Health Effects of Climate Change and Health Co-Benefits Resulting from Potential Kyoto-driven Policies:

A Canadian Perspective

Technical Report developed by

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Background

At the request of the Climate Change and Health Office of Health Canada, the McLaughlin Centre for Population Health Risk Assessment, Institute of Population Health, University of Ottawa prepared this technical report on "Health Effects of Climate Change and Health Co-Benefits Resulting from Potential Kyoto-driven Policies: A Canadian Perspective". The purpose of this report was to evaluate health and social impacts of climate change in Canada, and to examine the role of co-benefits in the development of Canadian policy on climate change within the context of the Kyoto Protocol.

This report draws on the entry document developed for a workshop, “Expert Panel Workshop on Climate Change and Health & Well-being in Canada”, hosted by the McLaughlin Centre, University of Ottawa, on April 15-16, 2002. At the workshop invited public health experts gave consideration to the health effects of climate change and health benefits of possible Kyoto-driven policies and developed key findings and recommendations to guide further research in this area. A summary document of the results of that workshop is available on the Institute of Population Health website at http://www.iph.uottawa.ca or on the Climate Change and Health Office, Health Canada website at http://www.hc-sc.gc.ca/cc

Executive Summary

Anticipated health impacts of climate change in Canada include the possibility of increased heat stroke, and a greater incidence of vector borne diseases as a consequence of migration of new insect species to a warmer Canadian climate. Climate variability can also be expected to lead to an increase in extreme weather events, such as the recent ice storm in eastern Ontario that led to adverse health impacts as a consequence of loss of heat, and the use of alternative fuels that lead to greater levels of indoor air pollution.

Of particular interest in controlling climate change are the potential co-benefits of controlling greenhouse gas emissions. Since industrial and automobile emissions are major sources of GHGs as well as particulate and gaseous co-pollutants, reductions in GHG emissions will lead to reductions in criteria pollutants, many of which have been shown to be associated with adverse health outcomes in the general population, particularly cardiorespiratory morbidity and mortality.

Accurate future predictions of global and regional climate are difficult due to the complex nature of the weather system. At this point, quantitative estimates of global change are subject to a high degree of uncertainty, although the current weight of evidence strongly supports a steady increase in average global temperature in the absence of major interventions to control greenhouse gas emissions.

In the absence of a sufficient period of observation and notable increases in global average temperature to date, epidemiologic links between increased climate variability and adverse health outcomes are not readily quantifiable at this time. In contrast, there exists a large database on the health effects of common air pollutants, which demonstrate consistent linkages between ambient air pollution and adverse health effects. This epidemiologic database is sufficiently strong to permit the development of useful risk projection models that can be used to quantify the population health benefits of interventions designed to reduce emissions of particulate and gaseous co-pollutants.

In addition to models linking ambient air pollution and population health, economic valuation models have also been developed to quantify the economic impact of co-benefits achieved by air pollution control. For example, the Air Quality Valuation Model (AQVM) developed by Health Canada can be used to predict the economic benefit associated with specific reductions in ambient air pollution. This model, which has been favourably reviewed by the Royal Society of Canada in their recent expert panel report on Review of the Socio-Economic Models and Related Components Supporting the Development of Canada-Wide Standards for Particulate Matter and Ozone, can be used to obtain quantitative predictions of the number of cases of a range of cardiorespiratory health outcomes that will be avoided through pollution mitigation, as well as the economic value of the avoidance of these adverse health effects.

Environmental changes will require adaptability measures that will match the level of climate variation in order to maintain human health stability. Certain populations may adapt with greater

ease. Specific subpopulations at greater risk may incur a disproportionate burden of the population health impacts of climate change, and concomitant health care costs. These subpopulations include the elderly, children, those with pre-existing health conditions, along with those who reside in marginal conditions and have a limited capacity to offer and replace infrastructure. Although individual health implications are not quantifiable, health costs related to health infrastructure stress such as increased hospital admissions and increased demands on local health care and social services are estimable. Regional variation in specific costs and benefits will be of particular interest to provincial and regional governments in planning local strategies for responding to climate change.

The present report considers the health impacts that might result from inaction under a Business As Usual (BAU) approach to climate change and the co-benefits, and the avoided costs that could result from enacting specific measures to implement the Kyoto Protocol in Canada. Developing a comprehensive health co-benefits policy statement regarding the Kyoto Protocol is a complex and challenging task. The potential impacts of climate change are widely disputed or accepted only with substantial caveats. As noted above, models linking climate change and health impacts are currently in their formative stages, and can provide only tenuous links between climate change and population health at this time.

It is clear, however, that a systemic approach to policy development regarding climate change must prevail in order that social and health impacts associated with climate change be given proper consideration in the development of rational science-based policies for addressing climate change. In order to implement a systemic approach to policy making with respect to climate change, a better understanding of the costs and benefits of either adopting the mitigation targets set out in the Kyoto Protocol or of proceeding with a Business as Usual emission slowdown is required.

While the impacts of climate change on health are generally complex and not well understood, they can be well-illustrated with respect to impacts on air quality. Because of the quantifiable impacts of air pollution on population health, this report pays particular attention to the impacts of climate change on air quality. Background is provided on factors affecting climate change, along with inventories of the health and social impacts of climate change mitigation measures and social and health impact models. Alternatives to these models are explored, as are the social and health costs and co-benefits likely to result from Kyoto-type GHG emission reductions.

It is clear at this time that considerable research and modeling efforts are required to better characterize the likely impact of GHG emissions on global change. Such research will permit better estimates of the direct health effects of climate change under specific climate scenarios, along with more accurate statements about the uncertainty of such estimates. Although risk projection models for air pollutants that are closely linked to GHG emissions are now relatively well-developed, additional research on the co-benefits of air pollution control will also contribute to the expanding scientific database from which to inform cost-effective science-based risk management policy decisions on adaptation and mitigation measures to address climate change.

The bulk of this report was written before the Government of Canada released its Options paper and its Climate Change Draft Plan. This has serious consequences for the estimates of the co-benefits in Canada. Through aggregate figures have been updated and publicly released, regional and sectoral updates have not been released.

Introduction

This report is the outcome of a workshop attended by national experts held at the University of Ottawa in April 2002. It discusses how certain health impacts of climate change can be assessed, in order to develop appropriate health policy recommendations. The document attempts to show how health co-benefits and avoided costs could result from implementing the Kyoto Protocol in Canada . It also considers the health impacts that BAU inaction might cause, as well as the uncertainty surrounding the assessments of such benefits and impacts. It also examines the health consequences of climate change mitigation measures which might be adopted by Canada, conditional upon Kyoto Protocol ratification and entry into force, against a BAU baseline in Canada. It is organized as follows.

Climate change (CC) is a complex phenomenon, for which many outcomes are possible. These outcomes can be described by a range of different scenarios depicting the range between either little or no change to the human environment to damaged and dysfunctional ecosystems. The likelihood of each of these scenarios is debatable, but the reality of climate change becomes more and more evident. A scientific consensus is emerging that if climate warming and variability continue to increase, then the impacts on the world's ecosystems and on human social, economic and health systems will continue to grow.

International agreements such as the United Nations Framework Convention on Climate Change (UN FCCC) and its Kyoto Protocol, show that many national governments recognize and would like to mitigate climate change. However, in order to develop and implement policies intended to reap the health benefits of the Kyoto Agreement, governments must be able to show convincing evidence of the health impacts of climate change. This requires a clear understanding of the current science of climate change, and of the range of possible impacts of climate change and particularly, climate variability on human health and well-being. Evidence also depends on the perceived advantages and disadvantages of the possible scenarios resulting either from adoption of "Kyoto targets", or from a Business As Usual (BAU) approach.

The report provides information relevant to the scientific understanding of the health and social implications of climate change relevant to Canada. Chapter 1summarizes the anticipated physical impacts of climate change in Canada. Chapter 2 presents an inventory of the information available on the health and social implications of climate change relevant to Canada. This could be considered as the baseline BAU scenario (without Kyoto coming into force). Chapter 3 discusses elements of the socio-economic context for BAU. Chapter 4 reviews the co-benefits of climate change policies. In particular, it will define the concepts of co-benefits, and discuss the health and environmental co-benefits for Canada. Chapter 5 provides a summary of the major issues and conclusions of the report and identifies directions for future research.

1. Brief Overview of Climate Change and Canadian Physical Impacts

Canada is a northern country and as such is expected to experience faster warming due to climate change than countries farther south. Temperature changes are projected to be greatest in the north. The central area of the country, including the Prairie provinces, Ontario, and Quebec, is likely to experience more frequent and severe heat conditions. Low-lying coastal areas face risks associated with a rise in sea level, including increased flooding and coastal erosion, particularly on the Atlantic coast. Ice-rich sediments and permafrost, for which climate is the fundamental environmental factor, are likely to begin to thaw. Thawing in these areas would greatly reduce ground strength, which may induce landslides, increase sediment contribution to rivers, and reduce or eliminate the ability of earth materials to support buildings and transportation facilities.

Table 1.1 Characteristics and Geographical Patterns of the Climatic Changes that are Simulated by 3-D AGCMs to Result from a Doubling of Atmospheric CO_2

- a greater mean annual warming at high latitudes than at low latitudes at the surface and in the lower troposphere (also referred to as a polar amplification of the warming).
- a greater warming in winter than in summer at high latitudes particularly over the oceans.
- a greater overall warming of the land surface than of the ocean surface.
- a greater warming of the surface air than of the surface, particularly over the oceans.
- greater warming in summer than in winter in those land areas where soils become sufficiently dry in the summer.
- a tendency to somewhat greater warming at night than during the day.
- a greater warming in the tropics than at middle and high latitudes in the upper troposphere.
- a greater warming in the upper troposphere than in the lower troposphere or at the surface in the tropics (so that the tropical lapse rate decreases).
- a greater warming at the surface and in the lower troposphere than in the upper troposphere at high latitudes (so that the polar lapse rate increases).
- a cooling of the stratosphere.
- an increase in global mean evaporation from the oceans by 5-10% in most models and a corresponding increase in the global mean rate of precipitation, so that there is an overall intensification of the hydrological cycle.
- a poleward shift in the mid-latitude belt of high rainfall associated with the westerly jet stream.
- an increase of precipitation in mid-latitudes in winter and increases or decreases in summer.

Source: Harvey, 2000.

The effects of climate change are already being experienced in the western Canadian Arctic. This region has warmed by about 1.5 degrees Celsius over the past 40 years, while the central Arctic has warmed by about 0.5 degrees Celsius (Government of Canada, 2002). Northern effects in Canada include the following:

- decreased extent and thickness of Arctic sea ice; permafrost thawing, coastal erosion, and altered distribution and abundance of some animal species;
- more open water in winter and spring, making hunting more hazardous;
- melting of permanent snowpacks in Yukon for the first time in thousands of years; and
- the appearance of southern species such as Pacific salmon and robins in the Arctic for the first time in memory, as cited by traditional knowledge research (ibid).

While increased precipitation is predicted for Canada as a whole, increased evaporation with higher temperatures is expected to more than compensate for this, leaving dry summers in the southern parts of Central Canada. Short duration, high intensity rainfalls are predicted, as well as increased heat discomfort with increased humidity. More intense and more frequent mid-latitude winter storms are predicted as well as more El-Niño like conditions exacerbating Prairie summer dryness. Over the last 20 years, insurance and government disaster payouts have increased fourfold. Agricultural yields may increase in the Eastern Prairies but a decrease in the West is expected, while increased summer stress may affect cattle in the West. Forest growth may increase in the North, but decrease in the South and along the coasts (Crabbé et al., 2001). In British Columbia, temperatures have generally risen by one degree over the past century, more inland and in the north than on the coast. These increases are due mostly to increases in winter and spring minimum temperatures and not to increases in the maximum temperature. Springtime precipitation has been declining while the annual trend is for increased precipitation. Glaciers have receded up to 1100 m (www.cics.uvic.ca).

"Most of southern Canada could experience declines in low-season river flows and lake levels and higher water temperatures. Snowmelt-dominated watersheds in western Canada will experience earlier spring peak flows and reductions in summer flows. These projected changes will have implications for water supplies, water allocation, hydroelectric production, waste assimilation and pollution concentrations, and freshwater ecosystems. There will be greater stresses on groundwater levels and quality, with levels declining in populated southern regions. High concentrations of pollutants could occur in rivers when the flow is low and the point sources are important. Similar concentrations are possible when the flow is high and the runoff from agriculture and urban areas dominates. Increased frequency of short-duration, high precipitation intensities would result in an increased risk of biological contamination, greater soil erosion and sedimentation, and chemical pollution. More extended drier conditions in agricultural areas could reduce nitrogen leaching into groundwater and nitrate contamination. Among the most severely threatened areas [by sea rise] are parts of the Atlantic coast, including central and northern Prince Edward Island. These are regions in which sea level is already rising, with demonstrable impacts." (Government of Canada, 2002).

2. Health Implications of Climate Change

2.1 Climate Change Health Impacts

Global-scale disturbances of the natural ecological systems due to the effects of climate change will present a significant new threat to human health and well-being (McCarthy, 2001; Patz et al., 2000; Last, 1998). The effects of climate change on human health are already apparent and are likely, if current trends continue to become more pronounced (Last and Sahni, 2001; Last and Chiotti, 2001). Assessing human health impacts associated with climate change is complex. We cannot adequately model anticipated impacts because we cannot account for a multitude of ecological and social inputs, or for the influence of future adaptation measures. We can, however, conclude that climate change will affect human health and human health infrastructure and service. Qualitatively, we can take stock of the impacts on health and well-being which could result from the anticipated climate change in relation to the health patterns that currently exist in Canada. However, we still need to strengthen the epidemiological evidence to show conclusively to what extent certain known climate conditions and changes will impact human health and health systems.

There are several key factors to be considered in assessing the implications of climate change and climate variability on human health. First, understanding the relationship between climate change and human health conditions requires the adoption of an ecological perspective, as the health and well-being of a population is dependent on the stability and health of the ecosystems which support it. Environmental changes will require adaptation measures that will match these changes in order to maintain population health. Second, the causation of human illness is influenced by a complex and interrelated set of factors, including genetic ones.

The effects of climate change on human health can be classified as being direct and/or indirect effects (McMichael et al., 1996; Martens, 1998; Patz et al., 2000; IPCC, 2001; Last and Chiotti, 2001). Simply defined, direct effects happen as a direct result of a climate variable (increased temperature results in a heat related illness), whereas an indirect effect happens as a result of a 'mediating factor' (eg increased climate increases the spread of a vector borne disease). Patz et al (2000) highlights four global health impact categories with mediating processes; these are: physical effects, physical/chemical effects, physical/biological effects and sociodemographic effects.

Although climate change is a global issues and the long term impacts are global, this report intends to focus primarily on the Canadian situation. Table 2.1 outlines some categories of anticipated health impacts from climate change and variability in Canada (CCHO, 2001).

Table 2.1 Canada's Health Impacts from Climate Change and Variability

Health Concerns	Examples of Health Vulnerabilities
Temperature-related morbidity and mortality	- Cold and heat related illnesses - Respiratory and cardiovascular illnesses - Occupational health risks
Health effects of extreme weather events	- Damaged public health infrastructure - Injuries and illnesses - Social and mental stress due to disasters - Occupation health hazards - Preparedness and population displacement
Air pollution-related health effects	- Changed exposure to outdoor and indoor air pollutants and allergens - Asthma and other respiratory diseases - Heart attacks, strokes and other cardiovascular diseases -Cancer
Water-and food-borne contamination	- Enteric diseases
Vector-borne and zoonotic diseases	- Changed patterns of diseases caused by bacteria, viruses and other pathogens carried by mosquitos, ticks and other vectors
Stratospheric ozone depletion	- Skin damage and skin cancer - Cataracts - Disturbed immune function
Population vulnerabilities in rural and urban communities	- Seniors - Children - Poor health - Low income and homelessness - Traditional populations - Disabled - Immigrant populations
Socio-Economic impacts on community health and well-being	- Changed determinants of health and well-being - Global burden of illness - Vulnerability of community economies - Health and social co-benefits and risks of GHG reduction technologies

Source: CCHO, 2002.

From the relationships between climate and environmental change and human health and well-being, it can be concluded that the human health effects in Canada fall into the following categories: extreme temperatures; extreme weather events such as storms and floods; weather or climate -related changes in air pollution and in water and food-borne contamination, and in infectious diseases transmitted from animals to humans or from humans to humans. This chapter will discuss such relationships between climate or weather and health effects, as well as the factors which may affect the vulnerability of individuals or communities to climate change related health effects. The chapter will conclude with a discussion of health impact scenarios for modeling future risks of the spread of vector-borne diseases such as malaria in human populations.

2.2 Vulnerability and Adaptability

Historical and archaeologic evidence of the effects of climatic changes in North America indicates that different population groups will cope with environmental changes such as those which will result from the current climate change. However, the evidence linking physical climate changes directly with health outcomes is limited, as is our knowledge of population sensitivities to such changes. Although climate changes may result in an increase in stressors which can affect population health, there is much uncertainty about the extent to which this may happen (Epstein, et al., 1997).

The vulnerability of a population is "a function to which a health outcome in a particular environmental-demographic setting is sensitive to climate change and the capacity of the population to adapt to new climate conditions" (IPCC, 2001a). Vulnerabilities are determined by multiple factors, which in part may be unique to environments, populations and individuals. Climate-related health determinants can be assigned to three main risk categories: individual factors, community factors and geographic factors. These factors are outlined in Table 2.2.

Part of the problem of predicting or anticipating regional climate change related health impacts is the inability to properly take into account the influence of public health adaptation measures. For instance, the dramatic two week heat wave in Chicago (1995) caused 700 premature deaths, particularly among the elderly and frail. However, when a similar heat wave occurred in Chicago in 1999, the mortality rate was considerably less (Last and Sahni, 2001). This was probably due in part to three factors: i) the residents of Chicago, having experienced the severe first wave, took precautionary measures and altered their habitat and lifestyle, e.g. by an increased use of air conditioners and better ventilation measures; ii) the public health authorities put in place an effective heat emergency response system for identifying and caring for vulnerable individuals; and iii), the first heat wave had already removed part of the most vulnerable segments of the population.

Table 2.2 Risk Factors and Health Determinants

Risk Factors	Health Determinants
Individual Factors	disease status (eg pre-existing chronic conditions)
	socio-economic considerations (such as household income, education)
	demographic considerations (such as age, gender)
Community Factors	public service quality and adaptability (such as water/sewer systems)
	information access
	food access
	local disease distribution and control
Geographical factors	occurrence of extreme events
	sea level and coastal proximity
	extend and distribution of mobile vector-borne diseases
	rural or urban location and access to resources
	environmentally sensitive regions

Source: IPCC, 2001c.

The above discussion of some of the aspects of population vulnerability and adaptability explains why some population groups may be at greater risk than others, or why they may find it more difficult to adapt to the impacts of climate change. Health Canada's Climate Change and Health Office (CCHO) has identified the following vulnerable population groups.

2.2.1 Vulnerable Population Groups

2.2.1.1 Urban Residents

Urban areas are likely to be especially vulnerable to climate change, as the health effects associated with heat stress and poor air quality tend to be more pronounced in urban regions than in suburban or rural areas. Densely built up city cores with many high-rise buildings represent a local environment with limited air circulation which readily absorbs and poorly dissipates solar energy. This creates a so-called "urban heat island" effect resulting in higher temperatures and a buildup of pollutants. The higher temperatures and greater number of heat waves associated with global warming may also exacerbate the formation of ground-level ozone and of other components of smog whose concentration is strongly related to environmental temperature. Cities also represent highly complex and energy-intensive built environments, and are endowed with mass transportation systems which depend on large amounts of reliable electricity. This energy dependence, and the high urban population density make large numbers of people vulnerable to both localized and regional environmental extremes, such as heat waves or cold waves, droughts, storms, or floods which may result in "brownouts" or power failures and in contaminated water supplies.

