for isostatic rebound. Cruikshank (1984) noted that traditional knowledge could be applied to historical research on climate, geophysical research and paleontology. Much of the Lutsel K’e Dene environmental knowledge is concerned with snow and ice, and hunters pay particular attention to quantity, quality and occurrence of snow cover and snow melt patterns, and freeze-up and break-up patterns and timing (Bielawski, 1994). A linguistic study by Basso (1972) revealed 13 categories of freshwater ice, based 20 compositional features, among the Dene of Fort Norman. Such knowledge is not static; it is often updated and modified. But nevertheless, climate change can play havoc with the use of such knowledge by making locational knowledge unreliable. A case in point is the change of ice break-up and freeze-up patterns in the estuary of the La Grande River (in this case due to hydro development), and the hardship this caused for the Chisasibi Cree trying to travel between the village and their hunting grounds (Berkes, 1988). Particularly distressing for the hunters was the fact that ice colour could no longer be used reliably as a cue to gauge ice thickness (but tapping the ice still provided a reasonably accurate indication).

The real experts of sea ice are the Inuit. This is perhaps not surprising considering that many Inuit traditionally lived and hunted on the sea ice. A compilation by Riewe (1991) shows that at least one-third of the total community hunting area is marine (i.e., open-water in the short summer but ice most of the year) in about half the Inuit communities in the NWT. Inuit knowledge of snow and ice is legendary (although sometimes exaggerated), and snow terminology of aboriginal peoples have been adopted by some northern ecologists because of the precision of this terminology, as illustrated in Table 8.3 summarized from Pruitt (1984).

Findings from two major traditional knowledge studies, in the Hudson Bay area and in the Northern Basins Study (N. Alberta/NWT) indicate local evidence for climate change, confounded by cumulative impacts of development. In the case of the former, a number of changes were noted

Table 8.3 Some specialized snow terminology

Term	Source	English equivalent
anmana	Inuit	space formed between drift and obstruction causing it
api	Inuit	snow on ground, forest
ciegar	Sami	'feeding trench' through undisturbed api
cuok'ki	Sami	layer of solid ice next to the soil
fies'ki	Sami	'yard crater' of thin, hard and dense snow caused by reindeer digging
kaioglaq	Inuit	large hard sculpturings resulting from erosion of kalutoganiq
kalutoganiq	Inuit	arrowhead-shaped drift on top of upsik; moves downwind
pukak	Inuit	fragile, columnar base layer of api
qali	Inuit	snow on trees
qamaniq	Inuit	bowl-shaped depression in api under coniferous tree
sandjas	Sami	fragile, columnar basal layer of api (=pukak)
suov'dnji	Sami	'feeding crater' excavated in the api
upsik	Inuit	wind-hardened tundra snow cover

Adapted and condensed from Pruitt 1984. The Inuit terms are from the Kovakmuit. Sami - Lappish from Northern Scandinavia.

(Bill *et al*., 1996). The local people noted that there were more fires, especially forest fires, and they were more intensive today. Hunters thought that the fires were related to loss of caribou habitat. Land was becoming drier and flow patterns of rivers had changed. Reduced water levels in the Peace-Athabasca Delta, hunters thought, was related to reductions of the populations of waterfowl, muskrat and many species of fish. These last two changes may have been partly related to hydroelectric development (W.C. Bennett dam in BC). More difficult to interpret was the reduction in song-birds (problems with overwintering habitat?). Reduction in the 'prairie' or sedge meadow habitat was related to a decrease of bison numbers. Increase in willow and forest encroachment in the Peace-Athabasca Delta was related to increase of moose. More directly on climate change, local people observed that it was more common today to experience snowfalls prior to sub-freezing temperatures (Bill *et al*., 1996).

In the case of the Hudson Bay study, representatives of six regions of the area, both Cree and Inuit, have provided detailed accounts of changes they have observed over the years. Many of these changes were suspected to be related to the cumulative impacts of hydroelectric development projects in Quebec, Ontario and Manitoba, and in fact the study was spearheaded by the Inuit community of Sanikiluaq, located on Belcher Islands, as part of their response to the Grande-Baleine environmental assessment. Some of the observed changes, change in goose migratory patterns from the James Bay coast inland, may well be related to hydro development (string of reservoirs attracting migratory geese). Other observed changes are difficult to relate to hydro effects. For example, in the area of Belcher Islands, Inuit hunters indicated that some 35 polynias present in the 1950s were reduced to 13 in 1960-70, and to three in the 1990s (Arrangutainaq *et al*., 1995).