2.2.1.2 Children

Children are more vulnerable than adults to many health effects caused by environmental factors. Their bodies have a greater surface to volume ratio than do those of adults, and they have a higher metabolic rate. Consequently they tend to gain or lose heat energy more rapidly. Children also tend to be physically more active than adults. As a result, children breathe more rapidly than adults, and they also consume more food and water per unit body weight. This, and their still developing tissues make them both physiologically and anatomically vulnerable especially to temperature extremes and to pollutants (Chance and Harmesan, 1998). For instance, Raizenne et al. (1998) found that hospital admissions for children increased as air conditions worsened. Children are also more susceptible than adults to toxins and pathogens in water and food (CICH, 2001, Wigle, 2001). The situation in Walkerton (Ontario) illustrated this as well as children fallen ill were the first indications of the outbreak - two were admitted to hospital and 20 were absent from school as a result of similar symptoms. Of the 2,300 people who became ill as a result of the contaminated water some were children who will now endure lasting effects (Walkerton Inquiry, 2002). In all environments, children's vulnerability is increased by their limited ability to control their environments and an limited capacity to adapt.

2.2.1.3 Elderly

Ageing causes a decline in cardio-respiratory capacity as well as other physiologic impairments that amplify the effects of extreme temperatures and of pollution, or of other stressful environmental conditions. Many elderly, like children, also have less control over their living environments than do younger adults.

2.2.1.4 Aboriginal Populations and Northern Communities

Global climate change models predict greater relative temperature increases in polar regions compared to southern regions. This implies that climate change and increased climate variability will alter the natural northern habitat for plants, fish, and wildlife, and damage natural resources in other ways. Canada's North is already being impacted by significant ecological changes resulting from global warming, such as melting of permafrost, changes in groundwater, in vegetation, and in wildlife habitat and wildlife migrations. Coastal and shore regions also experience substantial ecological changes due to increased water temperatures and changing water levels (IPCC, 2001). These regions host traditional communities, particularly of aboriginal populations, who rely on the environment for their livelihood. Thus, in these regions, traditional communities will experience a greater burden of the ill effects of climate change. In addition, such communities often lack the resources necessary for effective adaptation (CCHO, 2001).

2.2.1.5 Low Income

Many associations have been drawn regarding economic status and higher than expected exposure to health risks. There are several social factors that contribute to potential increased health risk from lower individual and household income.

- residences tend to be crowded and constructed with poor quality materials;
- residences tend to be located in close proximity to industrial areas;
- insufficient and inadequate clothing;
- lower access to climate control (e.g. heating or air conditioning to cope with extreme temperatures) due to cost etc.;
- inadequate access to health care;
- incomplete nutritious diets and often higher exposures to smoking; and,
- finally, above mentioned factors increase vulnerability to environmental extremes (e.g. poorly constructed housing would be at increased risk of damage during a storm than a house of higher quality).

2.2.1.6 The Ill

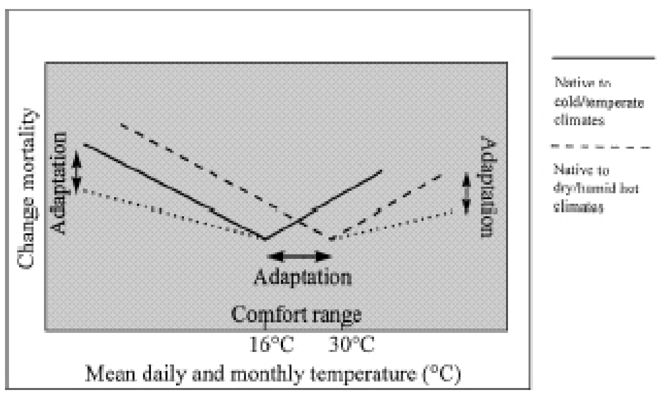
People suffering from a pre-existing illness, or who are immuno-compromised, may be at greater risk to climate change related health effects. The combination of extreme heat and air pollution stress especially targets people with cardio-respiratory diseases. Those with reduced immunity are more susceptible to vector, food and water borne diseases than the general population, and are more likely to suffer from physical stress related to extreme weather and events (CCHO, 2001).

2.3 Temperature-Related Morbidity and Mortality

Global warming leads to warmer than average temperatures and to increased climate variability (IPCC, 2001). Canada may thus experience overall warmer seasons, more frequent and more severe heat waves and other extreme weather events. Extreme heat events are sporadic, but recurrent (McGeehin and Mirabelli, 2001). Heat waves and extreme summer temperatures are associated with premature deaths and hospitalizations. Studies on deaths and hospital admissions related to extreme weather indicate that these affect mainly certain population groups such as the elderly, the very young, and people who are not in good health. Deaths due to heat waves or cold waves are generally related to cardiovascular and respiratory diseases. Exposure to extreme heat can result in dehydration, heat cramps, heat exhaustion, heat syncope and heatstroke (McGeehin and Mirabelli, 2001). The most common cause of death and acute illness related to extreme heat is heatstroke (CDCP, 1997) due to an excessive increase of body temperature, which may also impair mental functions (CDCP, 1993; McGeehin and Mirabelli, 2001). Heat aggravates chronic health conditions such as ischemic heart disease, stroke, respiratory diseases and diabetes; and can initiate emotional distress leading to an increase in accidents, suicides and homicides.

The impact of heat waves and extreme summer temperatures depends on how well a population is physiologically adapted to warm climates, and thus the population's heat tolerance threshold. Therefore heat related mortality rates are likely lower in warm climates than in cooler, Northern climates (IPCC, 2001a). Acclimatization to extreme heat is easier in locations where a range of social and technological adaptation practices are in place. Martens et al. (1995) described the range of temperature related mortality/morbidity using a "V-shaped" relationship. Based on a meta-analysis of selected urban populations and their comfort zone temperature range and the range of 'adaptability' should the temperature increase based on whether the population was native to hotter or cooler average temperatures (see Figure 2.1).

Figure 2.1: V-shaped Relationship between Temperature and Mortality



Source: Patz et al, 2000. Reproduced from Martens, W.J., 1998.

In Canadian cities, the average number of annual hot days (over 30°C) is projected to increase as a result of climate change (Hengeveld, 1995, Suzuki Foundation, 1998). Kalkstein and Smoyer (1993) concluded that future heat related mortalities in two Canadian cities would considerably increase if a doubling of atmospheric CO_2 levels were to occur.

The impact of extreme heat is more apparent in urban regions than rural regions due to the urban heat island effect (Landsberg, 1981). Urban core regions, in particular, experience higher daily temperatures than the suburbs and surrounding rural areas because of the scarcity of vegetation, high density heat absorbing buildings/concrete and poor air circulation. The result is a heat blanket effect which is often coupled with poor air quality, particularly smog (discussed in Section 2.4). Risk factors for heat-related illness or death include age, urban dwelling, socioeconomic factors and preventative behaviours (McGeehin and Mirabelli, 2001). The areas with the highest population densities (e.g. those with apartment buildings and high residential buildings) have the highest number of heat related deaths. Behavioral adaptations can improve the ability to resist to heat stress through access to and use of climate control technology, reduced activity, and fluid consumption (McGeehin and Mirabelli, 2001).

Age is a significant risk factor. Smoyer (1999) points out that the elderly are disproportionately at risk of weather related health effects. Regions that have a high proportion of persons over 65 years will experience more vulnerability to weather related health events than regions with populations under the age of 65 years.

The health implications of global warming are not all bad, and are not limited to summer seasons. Global warming is expected to lead to milder winters in North America (IPCC, 2001a), and higher winter temperatures may result in fewer cold-related deaths and injuries.

On the other hand, a warmer and wetter climate increases the growing season for vegetation, insects and bacteria. This may lead to an increased risk of vector-borne and zoonotic diseases (Last and Chiotti, 2001). Increased growth of vegetation may also lead to an increased production of allergens such as pollen (see Section 2.5).

2.4 Health effects of extreme weather events

According to Greenough et al., 2001, an extreme weather event is a climatic condition which far exceeds the average (or expected) range of conditions in a particular region. Such events outside the norm can have adverse health effects, dependent on the frequency and magnitude of the event(s) as well as the vulnerability of the population and the ecosystem supporting the population (IPCC, 2001a). According to IPCC (2001a), climate-related disasters occur when climatic hazards converge with a population's vulnerability. The severity of a disaster may be influenced not only by the environmental conditions, but also by socio-economic factors.

Extreme weather can cause both injuries related to the event itself, as well as indirect impacts including post event injury, infectious disease, or emotional anguish, depression, and related mental or physical illness due to economic loss and social disruption (see Section 2.9).

2.4.1 Storms

Climate Change is projected to increase the frequency and severity of storms (IPCC 2001 a). Storms that were to be expected "once in a lifetime" may occur as often as every 4 years (Francis and Hengeveld, 1998). For instance, the 1998 Ice Storm that covered large areas of northeastern North America with freezing drizzle for 4 days, caused not only direct human health impacts but also impacts on the health infrastructure (LCDC, 1998). A severe storm may cause physical damage and/or flooding which can make it difficult or impossible for the local health care system to provide help to an affected population. The hospitals of eastern Ontario and western Quebec dealt with an increase of 4.6% in emergency room (ER) visits from the same time period in the previous year (LCDC, 1998). These ER visits were due to accidental carbon monoxide or methanol poisonings, respiratory infections, cardiac and respiratory complications, or anxiety; others were due to direct effects such as injuries.

2.4.2 Floods

Floods account for a large share of natural disaster damage and injury (Greenough et al, 2001). Flooding is anticipated to increase as a result of climate change. Floods in urban areas with high population density may affect particularly large numbers of people. Communities located in aesthetically desirable or environmentally marginal lands along lake, river and coastal areas tend to be particularly prone to flooding. Like severe weather conditions, flooding seems to become a more common occurrence in Canada (Last and Sahni, 2002). Examples of recent large-scale flooding include the Red River Flood, and the Saguenay- Lac Saint Jean Flood. Flooding can cause injuries and death as well as a variety of delayed and long term health impacts. Flooding causes individual and community displacement exposing individuals to less sanitary environments, inadequate nutrition, and increased exposure to infectious diseases. The social disruptions experienced during such natural disasters can result in anxiety and depression. Flooding damages lands and communities, thus altering or disrupting productivity, and local food availability. Floods can contaminate sources of drinking water and water treatment plants with pathogens and toxic chemicals. The illnesses and deaths in Walkerton, Ontario in 2001 due to *E. coli* - contaminated water were caused by excessive rain which washed animal wastes from agricultural lands into a community well (Walkerton Inquiry, 2002; Krewski et al., 2002). Post flood conditions often support the development and growth of molds and fungi aggravating allergic and asthmatic symptoms.

2.4.3 Droughts

Droughts can cause crop damage or crop failures. In areas with inadequate food supplies this can lead to food shortages, starvation and/or malnutrition (IPCC, 2001). Shortages of water for sanitation may increase the opportunities for infection. There is a growing concern about the increasing drier seasons and their effects on arable lands in the Canadian prairies. A reduced crop production can affect the socioeconomic well being of communities by diminishing their resources, leading to an increase in stress related illnesses and deaths.

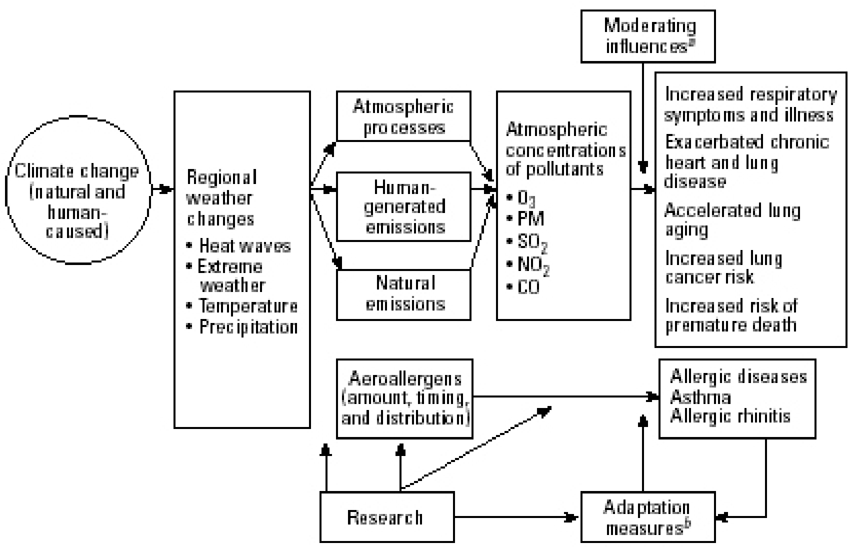
2.5 Air Pollution Related Health Effects

2.5.1 Framework for Assessing Health Effects of Air Pollution

Air contains pollutants that can damage human health. Some of the air pollutants are natural, e.g.

mold spores or pollen; others are derived from human activities in agriculture, commerce, industry, or transportation. Air pollutants may occur indoors as well as outdoors. Bernard et al. (2001) have graphically illustrated the relationships between climate change, air pollution and human health effects (Figure 2.5). Climate change may alter both the kinds and levels of air pollution. It can affect anthropogenic and natural sources of air pollutants, and can influence atmospheric pollutant chemistry and transport processes. The framework shown in Figure 2.5 illustrates the linkages between these components and health effects within the context of moderating factors (such as standard of living) and adaptation measures (such as emission policies).

Figure 2.5 Conceptual Framework for Linkages between Climate Change, Air Pollution and Human Health



Source: Bernard et al., 2001. Potential health effects of air pollution associated with climate change. Diagram includes the mediating influences as well as adaptative measures.

2.5.2 Air Quality Concerns

Poor air quality may have two adverse consequences for human health. Existing illnesses can be aggravated, and new illnesses can be caused by exposure to toxic or allergenic air pollutants. Last and Chiotti (2001) estimate that about 20 million Canadians are exposed to harmful levels of air pollution. Ground level ozone plays a critical role in the human health and air quality relationship, as it causes adverse health effects even at quite low levels of exposures (Ontario Medical Association, 2001, Oxman and Julian, 1993). The health effects of ozone when combined with other air pollutants such as inorganic oxides and volatile organic compounds (VOCs) which transform into nitrates, sulfates and organic aerosols, can cause severe respiratory and cardiovascular effects. Global warming is believed to increase the ambient concentrations of ground-level ozone as well as the number of ozone pollution events. 'Smog' is a weak atmospheric suspension of sulfuric and nitrous acids caused when fossil fuels emissions interact with water vapour, such as humidity on warm summer days.

Several regions in Canada already suffer severe smog episodes each year. They include the Windsor-Quebec corridor, and the Lower Fraser Valley, the Okanagan Valley as well as the Annapolis Valley and the St. John, New Brunswick region (Kalkstein and Smoyer, 1993; Smoyer and Rainham, 2000). If atmospheric GHG levels continue to increase, then each year the residents of such regions could experience many more illnesses and premature deaths due to heat waves and to increased air pollution. Some cities in Canada and in the United States are already issuing air quality and heat health warnings in order to reduce the number of hospital admissions and premature deaths.

Summertime ground level ozone concentrations are related to the frequency of hospital visits in urban areas (Burnett et al., 1997; Burnett et al., 1998 a, b; Schwartz, 1996; 1995; 1994; Thurston and Hayes, 1994; Pope, 1991; Delfino et al., 1994; Spix et al., 1998). In Canadian cities, ozone is a risk factor for summer hospitalization (Burnett et al., 1998). Illnesses related to summertime ozone level affect particularly the elderly and children under 2 years of age (Burnett et al 2001; Dales et al, 2000).

Increased exposure to ozone heightens the sensitivity of asthmatics and individuals with allergies (Beckett, 1991; Bromberg and Koren, 1995). Pollen season lengths and daily pollen levels are influenced by weather patterns. Anticipated climate changes may lengthen the pollen seasons, increasing the risk to chronic asthmatics, and may increase the incidence of asthma and of other respiratory conditions and diseases. Pollen levels and other biogenic air pollutants are affected by land use and land use practices. For example, changing farming practices can increase or decrease the pollen count in the air.

Indoor allergens such as dusts and molds are also climate sensitive. Increased discomfort associated with the outdoor climate may increase the time which sensitive people spend indoors, thus increasing their exposure to indoor air pollutants and allergens.

The urban heat island effect and the poor air quality typical of large cities may cause a higher incidence of air pollutant related illnesses and deaths among urban compared to rural residents. However, air pollution is not typically limited to urban areas and areas adjacent to industrial regions because some pollutants travel long distances with varying degrees of concentrations. Thus, some Canadian communities are at an increased risk of smog episodes due to the transboundary movement of air pollutant emissions from the US industrial heartland. Climate change may also increase the frequency of droughts, thunderstorms and lightning strikes, which may lead to forest fires, thus exacerbating the risk of illnesses and deaths.

2.6 Water and Food-borne Contamination

2.6.1 Drinking Water

Variable weather, particularly excessive precipitation and temperature patterns have had measurable impacts on drinking water quality. The days preceeding the outbreak of *E. coli* O157 at Walkerton, Ontario were marked by intense rainfall. This, coupled with human error and inadequate planning, overwhelmed the local water treatment infrastructure (Walkerton Inquiry, 2002).

Unfortunately, events similar to those at Walkerton are not unusual. In Canada, the number of boil water advisories is on the rise, as are outbreaks of related enteric illnesses. In British Columbia, the number of boil water advisories rose exponentially between 1986 and 1999 (Krewski et al. 2002). Although outbreaks of illnesses due to water contamination may not be directly related to climate change, changes in weather patterns leading to floods or droughts may put undue stress on natural water quality and on water and wastewater treatment systems. This means that drinking water treatment and distribution systems will need to adapt to more extreme environmental conditions. An inability of systems to do so will increase the number of boil water advisories and the risk of adverse health effects.

The *Report of the Walkerton Inquiry (Part 2)* point out that a number of studies suggested that climate change will be a significant factor in the long term provision of drinking water (Walkerton Inquiry, 2002, p 86). The Inquiry mandated to address the future of safe drinking water in Ontario makes several recommendations (following) in relation to drinking water in a changing climate based on the report *Water Sector: Vulnerability and Adaptation to Climate Change*:

- "[p]reparing water budgets for watersheds to identify the connections between surface and groundwater, areas of vulnerability to water takings and to determine limits for water extraction";
- "[i]mproving contingency plans for extreme events";
- "[e]ncouraging best management practices in rural areas to reduce sources of pollution";
- "[e]ncouraging community-based environmental stewardship".

2.6.2 Food Production, processing, transport and storage

Like water, food borne illness incidence is anticipated to increase. Food production can be directly influenced by climatic variability suffering greatly from drought and wet conditions. Pests and pathogen spread and growth may be influenced by the climate and the adaptive practices of the agriculture (IPCC, 2001). Extreme wet conditions can spread contaminants such as *E. Coli* as seen in the Walkerton situation where initial contact with *E. Coli* originated from a farming practice (Walkerton Inquiry, 2001b). Foods, particularly fruits and vegetables, may be irrigated and/or processed using contaminated water (Pollution Probe, 2002).

Fluctuations in annual productivity in the Canadian prairies impacts the quantity and quality of the food production as well as the well-being of the community which supports it. Not only can direct climate variation influence production but adaptation processes are also having impacts on farming practices perhaps making crops and livestock more or less vulnerable to disease. The indirect impacts of which can be felt in the human food chain. People in already marginal environmental and economic conditions are least resistant to stressful situations such as climate extremes and pests.

Food preparation and storage conditions can also be linked to food borne illness transmission. Increases in summer temperatures and the frequency of extreme heat days increase food's exposure to bacteria if food is not stored and refrigerated properly, and through the passing between foods during preparation process. Food preparation concerns were cited in Ottawa-Hull outbreak of *shigella sonnei* from a grocery-store salad during May, 2002 (Canadian Food Inspection Agency, 2002). Pollution Probe, in their recent report (2002) point out that a community such as the Toronto-Niagara region being somewhat of a global marketplace may be at a greater risk for tainted food exposure.

2.6.3 Coastal waters

Rising water temperatures at coastlines (both marine and fresh water) may stimulate the growth of pathogens and the production of biotoxins which accumulate in fish and shellfish due to the consumption of lower organisms such as phytoplankton (IPCC, 2001a). Residents of coastal regions or ethnic groups who traditionally consume fish and seafood may then be at greater risk of exposure to pathogens or biotoxins. Seals and waterfowl and populations who consume these marine species are at risk of associated biotoxins and organochlorines (St. Lawrence Action Plan, 2002). Not to only are specific ethnic groups subpopulations at risk, but women and children can be disproportionately impacted. Biotoxins increase the likelihood of spontaneous abortion and impact reproductive capacity. Women can also pass toxins to their children via breast milk. Children have a greater capacity to absorb toxins. Also, drought conditions and warmer temperatures combined with UV and ground level radiation impacts fish food production through a decrease in stock and diversity (Schlindler, 1998).

Water used for recreational purposes also can be a health risk in association with extreme weather events. Following significant rainfall beaches in urban areas are often closed for high bacteria counts. For instance during the summer (2002) the City of Ottawa would close Westboro and Britannia beaches (both on the Ottawa River) for at least 24 hours following rains of 5 mm or more due to high levels of bacteria (City of Ottawa, 2002). Unfortunately, the heat of summer (and in light of rising summer temperatures) people seek relief in water-related activities. In attempts to reduces the public's exposure to microbiological contamination by water in recreational use the St. Lawrence Vision 2000 Action Plan developed projects that would river aspects such as: assess 30 known bathing sites, conduct a virological analysis, bacteriological sediment quality, riverside population survey and an epidemiological study of *giardiasis* and associated risk factors (St. Lawrence Action Plan, 2000).

2.7 Vector-borne Infectious Diseases

The geographic distribution of vectors and intermediate hosts of transmissible diseases is ecologically dependent, in part because climate limits the ability of vectors and pathogens to exist or to multiply in an environment. Vector-borne diseases are therefore sensitive to variations in climate. A warming climate may allow the range of disease vectors and of intermediate hosts of infectious diseases to extend northward and uphill (IPCC, 2001a). However, disease transmission among human populations is determined by a complex interrelationship of ecological, geographic, demographic, socioeconomic, behavioral and cultural factors. Therefore, anticipating and modeling the effects of climatic change on disease transmission based on climate scenarios is still highly problematical (IPCC, 2001a).

IPCC (2001a) outlines in detail the infectious diseases that are most sensitive to climate changes. Some of these diseases may become more prevalent in North America. Recently, the spread of West Nile virus, Hantaan virus and Lyme disease have raised significant concern. Although the arrival and spread of West Nile fever in the US and Canada is not caused by climate change, the area of infection may be influenced. The virus was merely carried to a suitable new environment where a variety of susceptible mosquito vectors and birds allowed it to become established and to spread. The Hantaan virus is well established in North America, and is carried by wild mice whose urine and feces can transmit the virus to humans, to whom it can be fatal. In North America, the number of human cases is increasing. Lyme disease and a related illness, called Rocky Mountain Spotted Fever is caused by a bacterium transmitted by a tick which requires rodents and deer as animal hosts. Longer warm seasons and higher average local temperatures may permit increased proliferation of the hosts and vectors (Last and Sahni, 2002). The range of the animal hosts and ticks is spreading northward due to a warmer climate. As well, the development of wilderness lands, and increased human outdoor recreation activities have led to an increased contact between humans and ticks. Vector borne diseases can also be transferred by travelers from one ecological region to another.

2.8 Health Effects of Stratospheric Ozone Depletion

Several kinds of halogenated greenhouse gases (GHG) contribute to the depletion of stratospheric ozone, and thus increase human exposure to solar UV radiation (IPCC, 2001a). Human health effects of excessive solar ultraviolet radiation include the following (UNEP 1998; IPCC, 2001):

- Immunosuppression, enhanced susceptibility to infections and cancer

- Sunburn, loss of skin elasticity
- Basal and squamous cell cancer
- Corneal opacity (cataract)

2.9 Health and Well Being

In its widely accepted definition of health, WHO (1948) suggested that the term "health" means not only the absence of disease, but also the physical, mental, and emotional well-being of individuals and communities. Although mental and emotional health is rarely discussed in connection with climate change, particularly in discussions of the co-benefits of GHG emission mitigation, it can be assumed that long term adaptation to climate change will require greater attention to mental and emotional impacts.

2.9.1 Population Displacement

Severe climate conditions may result in population displacement, and Prothero (1994) suggests that there are two main health impacts of population displacement: i) those arising from the need to adapt to a new environment, and ii) the adverse results of living in a temporary space such as a refugee camp. These impacts are mostly cumulative. The displacement of a population to a new community or environment may increase the human burden on the local ecosystems, and it may also lead to demand for additional social and health services. Practices adapted to one environment may not be transferable to a different environment. This situation leads to increased physical and psychological stress and requires the acquisition of new skills and practices. This, and the social disruptions and the experience of displacement will affect the health and well-being of displaced persons, e.g. through decreased individual immunity to infectious disease. The health impacts of living in cramped and unnatural conditions, such as a refugee camp, are a result of overcrowding, poor nutrition, improper medical attention and inadequate sanitation and undue stress. Inadequate support by government agencies may lead to dissatisfaction and to political unrest.

2.9.2 Perceived Risk

Repeated messages of risk may create perceived notions of risk (both substantiated and unsubstantiated risks). Regardless of the severity of the risk, the implications may influence an individual's or community's quality of life and thus well-being through the awareness of the 'possibility of risk.

2.9.3 Discomfort

An earlier discussion on the health effects of increased temperature and extreme events indicated that there are emotional and mental effects that should be mentioned. For instance, we know that the frequency and severity of summer hot days increase likelihood of cardio-respiratory disease, however, there are less visible effects linked to well being. Discomfort due to lack environmental control, minor physical ailments (such as tiredness), displacement and changes in life-patterns may lead to a range of emotional responses which can include agitation.

2.10 Health Scenarios

Many climate scenarios have been developed for climate and physical attributes of the environment. It is possible to extrapolate these scenarios and to use them for assessing the possible health effects of climate change. The usefulness of such "health scenarios" will be limited by availability of data and by the inadequate ability to anticipate health effects (Last and Shani, 2002). The adaptability of climate scenarios to health will be assessed in a further discussion of quantitative modeling of the possible health impacts of climate change.

2.10.1 TARGETS and the Population and Health Submodel

The TARGETS model is an integrated assessment model that takes account of multiple environmental factors and of population and population health characteristics. The population and health submodel is one of the TARGETS contextual models (Rotmans and de Vries, 1996) and is based on the earlier work of Niessen and Hilderink (1997a) and van Vianen (1994). The population and health submodel framework integrates socio-economic conditions, demographics, environmental pressures and the impacts on population and health structure. This submodel can describe long term changes to populations and their health under various socio-economic and environmental conditions (Niessen and Hilderink, 1997b). The framework can assist in policy development. The model addresses health transitions, i.e. the typical changes in health and fertility as a society develops. This evaluation of health transitions is based on the epidemiological transition model (which depicts a society mortality rate changing from infectious disease mortality to degenerative disease mortality) and on the fertility transition model (change from a high fertility rate society to a low fertility rate society). In combination the health transition portion of the submodel addresses three stages: 1) reproductive needs, amenable disease and premature mortality; 2) population growth, economic development and environment; and 3) aging and demand for health care.

The TARGETS population and health submodel makes use of current models and theoretical approaches to determine population and health conditions. The main structure of the submodel draws upon the Pressure-State-Impact-Response (PSIR) framework which consists of four modules (Niessen and Hilderink, 1997a,b). The four modules are: 1) A pressure module which highlights health determinants influenced by income, education, environmental factors, and sustenance availability; 2) A state module which depicts the behavioral and population response and dynamics in relation to disease, fertility, age, and gender; 3) An impact module which describes the state module conditions with indices such as burden of disease, life expectancy, years of life lost etc.; 4) A response module which addresses political and decision making processes on health and behavior that influence disease processes (Niessen and Hilderink, 1997b).

2.10.2 Disease Modeling

Disease scenarios can be derived through disease modeling techniques adopted by scientists such as Pim Martens (1998). An example of disease modeling is described below, using Martens' (1998) modeling of vector borne diseases. Martens has created the model using malaria conditions. Although malaria may not be seen as having a direct impact on the health of Canadians, this model was included as an example of the quantification and surveillance of vector-borne diseases. To better understand the health effects of anticipated climate change, climate scenario values could be adapted into disease modeling and thus into disease scenarios.

2.10.3 Martens and the transmission of vector borne disease

Martens (1998) describes the interaction of temperature and precipitation on the transmission cycles of vector borne diseases (specifically malaria, dengue and schistosomiasis). Using malaria as an example, Martens (1998) calculates the rate of basic reproduction (R0) based on factors such as ratio of mosquitoes to humans, mosquito bites per person per day, efficiency of biting and the likelihood of a mosquito acquiring the disease from biting an affected person and the incubation period as a ratio of human recovery and survival of the mosquito. The incubation period and the survival of the mosquito is affected by climate. Simply stated, if the reproduction rate is greater than one ($R0 > 1$) the disease will proliferate. The disease will die out if the rate of reproduction is less than 1, or in other words, if sufficient checks on proliferation exist (e.g. human recovery, mosquito survival). Martens allowed for climatic effects on the rate of reproduction such that his disease model incorporates the acceptable ranges of temperature, moisture and humidity required for reproduction (these are temperature dependent variables). For example, the malaria parasite requires for its development in the mosquito vector a minimum environmental temperature of 14-15°C with maximum 32-34°C . The development of these models has led to the construction of baseline and range models that can be applied to climate and health scenarios. Martens (1998) points out that these disease model simulations indicated a major increase in the population exposure to disease transmission.

Although habitat for malaria mosquitos do exist in Canada, as is evident historically (e.g. building of the Rideau Canal between Ottawa and Kingston), malaria is not considered have population health impacts immediately associated with a warming climate. Vector borne health risks associated with an increase in Lyme disease and West Nile Virus (as examples, see sections 2.7) may require such complex modeling structure as Martens' malaria model.

3. Socio-Economic Impacts of Climate Change

3.1 Socio-economic Impacts

From a socio-economic perspective, climate change is a problem with relatively unique characteristics because it is global and long-term. It is not truly unique since bio-diversity loss, ozone depletion, acid rain (to a more limited geographical extent), all of which are features of Global Change, share similar features of a public good (or bad). The phenomenon is indivisible and has wide-reaching long-run costs (climate change, biodiversity loss, acid rain, etc.) and benefits (climate, biodiversity, air quality protection). Since the benefits are global, they tend to be underestimated. These global benefits could be weakened by the inaction of a significant GHG emitter. As will become clearer in the next chapter, health benefits from climate change mitigation, though still sharing public good property, are more local than other mitigation benefits.

Climate change is more long-term than most socio-economic problems. In particular, it requires much longer time horizons (several decades up to centuries) than those usually contemplated in public policy or in economic decisions. The latter seldom extend beyond 60 years for long-lasting assets such as dams, because of the erosion of their net benefits through the action of the discount rate. Finally, there is intertemporal asymmetry between costs and benefits. While costs are borne now, benefits are reaped in the future. Of course, the costs of climate change impacts are borne in the future as well, but they are, like the benefits, discounted explicitly or implicitly by policy-makers. As will become clearer in the next chapter, health benefits form climate change mitigation are less remote in time than the other benefits from mitigation.

Current costs are interdependent to the extent that they affect competitiveness among signatories and non-signatories to the Kyoto Protocol. Increased costs may be borne by signatories who trade with non-signatories. This situation applies currently to Canada, and gives a perverse incentive not to sign an international agreement on climate change. Costs may decrease as the number of signatories increase since opportunities for cheap emissions reductions may be increased as well; this is what motivates the so-called Kyoto flexibility mechanisms (see below). Since the benefits of climate change mitigation are global and mitigation costs are interdependent, voluntary actions, whether taken by countries, smaller jurisdictions or individual firms, do not make any sense unless they take these global benefits of GHG emissions reductions and their impacts on other parties' costs explicitly into account. Voluntary actions, though they are definitely in the interest of the party adopting them, do not necessarily provide global benefits. The argument about the limits of voluntary action must be tempered when the extended to health benefits as these tend to be more local than mitigation benefits.

Climate change results from interactions between the physical climate sub-systems and the biosphere sub-system, which make up the complex non-linear dynamic climate system (see Appendix B which describes the science of climate change). The biosphere encompasses environmental, technological and socio-economic subsystems. A complex system is fundamentally unpredictable because it is a middle-number system which escapes both the complete mathematical description of a Newtonian mechanical system and the statistical description of a system counting many identical components and a limited number of properties such as statistical systems. Therefore, statistical forecasting of future climate change and its impacts is ruled out (Weinberg, 1975). A non-linear system may be subject to catastrophic and chaotic behavior which leads to sudden and profound changes involving reinforcing (positive) feedback mechanisms (Schneider, 2001). Climate change thus requires decision-making under uncertainty, as the risks are poorly known, with potentially irreversible consequences. Moreover, there will be substantial time-lags between decisions and their consequences, as decisions require changes in entire technological systems, such as energy systems subject to large sunk costs and lock-in.

The essential question for policy developers and decision makers is whether climate change requires early and significant attention (Rotmans and Dowlatabadi, 1998). Policy developers and decision-makers are concerned about the risks of climate change, the costs of action, their distribution over time, avoidable losses, etc. However, the risks associated with climate change arise not just from a global temperature increase, since we are dealing with a highly interconnected complex system subject to all sorts of feedbacks. Moreover, regional temperature differentials matter more than an abstract average global temperature.

Since the complex climate system is unpredictable through forecasting methods, one must explore the possible futures through scenario projections. The global future is conditioned by the co-evolution of a complex web of social factors including technology, demographics, and their interplay with a changing biosphere, which can be described qualitatively (as a storyline) or quantitatively (through mathematical modeling). Most scenarios combine both features. Some factors which are essential in this context, such as governance, or social structures and institutions, escape quantification. The scope for the emergence of novel features expands with time, as does the potential for relatively rapid transitions to structurally different conditions. The inherent long-range uncertainty implies that probabilities cannot rigorously be assigned for either a given set of driving assumptions, or for the likelihood of structural shifts in societies and natural sub-systems. Therefore a spectrum of scenarios rather than a single baseline scenario is required for the formulation of robust policies (IPCC, 2001d).

When one looks at direct socio-economic impacts of climate change, one has to focus first on those which result from environmental perturbations of ecosystem functions (natural capital) and then on their consequences for population migrations and population health. There are indirect socio-economic impacts resulting from environmental perturbations on physical capital (e.g. pipeline breakage) and on social capital.

3.1.1 Socio-economic impacts from natural capital perturbations

Socio-economic impacts resulting from natural capital perturbations will affect renewable resources: land (through agriculture and forests), water (ocean level increase, decrease in freshwater availability and quality in drought-prone regions, fisheries), extreme events (winds, precipitations, etc., as examined in Section 2.1).

3.1.2 Population migrations

Massive disorderly population out-migrations may threaten world security. This may result from droughts, desertification, and floods which push a segment of a population to seek a more desirable environment. International migration is already pulled by the search for higher income in a world in which the gospel of free markets is increasingly spreading. When the scarcity of natural capital increases, the incentive to monopolize it increases as well, thereby further increasing existing income inequality, and pressures to migrate, which may create conflicts. If out-migrations are prevented through closed door policies, then local massive environmental collapses and further conflicts are likely.

The only distinction between environmental refugees and regular migrants (legal or illegal) on which there seems to be some degree of agreement is that the former leave their country involuntarily and somewhat precipitously and that, in comparison with the regular migrant, environmental refugees supposedly adapt less well to their host country (for social reasons pertaining to both the host country and the guest refugee). Some estimates of so-called environmental refugees (whose definition remains highly ambiguous) range from about 0.2% of the current population to 1.5% by the year 2050, most of them from China, India, Bangladesh and Egypt. Public policy has significant implications for environmental refugees, as their state of origin may or may not adopt policies which encourage environmental adaptation. Adaptation is clearly possible with slow-changing (desertification) and with recurring phenomena (droughts and floods). After extreme events, many refugees tend to return once recovery from the disaster seems possible.

Sea level rise and associated flooding, which already affect some island states in the Pacific (e.g. Tuvalu) will be a major cause of migration. Sea level rise forces people to move, because it causes both flooding of their habitat, and saltwater intrusion into groundwater. However, in many cases dykes can be used to reduce flooding , if sea level rise is not too fast and the mitigation measures are not too expensive. For example, the Nile delta is clearly vulnerable to sea level rise, but since the value of land in the delta is high, mitigation measures are likely to be adopted. This is less likely for South Pacific islands.

To the extent that tropical countries will be affected more negatively by climate change than northern countries, immigration pressures from the South will increase (MacKellar et al., 1998).

3.1.3 Socio-economic consequences of physical capital perturbations

Physical structures such as pipelines and other transportation structures may be affected by melting of the permafrost, while sewers systems, wastewater treatment plants, and other municipal infrastructures will have to cope with more intense rain events and severe winter storms. This will tax the emergency and snow removal systems. Hospital facilities will clearly be affected. The southern cities of Canada will likely experience a decline in the demand for space-heating and an increase in the demand for space-cooling. Municipal water systems may require expansion because of reduced local water availability and more frequent water quality problems (GCSI, 2000).

3.1.4 Socio-economic consequences of perturbations to social capital

Social capital will be affected by the need to modify institutions such as insurance systems, by-laws prohibiting settlements in low lying areas prone to flooding, and a reassignment of regional or local constitutional environmental responsibilities. Health institutions will be affected as well.

Institutions are a form of capital, namely social capital. At the microeconomic level, social capital may be viewed as a social network and associated norms which may improve the functioning of markets and the productivity of the community for the benefit of the members of the association. At the macroeconomic level, social capital includes the political regime, the legal frameworks and the government's role in organizing production to improve macroeconomic performance as well as market efficiency. Social capital, like natural and human capital, is at the same time an input and an amenity. As an input, it enhances the benefits of investments in other factors and, thereby, shares the "shift" feature of technology. Social capital is a public good and suffers, therefore, from under-investment. Examples of social capital are mutual credit (increase capital mobility) and insurance associations (spread risk), co-management (lower information costs), etc.

Social capital remedies market failures due to asymmetric information through, albeit fallible, information sharing. It builds trust through repetitive behaviour and transactions among players which generate information on players' past behaviour, and which thus stabilize membership. It creates a climate of cooperation analoguous to the indefinitely repeated prisoners' dilemma situation (Axelrod, 1984). Societies with a sizeable social capital derived from trust and civic cooperation are strong, are more productive, and provide stronger incentives to innovate and to accumulate physical capital. Trust and civic cooperation tend to increase human capital productivity. It is therefore important that Canada adopt a cooperative climate change policy.

Unfortunately there may be many misplaced incentives, such as inducing landlords to purchase the cheapest energy equipment without regard to its impact on operating costs (which are shifted to the tenants). Producers of fossil fuels have vested interests in preventing the spread of new renewable technologies. Current lifestyles, behaviours and consumption patterns based on cars as a mean of freedom, mobility, safety, symbol of personal status and identity, constitute major barriers to climate change mitigation anchored in social capital (IPCC, 2001d).

Social resilience, a feature of social capital, means an ability to cope under stress, to learn from and to reorganize to meet changed conditions. Social resilience clearly affects vulnerability to climate change. Social resilience is not the same as adaptive capacity, as adaptation results in long-term incremental changes. Social resilience modifies institutions to enable them to absorb and respond to short-term changes without passing a threshold which flips them into an alternative state of equilibrium, and is much like ecological resilience. Resilience maintains overall community persistence, adaptive capacity, flexibility, and ability to exploit positive opportunities (Barnett, 2001). The capacity to adapt or to mitigate climate change is part of the capacity to cope with other stresses (Yohe, 2001). Therefore, adaptation and mitigation must be integrated and not considered in succession. Systemic complementarity between climate change mitigation and other objectives such as sustainability enhances the adaptive capacity. However, differences between the capacity to adapt and the capacity to mitigate occur due to distributional factors and differences in interactions. Thus one could have strong adaptive capacity and weak mitigative capacity. Social resilience depends upon technological options, policy instruments, institutions, resources and their distribution, the stock of human capital, and the ability of decision makers to manage and use information.