In Southampton Island local people reported that snow has started coming before freshwater freezes, creating a different kind of lake ice. Whale Cove reported that snowfall had increased but that it melted earlier than it did in the past. Chesterfield Inlet, Southampton Island and Arviat all reported increasingly more erratic weather, such as snow melting by May, but blizzards occurring as late as June. A number of Hudson Bay communities reported that the main offshore currents and tidal currents have been weakening through the 1980s. Different communities were reporting changes in potential vector species. Whale Cove reported black flies as a new arrival, whereas Repulse Bay indicated that mosquitoes have declined (McDonald *et al*., 1995).

Climate Change May Affect the Health of Northern populations through Dietary Dislocations and Epidemiological Changes

An inability to hunt and fish no longer results in starvation, but it has been contributing to dietary problems and medical costs through elevated levels of cardiovascular disorders, diabetes and vitamin-deficiency disorders. A review of aboriginal wildlife and fish harvest studies shows that most of the harvesting in the Canadian Arctic fall in the range of 200 kg to 400 kg of potential food per person per year, and in the Subarctic 50 to 150 kg (Berkes and Fast, 1996). Estimated on the basis of the number of animals taken multiplied by the average edible weight per animal, these figures indicate the potentially edible meat per capita per year, minus wastage and meat consumed by dogs.

These harvests of wildlife represent high values compared to the meat and fish eaten by Canadians in the south. Furthermore, wild meat is very healthy food, and if consumed fresh provides all the dietary requirements for vitamins as well as minerals (Schaefer and Steckle, 1980). A harvest of some 300 kg of meat per year for every man, woman and child in the Arctic corresponds to a potentially available food weight of about 1.2 kg meat, and 300 g of protein per adult-equivalent per day (explanations and conversions may be found in Berkes and Fast, 1996). This protein value of 300 g may be compared with Nutrition Canada's minimum adequate standard of 60 g protein per day for a 70 kg person.

"Based on 24-hour diet recalls in 1992 and 1993, country food provided an average of 42 grams of protein for Inuit women under 45 in northern Quebec. The average was higher for men under 45 (43 g), and for those over 45 (54 g for women, 88 g for men). In six other Inuit community surveys, women under 45 obtained an average of between 50 and 80 g of protein from country food" (Hill, pers. com., 1997). Figures based on consumption studies will be lower since some of the potential food weight available from harvests will be wasted.

Climate change and general socio-economic change in the North, however, are not the only threats to local food sources, as there have been problems with arctic food chain contamination (Cameron and Weiss, 1993), through the long-range atmospheric transport of contaminants to the Arctic. PCBs and other organic contaminants also occur at concentrations that are a cause for concern in the arctic food web, especially in marine mammals. Among the heavy metals, mercury has received attention as the one most likely to have implications for human health; cadmium and possibly lead can also be a problem (Muir *et al*., 1992). The PCBs in the Inuit diet are especially important and some Inuit women in the Hudson Bay area are known have PCB concentrations in breast milk which are five times higher than those of southern Canadians (Dewailly *et al*., 1989). Overall there seems to be a seven-fold difference in total PCB for southern vs. northern human milk (Dewailly *et al*., 1993).These contaminants problems are not new; they have interfered with aboriginal resource harvesting since the mid-1970s (Berkes, 1980). It is conjectured that climate change may alter the pattern of transport of the various contaminants to the northern regions.

"Increased temperatures could result in an increased degree of revolatilization of contaminants presently stored in soils and oceans, implying that a greater quantity may become available for atmospheric transport and that the cycling of contaminants through the global ecosystem may change. Whether or not this would lead to increased deposition in the Arctic is unclear as increasing temperatures would likely alter precipitation regimes and therefore 'wash-out' of contaminants from the atmosphere" (Han, pers. com., 1997).

During the 1950s and 1960s, northern aboriginal peoples were settled into year-round villages. This settlement resulted in major changes in activity patterns (less physical activity), diet (less fresh meat and more fat, sugar and processed foods), demographics (more babies), and social and cultural values. This paper focuses mainly on diet-related problems as climate change may interfere with wildlife harvests. Human consumption of country foods in the North is high on a per capita basis, with average annual per capita consumption of country foods in Keewatin, Kitikmeot and Baffin Island regions estimated at 267 kg—more than twice the national average annual meat and fish consumption of southerners (DOE, 1991; Wein and Wein, 1995).