A major impact of climate change upon social capital is related to the equitable distribution of net benefits of climate change mitigation. Political pressure and the size of the possible losses for the losers from the mitigation policy are a potential barrier to the adoption of climate change measures; these losses may require compensation (IPCC, 2001d).

4. Co-Benefits of Climate Change Policies for Canada

This chapter will begin by a discussion of the distinction introduced by IPCC between co-benefit and ancillary benefit, a distinction essential to benefit-cost calculations for planned policies. However, few empirical studies make the distinction. Moreover, the distinction is not customary in Canada. Therefore, only the term co-benefit will be used in the chapter except when ambiguity would result. The chapter will investigate the relation between co-benefit and baseline and emphasize co-benefits' short-run and local character. While not raising intergenerational equity issues, co-benefits may raise intra-generational ones, such as "leakage" effects. The chapter emphasizes the uncertainty - tempered by their proximity in time - surrounding the few empirical estimates existing in the literature. In Canada, health co-benefits are relevant for Kyoto-driven policies, such as permit trading, public transit policies, etc., which may have locally differentiated health impacts. Criteria co-pollutants give rise to most of the health co-benefits and the latter are easier to estimate because of the availability of large epidemiological data-bases. Economic valuation of the co-benefits is subject to large uncertainties. Estimates of health co-benefits from the recently released Government of Canada Climate Action Plan are provided and compared to earlier ones. A concluding section offers a preliminary assessment of the Climate Change Draft Plan from the human health point of view.

4.1 The Concept of Co-Benefits

Climate change, being a global environmental problem, requires international agreements such as the 1992 United Nations Framework Convention on Climate Change (UNFCCC) and its 1997 Kyoto Protocol signed by Canada. The latter, if ratified by Canada, jointly with 54 other nations (94 countries have already ratified), which are jointly responsible for 55% of the world GHG emissions (the current figure is only 37.4 %), requires Canada to reduce its emissions by 6 % with respect to the 1990 baseline of national emissions. The required reduction for Canada (about 240 megatons of CO_2 equivalent) is about 33 % of projected emissions in 2010. However, Canada is entitled to sink credits (about 48 megatons of CO_2), which reduce its effective reduction commitment to about 210 megatons. Indeed, the Government of Canada estimates the sinks currently qualifiable for credits through international rules to be about 30 megatons to be increased to 36 megatons, with an additional 12 megatons qualifiable as credit for domestic rule (Government of Canada, 2002b).

GHG mitigation (preventing further climate change) generates benefits and costs, but still requires adaptation to a changed climate since mitigation, as required by the Kyoto Protocol, is both insufficient and subject to physical delays in reducing GHG concentrations. Emission reduction (mitigation) policies generate both co-benefits and ancillary benefits (IPCC, 2001d). Co-benefits are joint primary benefits resulting from the selection of one instrument aimed at reaching several targets (e.g. climate protection and better air quality) and are counted as a benefit in an integrated benefit-cost analysis conducted at the policy selection stage. Ancillary impacts are secondary impacts of GHG mitigation policies aimed at reducing GHG, either positive or negative, such as impacts on local air pollution resulting from the implementation of the climate policy, but not counted as benefit or cost at the selection stage of the policy. A local air pollution abatement policy may, therefore, provide ancillary benefits or costs in terms of climate protection (IPCC, 2001d).

As we will focus on health co-benefits and as the IPCC distinction between co-benefits and ancillary benefits is really not respected in the empirical literature and in Canada, from now on, we will use the more common term co-benefit and drop the term ancillary benefit unless ambiguity arises.

The valuation of co-benefits are scenario and baseline dependent. In particular, the co-benefits depend upon the policy assumptions included in the baseline. From an international point of view, a policy may be defined as a GHG policy while, at the local level, it may be considered as a two target policy, being aimed also at local pollution abatement. The accounting of co-benefits is scenario dependent to the extent that the scenarios depend on demographic, technological and regulatory regimes.

The definition of co-benefits depends on the answers to three questions:

- What are economic actors in a particular country doing at the present time with respect to air, water, waste, emissions, accidents, etc. independently of any proposed GHG mitigation policy?
- What will these actors do in response to the new GHG policies?
- What would these actors have done in the future had the GHG mitigation policies not been adopted? (Morgenstern, 2001).

Co-benefit estimates are baseline-dependent. They depend on population size, demographic characteristics and income, which affect willingness to pay, and baseline mortality rates. Co-benefits tend to increase with population density (e.g. urbanization), and also depend upon the economic and energy regulatory framework. If energy demand is reduced rather than switched to less carbon intensive fuels, co-benefits will be larger. Estimates of impacts must include the environmental regulatory environment in the baseline i.e. benefits from environmental non GHG policies in force at the current time or to be implemented in the near future. The degree of compliance to a regulation is also part of the baseline. With a cap on SO_2 emissions, abatement cost savings are considered as co-benefits for a GHG policy, as long as the cap on SO_2 is binding, bringing health benefits. Finally, the direction of dominant winds may make a significant difference regionally and locally.

Most of the key co-benefits are relatively short term and are "local" in that they affect communities located relatively close to the sites of emissions changes. They are short term because they result from no regret policies i.e. policies which are needed in any case because the economy is currently subject to market failures and because the benefits of moving to an efficient economy exceed the costs of the move. Despite their mainly local effect, co-benefits are also national in character since mitigation policy implementation is nationally determined. These opportunities for no regret policies are limited and become increasingly difficult to find.

Impact assessments should consider the leakage or "bounce back effect" of GHG mitigation on other non GHG pollutants which may become substitutes for the original GHG emissions. GHG measures may entrain ancillary costs such as shifting from gasoline to diesel fuel, which reduces emissions, but increases conventional pollutants. Similarly, shifting to hydro electricity has negative impacts on ecosystems, while a shift to nuclear energy may entail risks of radiation impacts. Reduction of the use of conventional fossil fuels in industrialized countries may decrease international fuel prices, and increase their adoption in non-industrialized countries, leading to a so called "leakage effect" (Krupnick et al., 2001).

Impacts are also dependent on whether or not other pollutants are capped, because ancillary impacts are obtained only if the cap holds tight.

Co-benefits and ancillary benefits are not necessarily externalities because some may be at least partially internalized. Externalities are uncompensated third party effects which are not taken into consideration (internalized) by the market. For example, a car accident may affect a third party but is not an externality if all parties are fully insured.

There are very few studies of ancillary impacts. Most existing studies convert policy tools into carbon tax equivalents. Therefore, knowledge of the incremental cost curve for measures to be adopted is very important. A measure is defined by the Federal Provincial Analysis and Modeling Group (AMG) as an action (e.g. installing scrubbers) accompanied by a policy (e.g. requiring an emission reduction). Co-benefits and ancillary benefits are not limited to the health area. Improvements to ecosystem health, visibility improvements, reduced materials damages, reduced crop damages, more limited use of private automobiles with the ensuing effects of reducing traffic congestion, air pollution and car accidents, are all co-benefits of GHG mitigation measures. From the empirical point of view, co-benefit benefit studies depend on the particular nation (national policy), location (economies, ecosystems, airsheds, etc.), and scenario. Therefore, international comparisons of co-benefit estimates are generally difficult. The co-benefit modeling exercise should be disaggregated at the local level (Krupnick et al., 2001).

Co-benefit estimates are at least as uncertain as estimates of other climate change effects, because their estimation requires multi-step modeling and a valuation step, each fraught with assumptions and errors. Estimation of the size of pollutant emissions, of their dispersion, their transformation and their impacts are required. Early studies tended to adopt fixed conversion coefficients between GHG and criteria pollutants. This methodology is questionable, as the relation between pollutants and GHG is non-linear. Valuation is based on statistical techniques which have large error bounds. The cumulative uncertainty is thus enormous, and needs to be clearly stated (Krupnick et al., 2001). However, the proximity in time of these co-benefits and, therefore, a better knowledge of the policy context in which they will be reaped, make them relatively more certain than the long run benefits of climate mitigation.

Avoided costs may result from the cost interactions among two different policies, one focused on GHG, and one e.g. focused on air quality. The adoption of a GHG focused policy may make it cheaper for firms to achieve an air quality target. For example, in the US, it has been estimated that to satisfy the SO_2 cap in the baseline, thermoelectricity producers needed to install scrubbers in plants with a total generating capacity of 82 Gigawatts (Gw). With GHG policies, the number required fell to 63 Gw saving about US $ 0.5 million (Morgenstern, 2001).

Implementation of Canada Wide Standards may contribute towards mitigation of climate change depending upon the technology being implemented.

In evaluating the costs of implementing the Kyoto Protocol, the significant health co-benefits of climate change policies should be taken into account by Canada at the outset. More precisely, ancillary benefits should be transformed into co-benefits by changing Canada's climate change policy into a two targets policy, which would be both climate-oriented and health-oriented.

4.2 Health Implications

The extent to which human health benefits will accrue from climate change policies will be determined by the answers to the following questions:

- By how much will Canada have to reduce its emissions to effectively reach a health motivated emission standard?
- Do sinks have a health impact?
- Will the type of emission reduction and sink affect population health?
- Will actions undertaken internationally have a direct domestic health impact? (e. g. to what extent do purchases of international emission reduction permits, JI and CDM projects affect air quality in Canada?

The answers to these questions are not clear, due to a large variance in methodologies and estimates in the existing studies.

As health co-benefits are short term and local in character, issues of intergenerational and international equity do not arise directly. Co-benefits arise within the same time horizon as the costs of mitigation. Co-benefits are largely limited to measures affecting air quality and transportation, and thus would occur in the present. Since they are local in character, they have to be taken into consideration in the design of national economic instruments for mitigation (Krupnick et al., 2001). For example, initial geographic allocation of grandfathered permits in DET may attempt to maximize health co-benefits. In this context, Ontario could receive a large initial entitlement assuming that its air quality is not affected by the US, which is, of course, not the case. Horizontal equity in Canada requires that when regional burdens of implementing Kyoto are compared, then regional health co-benefits should also be taken into account.

4.2.1 Co-Benefits of Reductions in Criteria Pollutants

A policy aimed at reducing road traffic or expanding public transit may yield co-benefits in GHG mitigation, particularly in urban areas. Similarly, co-benefits may result from a policy aimed at reducing air pollution. A major co-benefit from GHG reduction results from the reduction in emissions of local air pollutants. Policies to expand rapid mass transit provide this type of co-benefit. A joint European study estimates that the annual number of deaths linked to traffic based pollution exceeds the number of deaths linked to road accidents, and that more than one half of air pollution related health costs are road traffic related. Traffic congestion contributes to increased exposure to pollutants with levels in private vehicles 2 to 8 times those in the surrounding air (IPCC, 2001d). Traffic crashes are also a leading cause of death; the number of crashes would be reduced with expanded public transit. On the other hand, policies intended to increase fuel economy have little impact on urban ground level ozone concentrations, and could even generate ancillary costs such as decreased security (IPCC, 2001d).

The type of health co-benefit most intensively studied deals with reductions in criteria pollutants. These studies lead to the broad conclusion that co-benefits from reduction of co-pollutants are significant but vary considerably across countries, across sectors, according to the nature of policies adopted, etc. In many of the studies, the results are driven by decreases in NO_x and CO. VOC and PM reductions lead to smaller co-benefits. Direct particle emissions (Long-range Transport Suspended Particles and PM_{10}) are included, while secondarily formed compounds such as sulfates and nitric acid are excluded, despite the fact that the latter have large potential health effects. Therefore the full set of air pollutants should be considered. A considerable variance exists between European and US studies, because European studies are more aggregate, population density in Europe is higher, and more emissions are deposited there on land than off-shore, contrary to what happens in North America. Co-benefits have declined over time, mainly because the quality of their estimates has increased (Morgenstern, 2001). Because of the strong epidemiologic database on air pollution and population health, inclusion of heath co-benefits in cost-benefit analysis of appears to be feasible.

4.2.2 Valuation of Health Co-Benefits

According to a recent Norwegian study (D.S. Glomsro et al., cited in IPCC, 2001d), improved population health resulting from improved air quality could offset roughly 2/3 of the GDP loss arising from policies to reduce GHG emissions. A \$3 tax per barrel of oil levied in 1993, increasing by \$1 per barrel each year until the year 2000, would reduce atmospheric SO_2 and NO_x levels by between 6 % and 10% in 2000.

Large variations in benefit estimates reflect a lack of methodological agreement. The best measure may be the percentage variation in welfare loss that does not include climate change benefits. Another one might be co-benefit per ton of carbon emission reduction. Recent estimates in the US are in the range of US \$ 3-6 per ton of carbon abated with modest GHG reduction policies costing US $ 10 per ton of carbon (Morgenstern, 2000, p. 101). Applied - with all the previous caveats - to Canada, which has to reduce its emissions by 240 megatons of CO_2, this would lead to an undiscounted co-benefit of about Can $ 0.33 billion to Can $ 0.66 billion (1996$) per year for measures costing approximately Can $ 5 per ton of CO_2 abated, not an unreasonable figure.

Co-benefit estimates are very sensitive to assumptions about the mortality risk coefficient and the value of statistical life (VSL). The most important health effects are premature mortality and respiratory effects. Most of the existing studies rely on concentration response functions. As air pollution tends to be at low concentrations, assumptions about the existence or non-existence of pollutant toxicity thresholds for health effects are crucial. The existence of confounders and synergies among pollutants is also of great importance. As the benefits of increased life-expectancy occur in the future, this reduces the corresponding benefit, because willingness to pay to reduce mortality risks is age-dependent. Finally, assumptions about the type and concentration of particulate emissions resulting from GHG emissions affect the estimation of lives saved. Benefits from reduction of chronic respiratory illnesses and heart diseases are poorly known (Krupnick et al., 2001) (see Appendix A, Tables A.1 and A.2 taken from IPCC, 2001d).

4.2.3 The Health and Environmental Co-Benefits in Canada

Relative to the benefits from GHG emissions reductions, co-benefits are immediate, local and relatively certain. The net present value of these co-benefits discounted at 10% was estimated by the Federal Provincial Analysis and Modeling Group(AMG) Environmental and Health Impacts (EHI) Sub-Group as being between $CDN 2.7 and 4.5 billion (1996 $) over the next 20 years if the mitigation measures adopted are mainly domestic. This translates into $300 to $600 million (1996 $) per year in co-benefits. Most of these benefits result from reduced risk of mortality, as between 92 and 150 deaths would be avoided in 2010.

These estimates have been recently revised downward in the October 2002 Climate Change Draft Plan. The latter, if implemented, would avoid 600 premature deaths, 1000 cases of chronic bronchitis and hundreds of thousands of asthma attacks over 20 years. The co-benefits have been reduced to $ 160 millions (2001 $). There are three reasons for this drastic reduction. First, the 2002 Climate Change Draft Plan considers a reduction of 170 megatons rather than the full 240 megatons (Government of Canada, 2002b); however, the estimated “gap” between estimated emissions in 2010 and 1990 at the time of the first estimate was roughly equal to 170 megatons. Second, the economic models used in the two estimates are not the same. Third, as a result, the measures required to bring about the GHG emissions reduction are different.[1] Roughly, each ton of CO_2 removed generates $ 1 of health benefits. If the marginal cost of implementing Kyoto in

[1] Some explanation for these figures was provided through personal communication by Environment Canada. MARKAL and CIMS were the two micro-economic models used for the previous results. Energy 2020 is the micro-economic energy model used for the current results. The change in models led to changes in actions, which required less reduction in coal-fired electricity, and thus in criteria air contaminants, than for the previous results.

Canada were equal to the price of an international emission reduction permit for 1 ton of CO_2 - it would in an ideal world (all externalities internalized, perfect markets) -, this means that roughly 10 % of the benefit of abatement would be attributed to health if the permit price were in the Can $ 10 range as anticipated (Government of Canada, 2002b; Natsource, 2002). In a less than ideal world (for economists), the health co-benefit will be smaller than 10 % of the benefit of GHG abatement. However, a less ideal world may involve more domestic effective reduction in Canada, i.e. less recourse to emission reduction permits. Current planned use of permits cover nearly 40 % of the planned 170Gt reduction (Government of Canada, 2002b).

"These societal benefits represent the value that Canadians place on these co-benefits, as determined by estimates of their willingness-to-pay to achieve these avoided impacts"(AMG, 2000). These estimates are not comparable to GDP, because they do not represent actual outlays. The old estimates are at the low end of international estimates and pre-date the Bonn Agreements, the Marrakech Accords, and the US withdrawal from the Kyoto Agreement. These estimates correspond to US$ 5 to $ 11 per ton of carbon, while most of the estimates lie between US $2 to US$ 500. Obviously geography, population density, air contaminants covered, and baselines all contribute to the discrepancies between these figures. Moreover, these estimates do not cover all criteria pollutants and sulfate reductions in Western Canada (AMG, 2000). The EHI report estimated that actions to implement Kyoto could make an important contribution to Canada Wide Standards (CWS). "It achieves most of the required NO_x reduction, some of the SO_2 reduction, and makes minor contributions to achieving required $PM_{2.5}$ and VOC reductions". (AMG EHI, 2000). The largest emission reductions were expected by the AMG to occur in the electricity and transportation sectors. Under the new estimates, reductions are less drastic in the electricity sector than they were under the old estimates and the statement about CWS must no doubt be tempered.

The EHI estimates are based on spreadsheet models maintained at Environment Canada which estimate changes in atmospheric pollutants, SO_x , NO_x, VOC, particulates and carbon monoxide associated with various path scenario combinations defined by the AMG, using the energy change results from a micro model used by the AMG as inputs (see Technical Report).

A GHG inventory is available for Canada from 1990 to 1999 (EC, 2001). An Emission Outlook is available for 2000-2020 (NRCan, 1999). Four scenarios were considered: high, medium, low and BAU. From this, Criteria Air Contaminants (CAC) forecasts were effected, then changes in ambient air quality by regions were forecasted and, next, the Air Quality Valuation Model (AQVM) was used. The major economic sectors covered are: transportation, electricity generation, mining, smelting, pulp and paper, residential and commercial fuel use, waste management and waste disposal. NRCan had projected that emissions in 2010 would be about 764 megatonnes of CO_2 equivalent (NRCan 1999). They have been revised upward to 810 megatons. Therefore, these early projections are clearly an underestimate of BAU emissions in 2010, unless a major recession occurs before that year.

Though the early AMG/EHI estimates are obsolete, they are presented below for completeness only. Hopefully, these estimates will soon be updated by Environment Canada.

On the basis of the early NRCan projections, AMG\EHI had projected a 24 % increase in $PM_{2.5}$, a 20 % increase in SO_x , a 10 % increase in NOx and a 5 % increase in VOCs by 2020 with respect to a 1995 baseline where the GHG emissions were about 660 megatons. Given the underestimation of GHG emissions in 2010, these CAC estimates are probably a lower bound for the baseline. The variance among regions and sectors is quite large.

The largest percentage increases were in NO_x and VOC in the electricity sector (27% and 43%), due to increased production. Increases in SO_x mainly from the upstream oil and gas (33%), petroleum refining (29%) and base metal smelting and refining (14%) sectors were somewhat offset by declines in the electric power generation sector. All emissions from transport were expected to decline due to expected improvements in fuel quality and emissions intensities: SO_x(-15%), NO_x (-20%), VOC (-42%) and POM2.5 (-17%).

The largest NO_x reductions were expected in Quebec (-23%), Manitoba (-11%), and the Atlantic Region (-10%), with significant increases in Alberta (16%). The largest SO_x increases were in Saskatchewan (37%), BC (31%), Ontario (20%) and Alberta (19%) whereas emissions declined significantly in the Atlantic Region (-27%). The largest increases in $PM_{2.5}$ were expected in Alberta (27%) and Ontario (20%) (AMG/EHI, 2000). Tier 1 vehicle standards, but not tier 2 standards were included in the baseline. Low sulfur regulations for gasoline were included in the baseline but not the ones for diesel. Canada Wide Standards also were not included (AMG/EHI, 2000, p. vi). The latter assumption was expected to be the most significant, as no new air quality measure is included in the baseline.