A survey of the Inuit in northern Quebec indicated that country food continues to be a very important part of the diet of adults over 45, and that those under 45 consume significantly more store foods. The survey also found that those under 45 also consumed significantly more foods with little nutritional value than did those over 45 (Lawn and Langer, 1994). For women under 45 the most important country foods, in order of priority were: caribou; char; geese; ducks; ptarmigan; dried caribou and beluga skin. The researchers concluded that the trend away from country food by younger people could lead to an even lower nutritional status and a concomitant increase in the incidence of 'chronic lifestyle diseases' (Lawn and Langer, 1994). Both cultural survival and health were linked to continued availability of country foods. It is known that these country foods contain chlorinated organic compounds, thought to be the biggest threat to human health because of their "persistence in the environment, high biomagnification, generally high inherent toxicity, widespread use, and high tendency to be stored in the fatty tissues of animals" (DOE, 1991).

This issue has not been well studied, but concern is primarily related to developing fetus and breast-fed babies. Lichens trap radioactive fallout, and since lichens are the primary source of food for caribou there is some concern about the health of people eating primarily caribou, though risks are believed to be very low. Consumption of country foods also exposes individuals to unsafe levels of methylmercury in fish (DOE, 1991). The safety of the country foods being eaten was raised as a major concern at every community meeting as part of a study of food consumption, nutrition and health of aboriginal people conducted in Pond Inlet, Repulse Bay, Nain, Fort Severn, Davis Inlet, Arctic Bay, Gjoa Haven and Coral Harbour. Food security was a major concern as the result of low income levels, high food costs, high unemployment, inadequate social assistance, reduced access to country food and concern over the safety of country food (Lawn and Langner, 1994).

In this respect a major dietary problem is that as the consumption of fresh meat (i.e., not frozen or preserved) in the diet has declined, the nutrients formerly provided by this diet (Berkes and Farkas, 1978; Schaefer and Steckle, 1980) are not replaced by new foods. The pursuit of subsistence harvesting demands a high level of physical fitness. As members of subsistence societies fall prey to modern diseases they are less able to hunt for wildlife and so contribute to their family's welfare.

A warmer climate would result in melting permafrost and subsequently to thawing of wastes. The now-active waste bacteria would become able to move through the thawed soil, thereby greatly increasing the possibility of contaminating water resources (Harris, 1987). The increase of ultraviolet-B radiation caused by thinning of the ozone layer in the arctic stratosphere is a real threat to human and animal health as well as to productivity of terrestrial and marine vegetation, but impacts are presently minimized because little human skin is exposed to the sun when levels are highest in March and April. Similarly, most vegetation is still under snow at that time. Those traveling across the snow, however, including humans, dogs, wolves, musk oxen, Peary caribou, and birds such as the snowy owl, raven and ptarmigan could be at risk of eye damage (Roots, 1996).

It has been observed that latent conditions can become acute or chronic when individuals are exposed to stress, and there is some concern that the increased incidence of tuberculosis among Canada's native population could be such a response. Also, evidence of poor nutritional status has implications for the healthy development of fetus and children. Warmer climates would extend the suitable habitat of disease vectors such as mosquitoes, potentially spreading malaria for example. As animal habitats change the insects that live on them also change their habitat. Even the further encroachment of farming on marginal lands has potential implications for disease vectors (Hackett pers. com., 1997).

ADAPTATION OPTIONS

There is much evidence that aboriginal societies will be able to adapt to minor climate fluctuations—as they have done for centuries—whether they be of short or long term duration. For example, despite the loss of their resource base caused by extensive hydroelectric development, and subsequent difficulties associated with subsistence land use activities today, members of York Factory First Nation in northern Manitoba are still very much aware of the presence of wildlife in the waters and lands surrounding their reserve, as well as in their traditional hunting area around York Factory and along the Hudson Bay coast almost two hundred miles away. One hunter tracked in a study by Fast (1996), for example has adapted to changes in the flow of the Nelson River and is once again able to travel to York Factory by way of this river all summer long. One year he made the trip eleven times. He and several others fly to Gillam from York Landing. From there they travel the 28 miles to the Limestone Generating Station where he leaves his 18 foot 35 horsepower outboard aluminum canoe. Water is released daily at 8:00 a.m. at Long Spruce, and by ll:00 a.m. the water at the Limestone Generating Station is high enough to allow them to launch their canoes and paddle to Gillam Island. This stretch of the journey takes eight hours to complete. When they reach Gillam Island they wait for the Hudson Bay tide, which comes in as far as the island, to carry them to York Factory. This part of the trip takes about two hours, and they arrive at York Factory about 2:00 a.m., a day and a half after they started. Along the way, and once at York Factory, they hunt. They again 'ride the dam tide' to return home (Fast, 1996).