By far the greatest uncertainty about the baseline is the market penetration of new technologies in the future (AMG, 2000).

Relative to BAU, implementing the Kyoto Protocol would have the greatest impacts on SO_x and NO_x and smaller ones on PM and VOCs. The quantitative assessment of adverse health effects due to CAC involves fours steps:

- Conversion of GHG emissions into CAC emissions.
- Estimate of CAC growth in the baseline.
- Estimate of changes in ambient concentrations of pollutants.
- Estimate of health and environmental impacts.
- Estimate of the economic value of avoided health effects resulting from decreasing the Emissions (AMG, 2000)

Steps 1 and 2 are essentially based on assessments carried out by the Issue Tables and by the Science Impacts and Adaptation Group. There is therefore no way to replicate this process while incorporating the Bonn/Marrakech agreements, the pull out by the US, and the underestimation of the likely Canadian GHG emissions in 2012. Several models translate these changes in emission levels into changes in ambient air quality. Their results in turn provide inputs to the Air Quality Valuation Model (AQVM) (see Technical Report) which estimates both the physical impacts on health (mortality, hospital visits) and assigns a monetary value to these impacts. The latter are based on the health literature concerning willingness to pay for the avoidance of such risks (AMG, 2000). The physical impacts and monetary valuation are mainly focused on sulfates, ground level ozone and sulfur dioxide for which "there is fairly good data and modeling" (AMG, 2000). All path scenarios showed significant declines for NO_x (lower bound 9%) and SO_x (lower bound 14%).

The VSL used had a central value of Can $4.1 million which implies a willingness to pay of $ 400 for a mortality reduction of 1 in 10,000 (AMG, 2000).

The Kyoto Protocol has been weakened through the absence of enforcement, the wider admissibility of sinks, and the pulling out of the US. This will result in a much lower price for the international emission reduction permits which is currently estimated at about $10/ton of CO_2. (Natsource, 2002) Therefore, the incentive will be strong to substitute permits, either domestic or international, for effective domestic action. The AMG/EHI had estimated earlier that a wide recourse to emission trading would reduce the health co-benefits by Can $ 200 million per year, i.e. by one half to two thirds (AMG, 2000); this would mean a co-benefit of Can $1.25 per ton of CO_2 removed. The impact of thresholds is significant in that their assumed existence reduces benefits by one half (AMG, 2000). This observation must be balanced with the fact that the AMG/EHI did not cover all pollutants, and that it also omitted the contribution of sulfate reductions in Western Canada (Anderson, 2002).

4.3 Health Co-Benefits and the Climate Change Draft Plan: a Preliminary Health Assessment

Climate change policy should be systemic. It should be integrated with other policies such as those aimed at reducing air pollutants. It should also be integrated with policies which build upon people's preferences for affordable urban life without risks for personal security, without congestion and pollution. General equilibrium analysis is required, because changes in one sector are concomitant with changes in others which, in turn, influence the economy.

Since the future is very uncertain in terms of abatement costs, of climate change effects, of international policy regimes, and of technological opportunities, etc., it is essential to adopt robust policies i.e. policies which are effective under widely different scenarios.

Finally, policies should be adaptive in the sense that they should respond to new information on the science of climate change, the pace and character of technologies, or the actions of other countries. This probably requires policies which start with modest objectives (Jaccard et al., 2002).

Any limit on GHG emissions acts like an indirect tax (a carbon tax) on the supply of the products which are responsible for emissions, e.g. fossil fuels. Elementary economics tells us that the price of the product will generally be increased, and that the incidence of such a tax will normally be shared between producers and consumers of the product. How it is shared depends upon the relative shapes of the supply and demand curves. The less responsive to price the demand curve is, as is the demand for gasoline, and the more responsive to price the supply is, as is the supply for oil, the larger will be the burden carried by consumers. If one wishes to apply the polluter pays principle to the situation just described, then both suppliers and consumers are considered to be polluters. However, without tax revenue redistribution, consumers end up bearing a larger share of the tax. The only exception would be the US export market where non-renewable energy prices are determined in a market which is large (price is given) and whose prices do not take into account GHG regulations in Canada. The Canadian producer would bear the entire cost of the Canadian regulation, and the US consumer would be the 100 % polluter who would not pay anything for the environmental damage. Governments could in principle compensate the polluters for their revenue losses while achieving the environmental goal of the policy. Since the environment is a public good, one could argue that energy producers who sell energy only to the export market should not receive any compensation because they do contribute directly to environmental damage. On the other hand, if they sell green energy which displaces dirty energy in the US, some compensation might be justified. No doubt, this argument is at the root of the Canadian position towards getting credit internationally for clean energy exports.

The Federal Plan is a 3 step process in which the first step already under way is expected to reduce about 1/3 of the needed reduction; a second step just announced expected to reduce another 42 %; a third step, yet to be announced, to reduce the remainder or about 25 %. The third step roughly corresponds to the credits for clean energy Canada was hoping to obtain internationally for its exports to the US. (Government of Canada, Climate Change Draft Plan, 2002).

Building and transportation policies are expected to address about 10 % of the Kyoto gap in steps 1 and 2 through targeted measures. Industry is expected to shoulder about 44 % through domestic emission trading, technology and infrastructure projects (urban transit, CO_2 sinks and intermodal freight technologies), and targeted measures where needed. The remaining sectors (agriculture, forestry and municipalities) are expected to cover about 8 % plus offsets (credits); and the international market at least 6 % (*ibid*).

Building policies

- Energy efficiency with enhanced incentives
- Improved appliance and equipment standards.
- home energy evaluations

Transportation policies

The Federal Government is contemplating a mandatory 10 % ethanol content in gasoline for 25 % of gasoline to be increased progressively to 35 %. Apparently the GHG reduction benefits of grain ethanol are disputed, but are definite for cellulose ethanol. Since ethanol reduces smog by making fuel burn more cleanly, the health co-benefits of this measure may be substantial.

- 25 % improvements in vehicle fuel efficiency standards.
- increase use of urban transit systems
- reduce freight ands off-road equipment emissions and increase fuel efficiency
- increased use of bio-diesel.
- Demonstration and Development of fuel-cell refueling infrastructure
- Reducing car use

Agriculture and Forestry

- are expected to provide sinks and offsets (credits).

Municipal Policies

- capture and productive use of landfill methane.
- compost programs
- land use planning
- renewable electricity
- less carbon-intensive municipal operations

Small and Medium Enterprises

- subject to voluntary measures.

Electricity Policies

- 10 % of new electricity generation targeted for renewables

Industry Policies

A "cap and trade" DET is supported by industry, environmentalists and economists alike, as they see it as an effective way to allocate a cap on emissions among polluters. It is more effective than environmental taxes, because it is hard to match the tax to the environmental target without a lot of information which is difficult to obtain. The incidence of DET depends very much on design details. 100 % auctioning results in great losses for polluting producers; 100 % grandfathering would have the opposite effect if their incremental cost is low. Therefore, a mix of the two regimes is required. According to the Federal Government Climate Change Draft Plan (2002), grandfathering will cover 85 % of the permit allocation and will include all large industrial emitters. Grandfathering is based upon emissions intensity and government assessment of feasible technological abatement opportunities (See also David Suzuki, 2002).

At the Federal level, the National Action Program on Climate Change, the subsequent First National Climate Change Business Plan were dominated by policies that seek to motivate firms and households to take action, by appealing to their self interest and moral values. There are educational programs for the general public and for schools. The Federal Government offered itself as facilitator for those who want to take actions. The government is willing to coordinate voluntary emission trading among industries, and to provide training programs for agriculture and forestry management. At the provincial and municipal level, the approach is similar. Provincial governments facilitate car-pooling and efficient building programs. The Partners for Climate Program of the Federation of Canadian Municipalities, and the International Council for Local Environmental Initiatives assist in developing municipal action plans. Federal and provincial governments focus on emissions for which they are directly responsible, through energy efficiency improvements for public buildings, by buying low emission vehicles, by buying electricity from sources which are environmentally less damaging, and by other similar initiatives.

With the Climate Change Draft Plan, the policy philosophy has become more stringent: targets are assigned to some sectors, technology initiatives are being undertaken, and emissions trading is being developed.

The sectors that will undergo the most transformations are those in which the abatement opportunities are most cost-effective: electricity, transportation, infrastructure, fossil fuel extraction, refining and transport. On a per person basis, the regions which bear the greatest burden of abatement costs are the Prairie provinces, because the opportunities for cost-effective GHG reduction are greatest there (e.g in coal-based thermal electricity generation). Among sectors, transportation bears the brunt of the adjustments (Jaccard et al., 2002).

Under the Climate Change Draft Plan, the health co-benefits are estimated to be about $ 1 per ton of GHG removed. This is to be compared, *under ideal conditions* (all externalities internalised, perfect markets, etc.), with the expected price of $ 10 per ton of CO_2 for international permits which would be the cost of removing an additional ton of CO_2. In practice, the removal cost will be higher if only because the Federal government has not selected the least cost option for its policy (Government of Canada, 2002c). The least cost option is, however, not the most favorable for heath co-benefits as becomes evident when one compares option 1 and option 4 of the

Discussion Paper. Indeed, option 1 uses about twice as much permit trading than option 4. (ibid.)

DET and international permit trading seem to be the tools through which a substantial portion of the Kyoto target will be met in Canada (about 40 % of 170 Gt.). It is important to note that these two markets will be fully fungible i.e. a Canadian firm has the choice between purchasing a permit either on the domestic or on the international market.

For health, the distinction between a DET permit and an international permit is that a DET permit may entail an actual GHG emission reduction in Canada (if it is not a hoarded grandfathered permit) while an international permit does not, given the large amount of"hot air" available on the international market.

Moreover, 85% of the domestic permits will be grandfathered i.e. distributed free of charge on the basis of emission intensity of output and on expected availability of substitute clean technology. About 28 % of emissions (of 170 Gt) will be covered by grandfathered permits and, at least, another 6 % will be covered by international permits. The Federal government estimated that 70% of 170 Gt. GHG emission reductions will be achieved domestically, i.e. not through international permits or other Kyoto mechanisms. (Canada, October 2002). GHG and associated air co-pollutants will tend to be localized where the permits are grandfathered i.e. where the emissions occur and are expensive to remove (because of lack of feasible alternative technologies), i.e. in sectors such as coal-based thermal electricity, chemicals and transportation. This may create equity issues.

It is obvious that, had the Federal government lessen the proportion of emissions covered by permits, health benefits could have been greater. However, these greater benefits have to be balanced with the overall cost increase this smaller permit coverage would have entailed. Indications are that the cost increase would be substantial since the incremental cost of GHG emission abatement in Canada in one of the highest in the world.

The impact of the creation of offsets (transferable credits) which are fungible with Domestic Emission Trading is likely to beneficial to health, depending on where they occur and on the location of the buyer. Subsidies to renewable energy will not have any short-run health effects. Measures favoring bio-fuels, such as ethanol, do not seem to present significant health risks (Yacobucci et al., 2000)[2]. Targeted measures for transportation and households have not been released yet but may entail significant health effects. Health effects of sinks are unknown. Command and control regulation (by opposition to "smart regulation") and environmental taxes (by opposition to subsidies) are unlikely to be adopted in Canada and their health effects are, therefore, likely to be irrelevant.

4.4 Conclusion

A post Bonn\Marrakech Kyoto Protocol, environmentally weakened and less expensive to

[2] This reference was provided by Health Canada.

implement particularly due to the withdrawal of the US, means that the health co-benefits of climate policy will be smaller than they would have been had the initial Protocol had been implemented. The environmental efficiency of the Protocol, when it comes into effect, has been considerably weakened by widening the admissibility of sinks, by lax compliance requirements, and by increased fungibility for Kyoto flexibility mechanisms. Therefore, little reduction in GHG emissions worldwide will occur in the first budget period 2008-2012. Worldwide emissions will drop by only 3% below the 1990 baseline instead of 5% as originally anticipated. In addition, more of the domestic target can be achieved through Kyoto mechanisms and through DET. This means that more activities than other wise will be undertaken buy Canada abroad (via CDM and JI), and that more international emission reduction permits will be purchased, many of them corresponding to "hot air" i.e. to fictitious emission reductions. Therefore less domestic emission reduction will be undertaken in Canada. Health co-benefits are further reduced by the inaction of the US, whose air quality affects our own. Given the lax climate change policy in the US, but the tighter controls on nitrogen oxides (NO_x), sulfur dioxide (SO_2), and mercury (Hg), the air quality in some Canadian airsheds may not be improved at all by Canadian domestic climate change policy.

Though the 2000 AMG/EHI evaluation did not take all relevant pollutants into accounts (especially the ones relevant for Western Canada), it may be difficult to argue for Kyoto ratification by Canada mainly by citing the now weakened aggregate health co-benefits. However, these co-benefits will be highly localised to densely settled areas, especially in Alberta, in Lower Mainland B.C. and, to a lesser extent (because of the US air quality interference), in southern Ontario. Also, the expected health costs of a non-intervention baseline scenario, to which a weakened Kyoto remains dangerously close, could alone justify ratification. This is why baseline scenarios including health effects are needed. One half of air pollution in eastern Europe is due to price distortions (Thompson,1998). Both developed and less developed countries (LDCs) provide large energy subsidies, and subsidies to human settlements in fragile ecosystems are pervasive in LDC's (e.g. in the Amazon region). The degradation of these ecosystems can affect Canada both directly (e.g. by a decrease of forest sinks for GHG) and indirectly (e.g. through immigration pressures).

The Global Climate Change policy initiative proposed for the US by President Bush amounts to very little in terms of meeting the Kyoto Protocol target for the US since, through voluntary measures and tax incentives only, it purports to reduce the carbon intensity of US Gross Domestic Product (GDP) by 18% over a ten year period i.e. to the end of the first Kyoto Protocol budget period. This is tantamount to a Business As Usual (BAU) emission slowdown and not to an emission reduction. The US was responsible for over one third of the anthropogenic Greenhouse Gas (GHG) emissions in the world in 1990, the Kyoto baseline year, and is still responsible for about 25% of current world GHG emissions. President Bush has made it clear that he would not ask the US Senate to ratify the Kyoto Protocol. Without the US, Russia's ratification is crucial for the Protocol to come into effect. Japan has ratified and, barring unforeseen events, Russia will ratify the Kyoto Protocol, which will then come into force, probably in early 2003. The Australian Prime Minister, John Howard, has reiterated his opposition to the Protocol ratification without the adhesion of the US (*La Presse*, March 1, 2002). Canada, because of its small percentage contribution to world emissions in the Kyoto baseline year (2%), is not able alone to jeopardize the Kyoto Protocol implementation; however, in the absence of the US, Canada's ratification plays a very important symbolic role. The main benefit of the Kyoto Protocol coming into force would be to have the international institutional structure and Kyoto mechanisms in place in such a way that more effective targets can be negotiated as of 2005 for the second budget period 2013-2018. Nationally, the main benefit of Kyoto coming into force would be that policy mechanisms such as Domestic Emission Trading (DET), for which there is stakeholder support in Canada, would be in place by 2005 as well.

Given that the Federal Government of Canada is officially committed to ratification, one scenario about the future must clearly take into account climate policies requiring Canada to reduce its emissions by 6% below the 1990 baseline. This scenario is considerably complicated by the existence of significant sinks, by the relative fungibility of Kyoto mechanisms, and lax compliance rules. Another scenario is one in which no ratification occurs and/or the Kyoto Protocol does not come into force. The two scenarios must take current and soon to be implemented environmental and health regulations (e.g. Canada Wide Standards for Particulate Matter and Ozone) into account.

Canada has to implement the Kyoto Agreement without the US, its major trade partner. This may make it more costly, and may affect the living standard and employment in Canada. The implications for competitiveness are still uncertain. A change in income may lead to changes in health status. Increased unemployment may affect mental health, and may lead to increased alcoholism, suicide, and spouse abuse, although some of the pertinent studies are controversial (Krupnick et al., 2001).

Besides macro-economic implications such as impacts on GDP level and growth, inflation and employment, all which have social consequences (for the standard of living and for employment), mitigation policies have sectoral and regional impacts which depend upon the carbon intensity of industries concerned. Clearly, sectoral impacts will be strong on the coal industry which is carbon-intensive. Since 85 % of the permits are expected to be grand-fathered, permit revenue recycling from the remaining 15 % will not alter these impacts much (Government of Canada, 2002b). One can however assume that agriculture and the services sectors will tend to benefit from GHG mitigation measures.

Mitigation policies use market based tools: Domestic Emission Trading (DET) and international emission trading. DET is likely to be of benefit to older, capital and carbon intensive industries such as oil and gas, and electricity generation since emission intensity is likely to be a criterion for grandfathering (Government of Canada, 2002b). Therefore, the benefits of emission trading are likely to be reaped in the manufacturing sector and by the primary industries in Alberta, Saskatchewan and Ontario mainly. In pollution hot spots, where emission reduction permits may tend to accumulate, this could result in a deterioration of air quality and of population health.

Moreover, where GHG emission reductions are expensive to achieve (and the incremental cost for Canada is already the highest in the world according to Löschel, 2002), both DET and Kyoto mechanisms, including international permit trading, are likely to be used extensively to reach the Kyoto target. By actively engaging in cheaper Kyoto mechanisms, Canada will reduce its emissions only slightly. In the absence of climate policy in the US, no major change in air quality is therefore to be expected in Ontario from the reduction of GHG emissions (because of air pollution from the Ohio Valley). However, these benefits may be substantial in the Calgary-Edmonton region of Alberta, and to some extent also in the lower mainland of British Columbia. There is thus an effective cap on co-benefits because of transboundary air pollution. Regulatory measures for transportation, such as speed limits, could decrease road accidents, and could also have some GHG emission reduction related benefits.

Equity considerations are an intrinsic component of social capital. The perception that the burden (net of health co-benefits) of climate change mitigation measures is equitably distributed among regions and sectors of society is necessary for climate change mitigation measures to be implemented. Since health co-benefits would occur mainly where such measures would be undertaken (i.e. probably mainly in Alberta, Saskatchewan and Ontario), these health co-benefits should be taken into account at the outset whenever the regional burden is being estimated. This would require the determination of a regional baseline. Alberta will soon be the largest emitter of GHGs in Canada; however, local air pollution in Alberta is less intense than in southern Ontario. This means that co-benefits will be smaller in Alberta than they are in Ontario, despite the fact that Ontario is a smaller GHG emitter.

Population health is determined by socio-environmental factors, in addition to lifestyle and biologic factors. Health is a component of human capital and of social capital as much as education. Climate Change puts an additional stress on population and on the environment. Clearly, population vulnerability is dependent on health status and on socio-economic conditions. Demographic factors also play a role, but exposure to the climate change risk factors (e.g. melting permafrost for Northern populations, forest fires in the Boreal forest, drought in the Prairies, decreasing water level in the Great Lakes Basin, sea level rise in the Maritimes) matters as well (Eyles et al., 1999). Air quality co-benefits represent an opportunity to engage the public in climate change issues because the latter link directly to health benefits.

5. Summary of Issues and Conclusions

This report has reviewed the scientific understanding of climate change, the possible health and social impacts of climate change in Canada, the assessment of co-benefits associated with GHG mitigation, social considerations of climate change policy, and possible risk management approaches to climate change policy decisions. The key issues and conclusions of the report and directions for further research are identified below:

The Reality of Climate Change

- The current weight of scientific evidence, as well as many obvious changes in our environment, suggest that global warming is real, and that climate change, an important part of global change, is upon us. The rise in the earth's temperature, and a related increase in climate variability, are at least in part due to greenhouse gases (GHGs) such as carbon dioxide, which are being emitted as a result of human activities.

Health and Social Impacts of Climate Change and Climate Variability

- Climate change and climate variability brings with it significant population health risks, both now and in the future.

  Extreme weather events consistent with climate change (including more smog, hot spells, droughts, blizzards, summer storms, floods, and other natural disasters) are already affecting the health and welfare of Canadians, directly and indirectly, as are waterborne diseases associated with climate change related weather events (such as extreme rainfall and high temperatures).

  Air pollutants, including particulate matter and gaseous co-pollutants such as ground-level ozone, which are associated with the emission of GHGs, cause premature death and disease.

  Long-term direct population health impacts of climate change will likely include premature deaths and disabling illnesses due to increased temperature and increased air pollution, extreme weather events, water and food borne enteric diseases, as well as cancer and eye damage resulting from increased exposure to ultraviolet radiation due to stratospheric ozone depletion by GHGs.

  The population health effects associated with climate change will result in greater demands on the health and social infrastructures (including emergency services and social support systems) which help to maintain our health and well-being.

  These health and social impacts will result in significant costs to Canadian society, including increased health care costs, loss of productivity, and broader damage to the well-being of Canadians. These impacts will vary by region.

- Climate change may confer some health benefits in some parts of Canada, such as fewer cold-related injuries and deaths. However, the ecosystem changes resulting from climate change will likely have more negative than positive consequences for human health.
- In order to anticipate and cope with the health and social effects of climate change, Canada needs to further develop its science capacity for projecting the progression of climate change and of its impacts. Policy makers and planners need reliable estimates of the timing, location, and magnitude of climatic changes and of their possible impacts on population health and well-being in different regions of Canada. This requires improved mathematical climate and health effects modeling, and better means of tracking climate change impacts on population health and well-being. Existing health research data will permit quantitative estimates of the health impacts of air pollutants associated with GHG emissions.

Health and other Co-Benefits of GHG Emission Reductions

- Mitigation of climate change through GHG emission reductions can have important co-benefits, including population health benefits due to improvements in ambient air quality. The Federal-Provincial Analysis and Modeling Group estimated the co-benefits of better air quality to be in the range $160 million (2001$) per year over the next twenty years, largely through a reduction in premature deaths and chronic disease, if the Kyoto Protocol is implemented mainly domestically.
- The development and use of new pollution abatement technologies to achieve these health co-benefits can result in other economic benefits to society.

Climate Change Risk Management

- Canada needs to take a precautionary approach to climate change risk management policy development, because this is required by the UNFCCC, and because significant health risks as well as long-term ecological consequences are likely to result if no global actions are taken to mitigate climate change, in spite of the uncertainties regarding such adverse impacts.
- Canada stands to gain from a compliance with the Kyoto Protocol. It will result in avoided costs to the Canadian health care system, in productivity gains for the Canadian economy, in increased well-being for Canadian society, and in an enhanced respect for Canada by the international community.
- The stabilization of atmospheric GHG concentrations at current levels cannot be achieved without a much greater reduction in GHG emission levels than those required under the

Kyoto Protocol. However, compliance with the Kyoto Protocol is a critical first step in creating the national and international mechanisms which are needed to mitigate climate change, and to ensure the health and well-being of future generations, as well as their prosperity.

- Population health cost and benefit assessments are essential in weighing the advantages and disadvantages of ratifying the Kyoto Protocol. Ratification by Canada will result in avoided costs for the Canadian health care system and in increased well-being for Canadian society, both in the short term and in the long term. Health benefits should be included as negative costs in estimating the burden of climate change within the health and social sectors. Of particular importance in this context are the health co-benefits associated with reductions in ambient air pollution that will occur as a consequence of reducing emissions of GHGs, estimated at $160 million per year. These benefits occur in the short term, and are more certain than the long-term benefits of reducing the direct health effects of climate change. Long-term direct health impacts include morbidity and mortality due to increased temperature and natural catastrophes, and a greater risk of diseases due to poorer water quality or transmitted from animals to humans.
- The health co-benefits of the implementation of Canada-Wide Standards (CWS) for air quality should be considered when programs for attaining the CWS are developed. The development and use of new technologies to achieve health co-benefits can result in economic benefits to society as a result of innovation.
- In developing a risk management strategy for climate change and health, there is a need to balance short-term and long-term policy options and impacts, and to develop an appropriate mix of cost-effective interventions to achieve our national and international policy objectives. Consideration needs to be given to more immediate impacts such as health co-benefits, as well as longer-term impacts relating to the direct health effects of climate change.
- No region or social group should bear an unreasonable portion of the costs associated with the health and social impacts of climate change. Special consideration needs to be given to vulnerable groups, including children, the elderly, the poor, First Nations and Northern populations, and those with pre-existing health conditions.
- Scenarios for assessing the health risks of climate change and climate variability should be constructed and updated periodically, using the best available information on climate change anticipated in different regions of Canada, and on the potential health risks associated with such changes. These scenarios, while reflecting the range of uncertainty associated with future climate change impacts, will permit comparisons of different policy responses and associated costs.
- Canadians are largely unaware of the health and social implications of climate change and climate variability. Informative health messages should be developed to improve the

public's understanding of this important population health issue, which concerns both present and future generations.

Directions for Further Research

1. Scenarios for climate change are in need of further research and development. IPCC (2000) concluded that there are global and regional scientific databases for defining baseline conditions. There is a need to incorporate into these databases other variables that influence climate, and the climate sensitivity and adaptability of ecosystems and of human populations. Scenarios for climate change need to incorporate and represent socio-economic information, land use and environmental information, scenarios at greater spatial resolutions. There is also a need to develop scenarios that link science and policy (IPCC, 2001).
2. Climate scenarios need to be linked to scenarios for health effects and for adaptation to future health conditions. Health issues have been rarely included into climate scenarios, and are influenced by regional conditions. For example, air quality depends on proximity to human sources of air pollution, and on geographic features, as well as on climate. Vector bone diseases which may be moving northward, may acquire different characteristics and / or may require different control methods in different regions. Climate models thus need to be region-specific in order to effectively project the human health implications of climate change and climate variability.
3. Research is required to better understand environmental and health co-benefits, especially at the very disaggregated level, where they may be quite significant despite their uncertainties. Because of the inherent inability to conduct international comparisons, studies need to be conducted in Canada where the baseline can be kept relatively constant.
4. The socio-economic models supporting air quality policy decisions need improvements, as recommended in the Report of the Royal Society of Canada Expert Panel to Review the Socio-economic Models and Related Components Supporting the Development of Canada-wide Standards for PM and Ozone.
5. Improved health risk assessment and population health surveillance are required to better understand the linkages between climate change, air quality, water- and food-borne contamination, vector-borne diseases, population vulnerability factors, and health effects in Canada to inform mitigation and adaptation strategies to protect public health.
6. Research should be undertaken to better understand the synergistic health co-benefits that are possible through emission reductions strategies to meet Canada-wide standards for PM and ozone and to achieve desired GHG emission reductions.

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Appendix A

Table A.1: Scenarios and Results of Studies on Ancillary Benefits Reviewed

Study	Area and Sectors	Scenarios (1996 US$)	Average Ancillary Benefits (US$/tC; 1996 US$)	Key Pollutants	Major Endpoints
Dessus and O'Connor, 1999	Chile (benefits in Santiago only)	Tax of US$67 (10% carbon reduction) Tax of US$157 (20% carbon reduction) Tax of US$284 (30% carbon reduction)	251 254 267	Seven air pollutants	Health-morbidity and Mortality, IQ (from lead reduction)
Cifuentes *et al*.,2000	Santiago, Chile	Energy efficiency	62	SO_2, NO_x, CO, NMHC Indirect estimations for PM_{10} and resuspended dust	Health
Garbaccio *et al.,* 2000	China – 29 sectors (4 energy)	Tax of US$1/tC Tax of US$2/tC	52 52	PM_{10}, SO_2	Health
Wang and Smith, 1999	China – power and household sectors	Supply-side energy efficiency improvement Least-cost per unit global-warming-reduction fuel substitution Least-cost per unit human-air-pollution-exposure-reduction fuel substitution		PM, SO_2	Health
Aunan *et al*, 2000, Kanudia and Loulou, 1998	Hungary	Energy conservation Programme	508	TSP, SO_2, NO_x, CO, VOC, CO_2, CH_4, N_2O	Health effects; materials damage; vegetation damage

Study	**Area and Sectors**	**Scenarios (1996 US$)**	**Average Ancillary Benefits (US$tc; 1996 US$)**	**Key Pollutants**	**Major Endpoints**
Brendemoen and Vennemo, 1994	Norway	Tax US$840/tC	246	SO_2, NO_x, CO, VOC, CO_2, CH_4, N_2O, Particulates	Indirect: health costs; lost recreational value from lakes and forests,; corrosion Direct: traffic noise, road maintenance, congestion, accidents
Barker and Rosendahl, 2000	Western Europe (19 regions)	Tax US$161/tC	153	SO_2, NO_x, PM_{10}	Human and animal health and welfare, materials, buildings and other physical capital, vegetation
Scheraga and Leary, 1993	USA	US$144/tC	41	TSP. PM_{10}, SO_x, NO_x, CO, VOC, CO_2, Pb	Health – morbidity and mortality
Boyd *et al*., 1995	USA	US$9/tC	40	Pb, PM, SO_x, SO_4, O_3	Health, Visibility
Abt Associates and Pechan-Avanti Group, 1999	USA	Tax US$30/tC Tax US$67/tC	8 86	Criteria pollutants	Health – Mortality and illness; Visibility and household soiling (materials damage)
Burtraw *et al*., 1999	USA	Tax US$10/tC Tax US$25/tC Tax US$50/tC	3 2 2	SO_2, NO_x	Health

NMHC, non-methane hydrocarbons; PM, particulate matter; PM_{10}, Particulate matter less than 10 microns; TSP, total suspended particulate; VOC, volatile organic compounds; IQ, intelligence quotient.

Source: IPCC, 2001d.

Table A.2: Modelling Choices of studies on Valuation of Ancillary Benefits Reviewed

Study	Baseline (as of 2010)	Economic modelling	Air pollution modeling	Valuation	Uncertainty treatment
Dessus and O'Connor, 1999	4.5%/yr economic growth; AEEI: 1% Energy consumption: 3.6% PM: 1% Pb: 4.1% CO: 4.8%	Dynamic CGE	Assumed proportionality between emissions and ambient concentrations	Benefits transfer used: PPP of 80% US BSL: $2.1 mill. VCB: $0.2 mill. IQ loss: $2500/point	Sensitivity tests on WTP and energy substitution elasticities
Cifuentes *et al.*, 2000	For AP control, considers implementation of Santiago Decontamination Plan (1998 to 2011)	No economic modelling Only measures with private, non-positive costs considered	Tow models for changes in $PM_{2.5}$ concentrations: (1) Box model, which relates SO_2 and CO_2 to $PM_{2.5}$ (2) Simple model assumes proportionality between $PM_{2.5}$ concentrations apportioned to dust, SO_2, NOx, and primary PM emissions. Models derived with Santiago-specific data and applied to nation	Benefits transfer from US values, using ratio of income/capita Uses original value for mortality decreased by 1 Standard deviation VSL = US$407,000 in 2000	Parameter uncertainty through Monte Carlo simulation. Reports centre value and 95% CI

Study	**Baseline (as of 2010)**	**Economic modelling**	**Air pollution modelling**	**Valuation**	**Uncertainty treatment**
Garbaccio *et al.,* 2000	1995 to 2040 5.9% annual GDP growth rate; carbon doubles in 15 years; PM grows at a bit more than 1 %/yr	Dynamic CGE model; 29 sectors; Trend to US energy/consumption patterns; Labour perfectly mobile; Reduce other taxes; Two-tier economy explicit.	Emissions/concentration coefficients from Lvovsky and Hughs (1998); three stack heights	Valuation coefficients fromLvovsky and Hughs (1998); VSL: US$3.6 million (1995) to RMB 82,700 Yuan (RMB 8.3 yuan = $1) in 2010 (income elasticity = 1). 5%/yr increase in VCB to US$72,000	Sensitivity analysis
Wang and Smith, 1999		No economic modelling	Gaussian plume	Benefit transfer using PPP. VSL = US$123,700, 1/24 of US value	

AEEI, Autonomous Energy Efficiency Improvement; $PM_{10, 2.5}$, particulate matter less than 10 or 2.5 microns, respectively; CGE, Computable General Equilibrium Model; PPP, Purchasing Power Parity; WTP, Willingness To Pay; AP; air pollution; CAA: Clean Air Act; NAAQS: National Ambients Air Quality Standards; SIP: State Implementation Plan; CRF: concentration-response function; CL: confidence Level; VSLY: Value of Statistical Life Year, value of Statistical Life; RIA: Regulatory Impact Analysis; VCB, value of a case bronchitis.

Study	**Baseline (as of 2010)**	**Economic modelling**	**Air pollution modelling**	**Valuation**	**Uncertainty treatment**
Aunan *et al.,* 2000	Assumes status quo emissions scenario	Two analyses: bottom-up approach and macroeconomic modelling	Assumes proportionality between emissions and concentrations	Benefit transfer of US and European values using “relative income” = wage ratios of 0.16	Explicit consideration through Monte Carlo simulation Reports centre value and low, high
Brendemoen and Vennemo, 1994	2025 rather than 2010 2%/yr economic growth 1% increase in energy prices 1%-1.5% increase in electricity and fuel demand CO_2 grows 1.2% until 2000, and 2% thereafter	Dynamic CGE		Health Costs of studies reviewed based on expert panel recommendations Contingent valuation used for recreational values	Assume independent and uniform distributions
Barker and Rosendahl, 2000	SO_2, NO_x, PM expected to fall by about 71%, 46%, 11% from 1994 to 2010	E3ME Econometric Model for Europe		US$/emissions coefficients by country from EXTERNE: € 1,500/t NO_x for ozone (€ 1 = $1); NO_x and SO_2 coefficients are about equivalent, ranging from about € 2,000/t to € 16,000/t; PM effects are larger (2,000-25,000) Uses VSLY rather than VSL: € 100,000 (1990)	

Study	**Baseline (as of 2010)**	**Economic modelling**	**Air pollution modelling**	**Valuation**	**Uncertainty treatment**
Scheraga and Leary, 1993	1990 to 2010 7% growth rate carbon emissions Range for criteria Pollutants 1%-7%/yr	Dynamic CGE			
Boyd *et al.,* 1995	Static CGE			US$/emissions coefficients	
Abt Associates and Pechan-Avanti Group, 1999	2010 baseline scenarios – 2010 CAA baseline emission database for all sectors, plus at least partial attainment of the new NAAQS assumed. Benefits include coming closer to attainment of these standards for areas that would not reach them otherwise. Includes NO_x SIP call	Static CGE		From Criteria Air Pollutant Modelling System (used in USEPA Regulatory Impact Analysis and elsewhere)	SO_2 sensitivity - SO_2 Emissions may not go beyond Title IV requirements – NO_x sensitivity - NO_x SIP call reductions not included in final SIP call rule

Study	Baseline (as of 2010)	Economic modellng	Air pollution modeling	Valuation	Uncertainty treatment
Burtraw *et al.*, 1999	Incorporates SO_2 trading and NO_x SIP call in baseline	Dynamic regionally specific electricity sector simulation model with transmission constraints. The model calculates market equilibrium by season and time of day for three customer classes at the regional level, with power trading between regions.	NO_x and SO_2. Account for conversion of NO_x to nitrate particulates	Tracking and Analysis Framework: the numbers used to value these effects are similar to those used in recent Regulatory Impact Analysis by the USEPA.	Monte Carlo simulation for CRF and valuation stages.

Source: IPCC 2001d.

Appendix B. The Science of Climate Change

B.1 What is Climate Change?

The climate system consists of a number of linked subsystems including:

- the rivers, lakes, and oceans (hydrosphere)
- the atmosphere and stratosphere
- the living organisms including humans (biosphere),
- the snow deposits, glaciers, permafrost zones and sea ice (cryosphere), and,
- the land mass (lithosphere).

The fundamental energy processes that drive the climate system are heating by short-wave incoming solar radiation and cooling by long-wave infrared radiation to space. Natural changes in solar energy radiation reaching the earth constitute the primary external forcing on the climate system. Another principal factor is the reflectivity (albedo) of the earth surface which varies with surface cover, and which is therefore affected by land use. "Radiative forcing is a measure of the influence a factor has in altering the balance of incoming and outgoing energy in the Earth-atmosphere system, and is an index of the importance of the factor as a potential climate change mechanism. It is expressed in watts per square meter"(IPCC, 2001b). Climate is a description of the average behavior of the atmosphere with its variance, probability of extremes and space and time covariance properties; it is thus an aggregate of the weather. Climate change is the change in the regional and global-scale climate which is due to human activities, but superimposed on a background of natural variability (Harvey, 2000). This natural variability results from changes in solar activity, alterations in the earth's orbit about the sun, volcanic activity, etc. (www.cics.uvic.ca). Climate change is expressed as a difference over a period of time. The time unit generally chosen to establish a baseline for observations of the climate and of climate variability is typically about 30 years. Climate variability is expressed as a difference between the climate trend during an observation period and during a reference period, usually the most recent 30 year period (www.cics.uvic.ca).

Paleo-climate data based e.g. on measurements of tree rings, or on changes in the chemical composition of fossils or of ice cores, have been used to reconstruct past climates which existed up to one million years ago. Over this period, mean global temperatures are estimated to have varied by 5 to 7 degrees Celsius (Wuebbles et al., 1998). Over the last 10,000 years, globally averaged surface temperatures (average near surface air temperature over land, and sea surface temperature) have varied by approximately 2 degrees Celsius (Wuebbles et al., 1998). Reliable global temperature data are available since 1890 only. The evidence that globally averaged climate has warmed (by 0.6 degree Celsius) during the preceding century is overwhelming (IPCC, 2001b). Warming trends are similar in both Northern and Southern hemispheres (Wuebbles et al., 1998). Global temperatures in recent years are very likely (over 0.9 judgmental probability) to have been the warmest in the historical record. A similar warming occurred in the troposphere with a marked cooling of the stratosphere, both consequences of increasing GHG concentrations and halocarbon-induced stratospheric ozone depletion predicted by climate models (Wigley, 1999). This global warming is likely (over 2/3 judgmental probability) to be unprecedented over the past 1,000 years (IPCC, 2001b).

The science of climate change helps us to understand the interactive processes involved in the transformation of the emissions of gases that absorb solar and terrestrial radiation energy, and which therefore are termed greenhouse gases (GHG), and of short-lived liquid and solid particles (10-3 to 10-6 m in diameter) suspended in the air (the so- called aerosols). The atmospheric concentrations of these gases and particles, as well as the amount of water vapour, affect the atmospheric heat balance, and thus also affect the impacts of this heat balance upon climate. "Many uncertainties remain in understanding the effects of the changing atmospheric composition on climate. Many of the uncertainties stem from an insufficient understanding of the interactive climate feedback processes [such as chemical interactions among GHG and between GHG and other gases] that are key to determining the extent of the climate response from a given change in climate forcing" (Wuebbles et al., 1998). The greenhouse effect is a natural phenomenon due to the presence of an atmosphere containing water vapour and GHG. The greenhouse effect results from the fact that the atmosphere absorbs more infrared energy than it re-radiates to space, resulting in a net warming of the earth-atmosphere sub-system. The enhanced greenhouse effect results from increases in GHG concentrations which lead to positive radiative forcing (forcing is assumed to be zero without anthropogenic warming) or when aerosol properties are changed. GHG gases have atmospheric lifetimes of a decade or more while most aerosols last weeks only (IPCC, 2001b; Wuebbles, 1998) Aerosols also affect cloud cover and albedo. GHG have a warming influence, while aerosols (especially sulfates), generally have a cooling influence. Climate sensitivity (ratio of global mean temperature response to the global mean radiative forcing) depends upon a variety of radiative dampening factors (negative feedbacks) which determine the ease with which excess energy can be radiated into space. For a wide range of radiative forcings, climate sensitivity is largely independent of the magnitude, nature, and spatial pattern of the forcing. In other words, climate sensitivity may be subject to abrupt changes. In the past, when natural CO_2 emissions produced atmospheric CO_2 levels similar to current ones, major climate changes occurred, each time precipitating an ice age but only after many thousands years (www.cics.uvic.ca).