This is one illustration of the adaptability of subsistence societies in the face of environmental change. The types of changes anticipated to accompany climate change as described, however, are likely to severely challenge the capacity to adapt of many subsistence societies. The effects are likely to be wide-spread, with regional variations, and attempts to modify or prevent events/effects for vast northern regions are not likely to be viable once the impacts begin to be felt. The transition to settlement life over the last forty years has reduced, though not eliminated, their options for traveling to new areas in response to animal migrations. Loss of waterfowl and fish populations will have serious implications for the subsistence economy because these resources will not likely be replaced by other wild food sources. Even an increase in government financial government support, were it to be provided, would not compensate for the losses in overall well-being. A move to urban centres, should the subsistence economy collapse, would in all likelihood not enhance the overall well-being of these people either.

RESEARCH AND MONITORING NEEDS

We focus on three areas of research and monitoring needs: (1) linking the available biological and ecological information on the impacts climate change to local resource use and the northern economy; (2) developing adaptive management strategies with emphasis on the resilience of social and ecological systems, and on flexibility to respond to uncertainty and largely unpredictable climate change; and (3) studying the issue of the health of northern populations relative to the potentially significant implications of climate change for the long-term availability of this country food.

Regarding the first point, research is needed to acquire biological information on the potential impacts of climate change on resource use. But perhaps more importantly, more work is needed to link available ecological information to economic change; there is very little in the available literature that links the ecological system with the social system. A major confounding factor is the impact of other social and environmental changes, including cumulative impacts of large-scale development. There is no agreed-upon methodology to separate out the effects of climate change from cumulative impacts of development and other changes. Large unknowns at present include the understanding of the limits to adaptability in northern subsistence economies. Northern indigenous populations are better adapted to extreme events and annual, as well as seasonal, fluctuations as compared to non-indigenous groups. It is not clear whether acculturation has made these groups less vulnerable or more vulnerable to effects of climate change. A better understanding of the non-linear and discontinuous (unexpected) effects (Holling, 1986) of climate change on Arctic and Subarctic regions is needed, to help subsistence societies begin to anticipate and so begin to plan for unpredictable change, and to begin to assess the measure of risk they face.

Regarding the second point, research is needed to develop adaptive management strategies with the capacity not only to track changing conditions, but also to provide the flexibility to respond to uncertainty and environmental complexity in the context of rapid, and largely unpredictable, change (Holling, 1986). Adaptive management in this context refers to feedback learning, learning-by-doing and policies designed as experiments from which resource managers can learn. Fisheries management, for example, may have to manage both expanding and collapsing stocks, as climate change affects various stocks differently. Dramatic changes in the populations of mammals and birds will leave present management practices out of step with the changing environment. The implementation of effective adaptive management capacity will be a key factor influencing the extent to which the subsistence economy can be sustained in the years ahead.

Adaptive management is directly relevant to the maintenance and resilience of the social system as well. Increasing uncertainly implies that flexibility or keeping options open will become increasingly more important for long-term survival. One way of framing this issue is in terms of the resilience of the socio-economic system (Berkes and Folke, 1997); that is, the buffering capacity of the socio-economic system to absorb perturbations (such as impacts of climate change) and still retain its system characteristics. The ability of northern aboriginal groups to obtain their protein from their environment is perhaps one of the more important elements of such resilience of the socio-economic system because it encourages self-reliance.

A third area of study must address the issue of the health of northern populations. A direct link between the health of northern people and the extent to which they are able to enjoy a regular source of country food in their diet has not been proven. The ability to live at least partially off the land is not only important for socio-economic resilience; at a very practical level, it is important for individual nutritional health. Climate change has potentially significant implications for the long-term availability of this country food. As in the case of the Chisasibi Cree, rapid environmental change can make the local knowledge of the environment useless, and interfere with the ability to travel on and to harvest the land (Berkes, 1988). However, as in the case of hunters of the Nelson River, there is evidence of a high degree of adaptability even to massive change (Fast, 1996). The issue then is to know the limits to adaptability, and to make social and economic conditions conducive for the emergence of new adaptations. The issue may be generally applicable to rural populations elsewhere in Canada as well: there are costs associated with isolated populations becoming more and more dependent on the larger society for all their needs. There is no known basis which can be used to estimate the costs associated with increasing dependence, or, alternatively, the costs associated with the facilitation of potentially viable adaptations.

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