It can be stated as very likely (over 0.9 judgmental probability) that the observed build-up of carbon dioxide (CO_2) over the past 100 years is due to human activity and likely (over 2/3 judgmental probability) that the warming observed over the last 50 years is due to increased GHG concentrations. Much of the GHG concern is with regard to CO_2 because of its rapid build-up. Preindustrial concentrations of CO_2 were about 280 ppmv (parts per million volume) and have increased by 31% since 1750. Current CO_2 concentrations have not been exceeded during the past 420,000 years and likely not during the past 20 million years. The current rate of increase is unprecedented in the last 20,000 years (IPCC, 2001b).

The main contributors to CO 2 emissions are fossil fuel use (about 75% of the contribution in the last 20 years) and land use (deforestation and biomass burning for the balance of the contribution). However, other GHGs, such as ozone (O3), methane (CH_4), nitrous oxide (N_2O) and chlorofluorocarbons (CFC's, particularly CFC13 and CF2Cl2) contribute to about one-half of the enhanced greenhouse effect. Most of them have a radiative forcing much higher than that of CO_2, which makes methane almost as large a contributor to global warming as CO_2, even though methane emissions are much smaller than CO_2 emissions (Wuebbles,1998). The present concentration of methane has increased by 151% since 1750 and has not been exceeded over the last 420,000 years. Slightly more than half of methane current emissions are anthropogenic (fossil fuels, cattle, rice agriculture, landfills). Nitrous oxide has increased by 17% since 1750. Its current concentration has not been exceeded in the past 1,000 years; about 1/3 of the current emissions are anthropogenic (agricultural soils, cattle feedlots and chemical industry). CFC emissions (which created a negative radiative forcing) have decreased, but their substitutes are GHGs. Strong evidence indicates that the increasing concentrations of these gases are related to human activities. Climate models show that these increasing concentrations increase the radiative forcing on climate (Wuebbles et al., 1998; Harvey, 2000; Wuebbles et al., 1998; www.cics.uvic.ca).

Currently the ocean and the land jointly absorb (are sinks for) about one-half of the CO_2 emissions caused by human activities. As the CO_2 concentrations of the atmosphere increase, the ocean and land sinks will decrease their intake of CO_2, thereby creating a positive feedback on global warming (IPCC, 2001b).

IPCC estimated that stabilization of GHG concentrations at current levels, which is the objective of the 1992 United-Nations Convention on Climate Change (UNFCCC), would require the following reductions in anthropogenic emissions: CO_2, 60%; CH_4, 15-20%; N_2O, 70-80 % ; CFC's, 70-85%; HCFC-22s, 40-50% (Wuebbles et al., 1998).

B.2 Anthropogenic Causes of Climate Change

When fossil fuels (coal, oil, natural gas) are burned to produce energy, the burning process releases carbon which mixes with the atmospheric oxygen to form CO_2. 85% of current energy produced is from burning fossil fuels. CO_2 emissions can be calculated by means of the following equation:

> *Population x economic output per capita ($/P) x energy per unit of economic output (Joules/$) x emissions per unit of energy (E/J) = CO_2 emissions*

E/J is highest for coal, while it is lowest for natural gas. In order to reduce GHG emissions, it is therefore necessary to increase the share of natural gas in the fossil fuel mix . The use of renewable energy does not generate any CO_2 directly. It is therefore also desirable to increase the proportion of renewable energy in the total energy mix. The production of synthetic oil and gas from coal or from oil shale requires large amounts of energy. Their use therefore entails substantially higher GHG emissions than their natural equivalent. The measure of emissions from this source is very accurate. The per capita world emissions of CO_2 from fossil fuels amount to about 1 ton of carbon per year or 3.67 tons of CO_2.

A second major source of CO_2 emissions is deforestation. Deforestation leads either to the decomposition of debris after timber has been removed or to fires to clear these debris (a common practice in tropical countries). The measure of emissions from this source is very imprecise because abandoned deforested land becomes reforested and absorbs carbon from the atmosphere (though rarely up to its original carbon content); also, the carbon content of the forest-bearing land is altered. This raises the issue of the measurement of carbon sinks.

A third major source of emissions is the chemical release of CO_2 from the production of lime and ammonia especially, and also of cement on top of the releases from the burning of the fossil fuels required by the production processes.

In 1998, Australia was the largest emitter of CO_2 per capita (23.5 t), followed by the United States (18.5t) and then by Canada (14.8 t). The largest emitter of methane was China (33.83 megatons) followed by the United States (28.17 megatons) and then by Russia (27.36 megatons).

While GHG emissions due to human activity are only of the order of 6-8 gigatonnes (Gt) of carbon per year, natural emissions are of the order of 160 Gt per year (60 Gt from plant and soil carbon respiration and 100 Gt from diffusion in oceans). However, even though the carbon emissions attributable to human activities amount to only about 5% of natural GHG emissions, all of the emitted GHG continuously cycle between the atmosphere and other reservoirs. Nitrous oxide and other non-carbon based GHG gases and aerosols are eventually converted to other matter through chemical processes. The principal removal process for CO_2 from the air is uptake by plants and other photosynthesizing organisms, and inflow into the oceans. As atmospheric CO_2 concentrations increase, so do natural CO_2 emissions, because increased photosynthesis leads in the end to increased decomposition of organic matter. The long-term removal of CO_2 from the atmosphere occurs when it is transported into deep ocean sediments, a process which takes many years.

Methane is a product of the anaerobic decomposition of organic matter. Large amounts of methane have been trapped underground during the formation of fossil fuels (especially coal), and are released as a by-product of fossil fuel extraction and burning. Methane in petroleum is flared at the extraction level. Natural gas is 95 % methane, some of which leaks during extraction and distribution. Anaerobic decomposition of vegetation flooded for of hydro-electric reservoirs can produce methane emissions which may for some years after flooding exceed methane emissions from thermal plants with installed capacity equivalent to hydro plants. Methane is released by the burning of biomass, during rice cultivation, from decomposing matter in landfills, from sewage treatment plants and by cattle. Emission estimates are fairly imprecise (by at least a factor of 3). Anthropogenic emissions are about twice the natural emissions.

The primary sources of nitrous oxide (N_2O) are nitrogen fertilizers which are responsible for 50 to 75% of emissions, and to a lesser extent, industrial processes. Nitrous oxide results also from pollutant emission control processes for NOx (e.g.catalytic converters of cars and trucks). As N_2O emissions are highly dependent on soil conditions or on the temperature of the industrial processes which use fossil fuels, the emission estimates are at least as imprecise as those for methane.

Halocarbons are GHG which contain bromine, chlorine or fluorine as well as carbon, and are used for refrigeration and cooling processes such as air conditioning. They include chlorofluorocarbons (CFC's) as well as their more ozone friendly substitutes, the hydro fluorocarbons (HCFC). Emissions depend very much upon leakages, which are determined by extent of maintenance. Estimates of their emission are very imprecise.

Aerosols, especially sulfates, and soot (a by-product of incomplete combustion) result from the burning of coal or other fuels, and from the smelting of sulfur-containing ores of zinc, copper, or lead . Technologies exist to reduce the emissions of these aerosols. Estimates of aerosol emissions vary considerably (Harvey, 2000).

The most promising interventions to reduce GHG emissions from land-use are slowing deforestation and afforestation, and reducing livestock methane emissions and nitrous oxide emissions related to agricultural activities. Slowing deforestation would require economic reforms aiming at protecting forests and maximizing non-timber values, removing incentives to cattle raising, etc. Intensive livestock management leads to increased emissions for a same herd size and is likely to involve the use of inorganic fertilizers on grasslands which generate nitrous oxide. Afforestation should not be based exclusively on carbon storage but on other values including land values.

B.3 What are the Expected Global Impacts of Climate Change?

When one looks at the environmental impacts of climate change, one has to take into account that, in many cases, climate change is a stressor in addition to existing ecosystem stressors resulting from either non-sustainable harvesting or air pollution. Climate change is simply one component of cumulative anthropogenic stress on climate physical sub-systems, which include bio-diversity loss, ozone depletion, acid rain, etc. i.e. Global Change. In other words, climate change impacts on ecosystems must take into account the fact that most ecosystems are already weakened.

B.3.1 Scenarios of Climate Change

Scenarios are images of the future, or alternative futures (IPCC, 2000c). A set of scenarios assists in the understanding of possible future developments of complex physical and social systems which are poorly understood. The climate system is such a system. Climate scenarios are descriptions of the future climate that are based on computer models of the atmosphere-ocean system. Each scenario is based on specific assumptions as to how the human socio-economic system will evolve in the future. Technology, economic growth, population size, demographic characteristics and income, regulatory regime, baseline mortality rates, etc. are all components of scenarios. There are three main types of climate scenarios employed in climate studies and climate impact studies, these are: 1) incremental scenarios which measure the impact of climate change based on an alteration of the baseline to meet anticipated changes; 2) analog scenarios based on histories in other regions which are not often applied; 3) climate-model based scenarios which are the most common, are based on general circulation models (GCMs), and involve the adjustment of the baseline by the absolute or proportional change between current and future climates (IPCC 2001a). Traditionally climate models have been focused on the variations in mean climate, but now include changes in extreme events (IPCC, 2001a).

IPCC has published scenarios in its Special Report on Emissions Scenarios (SRES) which are widely referred to by the international community (IPCC, 2000c). IPCC Special Report on Emission Scenarios (SRES) has opted for a multiple baseline or BAU approach in which each baseline contains subjective elements and is not the subject of probability assignment if only because the emission ranges overlap (IPCC, 2000c; Schneider, 2001). The SRES counts 40 baseline scenarios (based on the about 400 existing in the literature) regrouped into four scenario families called A1, A2, B1 and B2. The A's embrace the economic worldview, while the B's embrace the environmental worldview. The index 1 stands for significant globalization while 2 stands for increased regionalization. A1 scenarios are further broken down into 3 subgroups according to technological assumptions. This makes six scenario groups. "Together they cover most of the uncertainty of future emissions..."(IPCC, 2001d). Corresponding emission trends are not monotonically increasing within a given scenario; emission trend reversals and emission path crossovers among various scenarios are possible (ibid.). Post-SRES mitigation scenarios, defined relative to a SRES baseline, give the following general results: IPCC SRES scenarios A1 and A2 are thought to result in higher cumulative emissions during the period 1990-2100. IPCC SRES scenarios B1 and B2 are thought to result in lower cumulative emissions during the period 1990-2100 (www.cics.uvic.ca). Technology and policy measures required for GHG concentration stabilization A1 scenarios do not run into major problems in implementing mitigation while A2 scenarios do. Two of the A1 and the A2 scenarios require stronger technology and/or policy measures and earlier emission reductions than do B1 and B2 and the third A1 type scenario. B1 and B2 scenarios do not run into major problems either, even though B1 scenarios are confronted with higher incremental abatement costs, but they assume lower total costs (because emissions are lower) than A1 scenarios (IPCC, 2001d). Mitigation scenarios generally assume GHG concentration stabilization at 550 ppm, and conclude that Kyoto commitments may be adequate for stabilization at this level or a higher one. However, for some scenarios, significant emission reductions are required by the year 2020 (ibid.) Lowering GHG concentrations to 450 ppm would require emission reductions in developed countries "that go significantly beyond the Kyoto Protocol commitments" (ibid.). Policies governing agriculture, land use and energy systems need to be linked in order to achieve climate change mitigation. "Integration between global climate policies and domestic air pollution abatement policies could effectively reduce GHG emissions in developing regions for the next two or three decades. However, control of sulphur emissions could amplify possible climate change, and partial trade-offs are likely to persist for environmental policies in the medium term" (ibid.). Large and continuous energy efficiency improvements, afforestation and introduction of low carbon energy such as natural gas in the early part of the century and of biomass energy, carbon sequestration, nuclear power and solar energy over the century are common features of mitigation scenarios (ibid.).

In addition to climate change scenarios, there are also global futures scenarios which may not take climate change into account, but which may consider human health. Of 124 non-climate global scenarios surveyed by IPCC, 38 include a human health component (IPCC, 2001). These global scenarios tend to be non-quantitative. These scenarios can be classified into 4 groups: 1) a pessimistic/catastrophic group in which the world collapses; 2) a pessimistic/ economic worldview group in which current trends are maintained but problems get worse; 3) an optimistic/high-tech group for which technology and markets overcome all problems; 4) an optimistic/sustainable development group of either "Our Common Future" persuasion which allows for growth or of a steady-state type which does not. When global scenarios take emissions into account, the latter are not necessarily correlated with economic activity or rising population. ".... low emissions futures are associated with a whole set of policies and actions that go beyond the development of climate policy itself". This suggests that " the choice of future 'world'[one of the four groups of non-climate scenarios] is more fundamental than the choice of a few driving forces in determining GHG emissions" (ibid.).

Global Climate Models

Global climate models are the only credible tools for simulating the physical processes that determine global climate. Climate change scenarios need to be physically plausible, and represent a sufficient number of climate variables that allow for a meaningful impact assessment. Projected increases in global mean temperatures by the year 2100 range from 1.4 to 5.8 degrees Celsius (IPCC, 2001b), depending on the emissions scenarios considered (zero change is excluded, an increase of 3 degrees being considered most likely). Climate scenarios available from the Canadian Centre for Climate Modeling and Analysis, as well as from 28 other international sources (total of 29 scenarios) assume BAU. Scenarios can be modeled for the years 2020, 2050, and 2080 at geographic grids of 300 x 300 kilometres. Multiple scenarios are helpful in characterizing uncertainty associated with climate change. Mean, minimum, and maximum provide an indication of the range in predictions of values of climate variables. Climate models are highly sensitive to input parameters (running the same model twice with slightly different inputs will give notably different predictions because of the chaotic property of climate models, with variability increased with decreasing grid size). Variability among scenarios will generally be greater than the variability among models run under the same scenario. Climate scenario models that are most widely accepted are those developed by United Kingdom Meteorological Office, the United States National and Atmospheric and Oceanographic Administration, Goddard Space Centre, World Meteorological Organization and much climate modeling research has taken place the University of Maastricht (Netherlands) (Last and Sahni, 2002). National and regional climate scenarios for Canada have been developed at the Canadian Institute for Climate Studies. Regional climate models for Canada are still under development. Their use for predictions is premature at this time.

Canada has engaged in climate modeling since the 1970s, combining the work of Environment Canada, Canadian universities, the Canadian Institute for Climate Studies (CICS), and the

Canadian Centre for Climate Modeling and Analysis (CCCma) (Hengeveld, 2000). Initially, studies in climate modeling began with the general circulation models (GCMs), which simulated the patterns on earth's surface and the atmospheric levels directly above, and gradually evolved to include more complex interactions of oceans and upper atmospheres. Advances in technology and a better understanding of oceanic conditions led to the development of more sophisticated models such as Atmospheric-Ocean General Circulation Models (AOGCMs). The Canadian Centre for Climate Modeling and Analysis created the Canadian coupled model known as CGCM1 by the mid 1990s, which was recognized by IPCC and US National Academy of Science (Hengeveld, 2000) and is still applied.

The current atmospheric general circulation model is known as the CCC AGCM2. This second generation model has been used extensively for equilibrium climate change simulations with and without the direct effects of sulfate aerosols. The CCC AGCM2 is also used in the production of operational seasonal climate forecasts at the Canadian Meteorological Centre. The CCC AGCM2 is the atmospheric component of the recently developed first generation coupled global climate model, which is known as CGCM1. CGCM1 couples the atmospheric AGCM2 to a specially adapted version of the GFDL Modular Ocean Model (MOM) and a thermodynamic sea-ice model. A transient climate change experiment which takes into account the effects of historical and projected changes in greenhouse gas concentrations and sulfate aerosol distributions for the period 1850 to 2100 has recently been completed. Selected data from these simulations have been contributed to the IPCC Data Distribution Centre to facilitate their use for climate impact studies. This model has also been used for the US National Assessment. Scenarios developed from the model are available from USGCRP's web site. Data are also available from Environment Canada (www.uvic.cics.ca).

A third-generation atmospheric model CCC AGCM3 has become operational at CCCma. It operates at higher resolution and includes improved boundary layer, convection, cloud and radiation parameterisations, an optimized representation of the earth's topography, and a new land surface module (CLASS). AGCM2 forms the basis of the Canadian Middle Atmosphere Model (MAM) which was developed by the MAM group of the Climate Research Network. The next version of the coupled global climate model, which couples AGCM3 to the NCOM ocean model and a dynamical sea-ice model, is under development.

Diagnostic studies of both the observed and simulated climate system are also an integral component of CCCma's work. An extensive climate diagnostics package that is fully integrated into CCCma's modeling environment has been developed. CCCma participates in a broad range of international studies and programs.

The second version of the Canadian Global Coupled Model (CGCM2), is based on the earlier CGCM1 but with some improvements aimed at addressing shortcomings identified in the first version. In particular, the ocean mixing parameterization has been changed, and sea-ice dynamics have been included following Flato and Hibler (1992). In addition, some technical modifications were made in the ocean spinup and flux adjustment procedure. A description of CGCM2 and a comparison, relative to CGCM1, of its response to increasing greenhouse-gas forcing can be found at www.ccma.ca and www.ec.bc.gc.ca .

When SRES scenarios are employed to force climate models, the projected change in temperature is a 2.0 to 3.1 degrees Celsius rise compared to 1.4 to 2.6 degrees for the IS92 series. This is due to SRES having lower Sulphur Dioxide emissions (sulfate aerosols reflect sunshine so less means additional warming). Note also that the sea level will rise about the same amount under either scenario - roughly 40 to 60 cm by 2100 with SRES and by about 5 to 10 cm higher if different assumptions about sulfur dioxide are made.

Plots can be used to identify those experiments which indicate the most extreme changes, e.g., warmest and wettest, coolest and driest, in order to aid scenario selection. These plots are a summary of the temperature and precipitation changes associated with the GCM experiments averaged over the land area within the Canadian window. For example, precipitation scenarios comparing winter (December to January) and summer (June to August) for the year 2020, illustrate on a grid box by grid box basis, where an increase in precipitation is projected to occur. It gives no indication of the magnitude of this precipitation increase. It can be considered to indicate the probability of a precipitation increase, based on the number of experiments available.

For winter 2020, there is generally good agreement amongst the models that precipitation will increase. In the summer 2020, it is difficult to come to any conclusions since about 50% of experiments indicate an increase in precipitation - thus implying that the other 50% indicate a precipitation decrease. Because most precipitation in summer arises from showers and thundershowers, there is evidently some difficulty in simulating convective precipitation.

Ideally, researchers should use as many scenarios as possible, since although changes may be similar at this scale, the actual patterns of change may be quite different, thus leading to different impact results; however, it is recognised that this may not always be possible. In such cases, at least three scenarios should be used, two representing the extreme changes and one a mid-range value. It may not be possible to use all available experiments, since the necessary climate variables may not be available for all experiments.

Another way of selecting scenarios is to identify the climate variable to which the impacts model is most sensitive (maybe in a particular season) and then use the scenarios which represent the most extreme and mid-range values for this particular variable.

Alpine regions are those parts of the mountains that lie above the upper limit of continuous forest, or timberline. The exact nature of future climate changes in the mountains is not well known. However, we do expect that a general increase in temperature will bring about a northward movement of the timberline and a decrease in the extent of glaciers, icefields, winter snowpack and permafrost. Hazardous effects, such as glacier outburst floods and debris flows may accompany glacier recession. The reduction in the extent of alpine tundra, together with glacier recession, will bring about considerable modification of alpine scenery, with a possible impact on tourism. Changes in the winter snowpack will affect recreational skiing and the viability of many ski areas. The most far-reaching result of predicted climate change in alpine areas is likely to be the effect of decreased snowpack and glacier ice on the discharge of the rivers that drain from the mountains. In western Canada, seasonal snowmelt and glacier melt are major sources of water for the rivers of the plains and the dry southern interior of British Columbia. Decreased river discharge in summer may adversely affect water use for agriculture, hydro-electric generation, industry and domestic purposes.

B.3.2 Current Global Impacts

Sea levels have increased by 0.1 - 0.2 m over the 20th century. It is very likely (over 0.9 judgmental probability) that precipitation has increased by 0.5 - 1% per decade in the 20th century over most mid- and high latitude continents of the Northern Hemisphere. It is likely (over 2/3 judgmental probability) that rainfall has increased 0.2 - 0.3 % per decade over tropical land areas. It is also likely that precipitation has decreased over much of the Northern Hemisphere sub-tropical area by 0.3% per year during the 20th century. In mid and high latitudes of the Northern hemisphere over the latter part of the 20th century, it is likely that there has been a 2 - 4 % increase in the frequency of heavy precipitations events. There is a greater proportion of rainfall resulting from heavy-rainfall events. Water vapour in the lower troposphere has increased with the global mean temperature during the last two decades.

It is likely that there has been a 2% increase in cloud cover over mid and high latitude land areas during the 20th century. Since 1950, there has been a decrease in the frequency of extreme low temperatures and a slight increase in the frequency of extreme high temperature. Warm episodes of the El-Niño Southern Oscillation (ENSO) phenomenon (which consistently affects regional variations of precipitation and temperature over much of the tropics, sub-tropics and some mid-latitude areas) have been more frequent, persistent and intense since the mid-1970's compared to the previous 100 years.

There has been widespread glacier retreat in non-polar regions over the 20th century. It is very likely (over 0.9 judgmental probability) that about 10% decreases of snow cover since 1960 and decreases by 2 weeks of ice cover over lakes and rivers occurred over the 20th century in Northern and mid-latitudes. Northern Hemisphere spring and summer sea-ice extent has decreased by 10 - 15% since the 1950's. It is likely that there has been a 40% decline in Arctic sea-ice thickness during late summer to early autumn in the last few decades and a somewhat slower decline during winter.

Global ocean heat content has increased since the late 1950's.

It is likely that higher maximum temperatures and more hot days over nearly all land areas were recorded in the second half of the twentieth century. It is very likely that higher minimum temperatures, fewer cold days and frost days over nearly all land areas were recorded. It is very likely that reduced diurnal variation in temperature were recorded over land areas. It is likely that the heat index which combines temperature and humidity increased over many land areas. In a few areas, it is likely that increased summer continental drying and associated risk of drought has increased (IPCC 2001b; Wigley et al., 2001). In Asia and Africa, droughts have increased in frequency and intensity in recent decades.

Current global impacts of climate change are summarized in Table B.3.2 below (from Harvey (2000).

Table B.3.2 Summary of trends in observed climatic variables (Harvey, 2000)

Variable	Analysis Period	Trend or Change
Surface air temperature and SST	1851-1995	0.65±0.05°C
Diurnal temperature range	1950-1993	0.79°C/century
Stratospheric temperature range	1979-1995	0.9°C
Extent of sea ice in NH	1972-1992	10% decrease in annual mean
Extent of sea ice in SH	1973-1994	Downward since 1977
Ice shelves off Antarctic Peninsula	Last 50 years	Dramatic retreat in the north
Alpine glaciers	20^{th} century	Widespread retreat
Length of NH growing season	1981-1991	12±4 days longer
Precipitation	1900-1994	Generally increasing outside tropics, decreasing in Sahel
Heavy precipitation	1910-1990*	Growing in importance
Antarctic snowfall	Recent decades	5-20% increase
Extratropical cyclones	Recent decades	Sharp increase in Pacific sector
Tropical cyclones	1945-1993	Decrease in mean annual maximum wind speeds in the Atlantic sector
	1944-1993	Decrease in frequency and intensity in the Atlantic sector
Global mean sea level	20^{th} century	1.8±0.1 mm/year

* Shorter records in some regions.

B.3.3 Expected Global Impacts

B.3.3.1 Equilibrium Response to a Doubling of the Atmospheric Concentrations

Assessing long-term climate sensitivity from the early stages of warming (i.e. the transient climatic response to increasing concentrations of GHG) is rendered difficult by the uncertainties of the ocean mixing parameters. However, regional patterns are substantially different from equilibrium simulations and climate sensitivity may be much smaller than equilibrium simulations because of cloud feedbacks. Therefore, the following focuses only on the equilibrium response to a doubling of GHG concentrations (Harvey, 2000).

Global averaged surface temperature is projected to increase by 1.4 to 5.8 degrees Celsius over the period 1990 to 2100 under *IPCC Special Report on Emission Scenarios* (SRES) scenarios (IPCC, 2000c). This warming is very likely (over 0.9 judgmental probability) to be without precedent over the last 10,000 years and the rate of warming will exceed the one recorded during the 20th century. It is very likely that nearly all land areas will warm more rapidly than the global average temperature, particularly in Northern altitudes during the winter, where the warming rate is anticipated to be on the order of 40% above the global average.

However, in South and South-East Asia during the Summer, and in Southern Latin America during the winter, the warming is expected to be below average. Recent trends in surface temperature are to become more El Niño-like in the tropical Pacific, more in the East than in the West, with a corresponding eastward shift of precipitations.

Global water vapour concentration and precipitation are projected to increase during the 21st century. Larger year to year variations in precipitation are very likely (over 0.9 judgmental probability) over most areas where mean precipitation is expected to increase.

Global mean sea level is projected to rise by 0.09 to 0.88 metres. This is due primarily to thermal expansion and transfer of water in glaciers and ice caps to the oceans.

It is very likely (over 0.9 judgmental probability) that higher maximum temperatures and more hot days over nearly all land areas will be recorded. It is very likely that higher minimum temperatures, fewer cold days and frost days over nearly all land areas will be recorded. It is very likely that reduced diurnal variation in temperature will be recorded over land areas. It is likely (over 2/3 judgmental probability) that the heat index which combines temperature and humidity will increase over many land areas.

In a few areas, it is likely that summer continental drying and associated risk of drought will increase. It is likely that tropical peak wind intensities and tropical cyclone mean and peak precipitation intensities will increase.

Even with little or no change in El Niño amplitude, global warming is likely to lead to greater extremes of drying and heavy rainfall, and to the greater risk of droughts and floods that occur with El Niño events. Asian summer monsoon variability will likely increase.

Northern Hemisphere snow cover and sea-ice extent are projected to decrease further. Glaciers are projected to continue their retreat. The Antarctic ice sheet mass is likely to increase because of increased precipitation while the Greenland ice sheet mass is expected to decrease.

The environmental impacts of CC include rising sea levels which will threaten habitat; permafrost melting which will release CH_4, increase floods, and make it difficult to build and maintain physical structures; increases in forest fires and crop failures due to longer and more frequent droughts; increases in the number and abundance of insects and of the pathogens they carry More warming will occur in the North than at lower latitudes, and over the continents than over oceans. More precipitation will occur at higher and mid latitudes than at lower ones (Crabbé et al., 2001). The growing season in the North Hemisphere has increased by 12± 4 days over the period 1981-91 (Harvey, 2000). The distribution of plants and animals has changed in a manner consistent with global warming. Mosquito borne diseases are reported at higher altitudes (Harvey, 2000).

Local climatic change can differ substantially from global average climatic change. However, information at the local level resulting from computer models is the least reliable. Projected local temperatures can vary by as much as a factor of 6 while global mean temperatures vary by a factor of 2. Therefore, climate change mitigation must be formulated at the global level while information at the local level provides an indicator of local risk (Harvey, 2000).

B.4 Climate Change Risk Management and the Precautionary Principle

Global climate change represents a threat to human and environmental health that may have serious and irreversible effects. However, as no one can accurately foresee the future, one cannot be certain about the severity of those possible effects, or where and when they might occur. Managing the risks of climate change requires decision-making in spite of these uncertainties. In managing the risks, it is essential to focus not only on the benefits (including co-benefits) and costs of GHG mitigation measures. Canada also needs an institutional and policy framework which can ensure the broadest societal participation, and which is based on the precautionary principle. Climate change mitigation cannot be separated from adaptation to climate change. To succeed, those who are responsible for managing the climate change and health risk in Canada, must use both sets of strategies with emphasis on robust, flexible and cost-effective long-term policies rather than on short-term emission reductions.

B.4.1 Preventing "Dangerous" Interference with the Climate System

"In general, hazards that (i) may affect a large segment of the population, (ii) occur with high probability, and (iii) can result in serious consequences, should receive a high priority for risk management. Climate change satisfies all three criteria, although there is considerable uncertainty surrounding (ii) and (iii). Since the effects of climate change may not be realized for decades, climate change might be assigned a lower priority in relation to more imminent hazards except in those cases where addressing imminent hazards (e.g. air pollution) may reduce rates of climate change. This highlights the importance of a risk management approach. In the absence of a risk perspective, the temptation is to wait and see." (Crabbé et al., 2000). However, if we wait long enough, it will be too late, despite our technological advances, to improve our prospects, no matter how bleak or catastrophic (ibid.).

The purpose of climate change risk management is to reduce GHG emissions from levels at which they are considered to be "dangerous", to levels where the risk of climate change is expected to be low. Risk management is also intended to reduce uncertainty. Climate-related risks may have a low probability, but may produce great impacts, and thus may be highly ranked as hazards, although they are subject to high uncertainty. Uncertainty is the imperfect knowledge of an event's probability, magnitude, timing, and location, and of its very existence. Uncertainty management does not imply risk removal (German Advisory Council, 1998).

Risk management cannot insure against all risks, and this is true also of managing the risks of climate change. Therefore, climate change mitigation measures must be complemented by adaptation measures which can help us to cope with a changing environment. Risk assessment must involve social considerations, as it is not just a scientific problem-solving process (Kane and Shogren, 2000). In the context of risk management, science and policy are necessarily interrelated (Jasanoff et al., 1998). In addition to mitigation strategies, risk-hedging strategies are needed, including adaptation strategies and so-called real options (Obersteiner et al., 2001). Adaptation means minimizing average and extreme impacts. Adaptation can be reactive, essentially through social resilience, or anticipatory. It is anticipatory by reducing the cost of adaptation, and it provides co-benefits by reducing variability. Examples of anticipatory adaptation are: early warning systems, incentives for relocation, and incentives to purchase insurance. Anticipatory financial adaptation is achieved by sharing residual risks through disaster relief and re-insurance. Real options include hardware (technologies that reduce vulnerability, constrain hazards, and remove GHGs), software (science that models risk and risk-hedging strategies), and orgware (strong institutions) (Obersteiner et al. 2001). As the price of international emission permits is highly uncertain, hedging strategies such as forward contracts and banking of permits will be required. (Anderson, 2002).

Climate Change is the first truly global, all-encompassing issue, in which all people without exception are involved, both as causal agents and as targets of impacts. Its global scale poses a major challenge for risk management. It is not adequate to take existing risk assessment frameworks and/or vocabulary and to apply them routinely to the risks of climate change. Climate change cannot be defined simply in terms of exposure in the standard risk assessment terminology. Risk cannot be defined solely in terms of the amount of "pollution" or the level of concentration of greenhouse gases. The climate change issue presents a new challenge on a new scale of complexity. There is no simple blueprint or prepared approach to follow. The climate change issue can only be approached in a "learning by doing" manner (Crabbé et al., 2000). Moreover, a whole range of sciences are required for both assessment and management.. The vulnerability and adaptive capacity of who and what is exposed is a fundamental variable in the definition of risk. It is a function of the interaction of human socio-economic systems, including human health and physiology, with the climate. Thus the role of public health agencies becomes essential in assessing and managing the risks. Yet the pre-existing condition of society (including its public policy) becomes the baseline and is thus crucial to determining the level of risk (and of benefits if any) (ibid.).

For government agencies involved in the climate change- related issues, such as Health Canada, it is vital that the agency's climate change initiatives relate to and build on its existing risk management capacity. Such capacity exists within Health Canada. Its risk management model emphasizes the importance of partners in managing risks to maintain and protect the health of Canadians. As well, all determinants of health are considered within a broad definition of well being. In using this framework for managing climate change-related population health risks, Health Canada may need to build a new capacity to exercise its leadership role. It may also need to raise awareness of the public health importance of many other environmental concerns.

Climate change is an environmental problem which demands attention to many different implications (public good, long time lags, large uncertainties, absence of exclusive jurisdiction). In the short term, it requires institutional designs and policy architectures that will help frame future policy debates. Policy stability is a virtue, and institutions tend to stabilize perceptions, interpretations and justifications . Therefore, government efforts towards mitigation ought to be first qualitative and then, quantitative. This approach is particularly important, because it can promote the wide participation which is so essential to achieve collective action to protect a public good. In this way, Canada could show flexibility in ratifying the Kyoto Agreement, and could demonstrate compliance by showing from the outset that its Kyoto target would likely be met, rather than by demonstrating at a future date that it was actually met. In the long term, choosing institutions capable of making mid-term corrections based on new information is more important than chosing particular policies. Despite the environmental shortcomings of the Kyoto Protocol, the institutional benefits of climate risk-management together with the health co-benefits, are the main reasons why ratification by Canada is so important.

A key task of current policy deliberations must be to seek inexpensive, politically saleable actions that can be taken today to decrease the costs of substantial reductions in future emissions (should they become desirable). Institutions can facilitate transitions between particular policies. Co-benefits reduce the cost of implementing the Kyoto Protocol and are likely to make it more saleable. Substantive actions on climate change will be taken by Provinces and Territories only if each believes that it will benefit on balance. One therefore must take into account interprovincial transfers and any intangible benefits from altruistic behaviour towards a Province, Territory, or Sector. The institutional design must induce broad participation (policy-broadening), monitoring, compliance and free riding prevention rather than deep cuts. For example, the political process is necessary to allocate quotas in any tradable quota system. The allocation cannot be done on the basis of a single principle. For a tradable permit system to work, we need institutions able to cope with changes in standards as information and province-specific circumstances change. Any geographically limited regime would induce investment in CO_2 intensive activities in non-participating provinces. The need to obtain their cooperation would increase the transfers required to broaden participation. There is currently a lack of concern for developing institutions to effect such transfers or to produce efficient allocation of abatement. These institutions would build information and participation that have considerable insurance value. This broad approach would prepare the ground for more stringent policies should they turn out to be justified. If the main benefits of mitigation are collected in some provinces, e.g. through co-benefits, one would expect them to bear a substantial part of the mitigation burden . If the ability to pay is deficient in some provinces, the richer provinces will have to redistribute their income by investing in less prosperous provinces, by or paying for their mitigation measures, in contradiction of the polluter pays principle. Negotiation on any particular set of issues is affected by the most recent experiences of the provincial parties on all of the sets of issues that both unite and divide them. This could involve health care funding and other transfers, management of the economy and income tax policy. (ibid.)

B.4.2 The Precautionary Principle

The Precautionary Principle is a decision making tool that has been developed for risk management. It is particularly useful when the uncertainty of the issue and the consequences of ignoring it are high. As well, it provides a prudent means to act when the potential for irreversible damage is significant. In the past, it has been valuable in dealing with the management of environmental and health issues. For instance, it has played an important role in guiding the development of policies to control hazardous chemicals (e.g. pesticides, PCBs) and for other environmental policies in Sweden and Germany.

The precautionary principle suggests that the greater our uncertainty, the more cautious and reversible our management actions should be. Some uncertainties cannot be removed, or can be reduced only at great cost.

The 1992 Rio Conference on Environment and Development has provided the most broadly accepted definition of the Precautionary Principle, which is enshrined in UNFCCC:

"In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation".

This is undoubtedly the most important definition of the Precautionary Principle developed thus far, and is widely quoted in numerous other documents regarding environmental protection, including CEPA 1999.

B.4.2.1 Prerequisites for Precaution

The Rio Declaration provides insight into the four (4) conditions that must be present in order for the principle to be applied.

1. Threats of (serious or irreversible) damage

The declaration suggests a clear trigger for the application of the Precautionary Principle: there must be a "threat" of "serious or irreversible damage". It is important to note the significance of the word "threat" A threat is a potential, future harm, not an actual or even necessarily likely harm. Also note that the Precautionary Principle may only be applied before harm has occurred, and any action taken in accordance with its application is therefore anticipatory and preventive.

2. Lack of full scientific certainty

The precautionary principle appears responsive to three situations of scientific uncertainty. The uncertainty may be in regards to (1) the consequences of the potential harm (i.e. its severity and prevalence), (2) the probability that it will occur, or (3) the efficacy of measures responding to the threat (Ogilvie, 2001).

3. Existence of (cost-effective) measures to prevent the harm

The Precautionary Principle cannot be applied to any situation where there exist no measures (most say, no cost-effective measures) to prevent the potential harm from occurring. Preventive measures include those available to assess threats of damage, as well as measures to prevent damage from identified threats (Ogilvie, 2001).

4. Ability to make a decision regarding the use of preventive measure

Implicit in any statement of the Precautionary Principle is the assumption that those parties that apply the principle will have the ability to make a decision regarding the use of the existing preventive measures. That decision may be in favour of the status quo the decision not to act is a decision in itself (Ogilvie, 2001).

Despite broad global support for the Rio Declaration, there is widespread debate and controversy surrounding the most appropriate manner in which to apply the principle. The Government of Canada has developed a Discussion Document on the Precautionary Approach / Precautionary Principle. It sets out guiding principles for using the precautionary principle in Canada. A recent multistakeholder workshop organized by Environment Canada to discuss the extent to which the guiding principles can be applied to CEPA 99, illustrated the complexity of the issues. The workshop debate recflected the diverse perspectives of various stakeholder groups on the following issues:

- How does the Precautionary Principle fit within the risk assessment / risk management framework (specifically, what is its relationship to traditional risk assessment ?)
- To what extent should the principle impose upon regulators a duty to act ?
- What proportion of the burden of proof is appropriately shifted onto those responsible for creating a risk ?
- What standard of evidence should be required of those who bear the burden of proof ?
- What weight should be given to consideration of the costs of preventive measures, and the potential benefits of the technologies they limit ?

The Canadian Chemical Producers Association (CCPA, 2000) has discussed the Precautionary Principle within the context of the new Canadian Environmental Protection Act (CEPA). They believe that it is consistent with a science- based approach to policy making, and they will use it when developing regulatory and policy decisions. The CCPA views the Precautionary Principle as a public policy tool for legislation and regulation, following the six principles regarding the implementation of the Precautionary Principle as recommended by the European Commission (1998). These include:

- beginning with an objective risk assessment which identifies the degree of scientific uncertainty at each of the four stages of the risk assessment (hazard identification, hazard characterization, probability of exposure, risk characterization);
- encouraging all stakeholders to play an active role in evaluating the risk management options;
- ensuring that these measures must reflect the risk to be managed and thus that the amount of effort should be proportional to the risk;
- assessing the costs and benefits of the measures, with the emphasis being placed on attaining a reasonable reduction in the risk.
- identifying who has the burden of proof, and thus who must perform the risk assessment (in some cases, it may be up to the manufacturer, while in others, the burden may lie with the public authorities) and
- recognizing that the measures are provisional and must reflect the most recent scientific information.

The CCPA has since included two additional principles for implementing the Precautionary Principle. These include:

- incorporating an independent scientific peer review of the risk assessment process and
- prioritizing the precautionary actions to ensure that the most important and urgent problems receive the highest priorities.

The Science and Environmental Health Network argues that the Precautionary Principle is a common sense way to protect the environment and population health. They state that this principle should be adopted when any activity threatens to harm the environment or human health, even in the absence of scientific validation. Thus, the Precautionary Principle would serve as an ideal decision making tool for examining climate change (Crabbé et al., 2000).

B.4.3 Proposed Policy Options to Reduce GHG Emissions and their Co-Pollutants

GHG policies have to be long-term, systemic, robust and adaptive. They should provide a clear signal of expected long-term costs while, ideally, they should not be too expensive in the short-run both financially and politically. Given that the first commitment period for the Kyoto Agreement starts in 2008, and that it will take at least another year to put policies in place, 5 years is a short time for these policies to show results. Therefore, there is a danger that the policies which will emerge will be short term ones, which will foster only transitory preference changes similar to those adopted during the world energy crisis of the 1970's. They could induce adoption of convenient but fairly unfruitful technologies, such as a rapid turnover of readily available, but short-lived equipment. Long term policies will seek to influence the character of technical change, land-use, urban forms and infrastructures, and R&D for higher efficiency and cleaner fuels, while warning about higher financial penalties in the future. To be durable, preference changes have to be sustained by financial incentives and technological support. These policies may miss the target for the first commitment period, but they would be cheaper and more environmentally effective for the following ones (Jaccard et al., 2002; David Suzuki, 2002).