Canadian Energy Research Institute

Potential Effects of Climate Change on the City of Calgary: Adapting to a New Environment

Prepared for the City of Calgary

Govinda R. Timilsina, PhD
Research Director

Paul R. Kralovic
Economist

DRAFT

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EXECUTIVE SUMMARY

This study assesses possible long term effects on Calgary of climate change and climate change mitigation measures. The effects highlighted in the study are related to built environment (e.g., water and energy supply, infrastructure and transportation), natural environment (e.g., vegetation, and air & water quality) and economic and social development.

Climate change would affect Calgary both positively and negatively. However, negative effects are likely to outweigh positive ones. Positive impacts are related to increased outdoor recreation, less snow removal, lower energy consumption for heating and higher agricultural production. Negative impacts include, among others, reduced quality and quantity of water supply; increased vector born and parasitic diseases, more waste with less water to clean it.

Climate change mitigation measures would provide associated benefits such as improvement in local air quality and thereby reductions in air quality related diseases; energy savings through energy efficiency improvements in buildings, industrial processes and vehicles; and an enhanced public transportation system. On the other hand, since the Calgary economy depends on oil and gas supply activities (e.g., production, processing, and transportation), the economy could suffer as climate change mitigation measures and policies negatively influence oil and gas supply activities in Alberta.

CHAPTER 1
INTRODUCTION

1.1 Background of the Study

The Canadian Energy Research Institute (CERI) has carried out this study for the City of Calgary's MegaTrend[1] project '*imagineCALGARY*'. The study primarily focuses on the potential impacts on Calgary of climate change and measures in response to climate change.

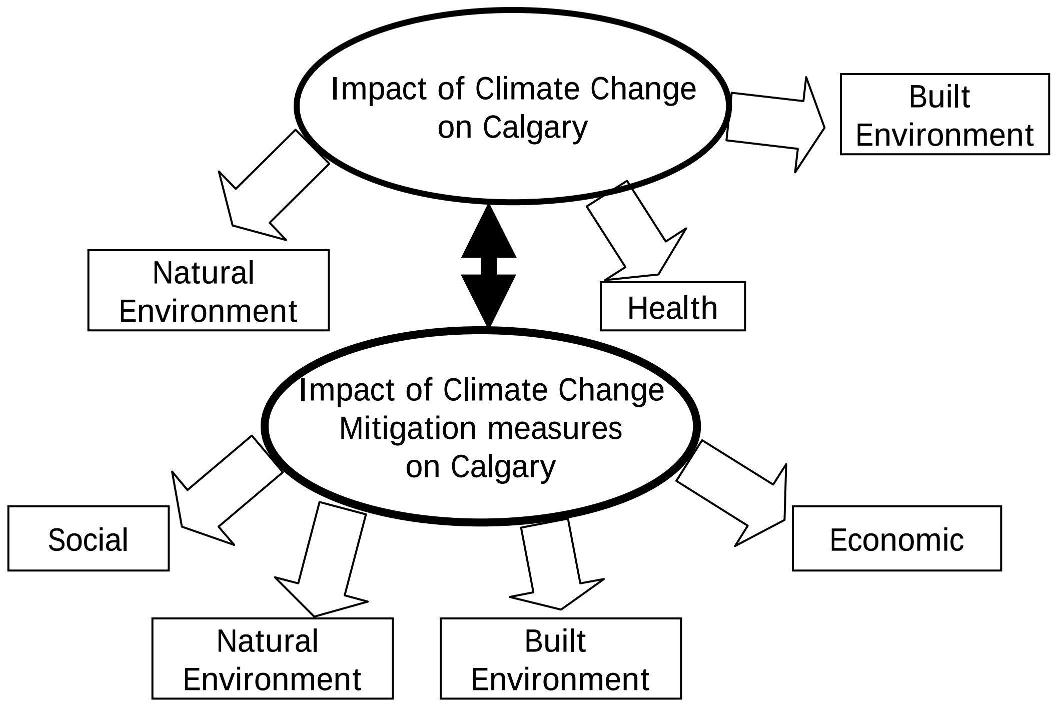
The overall objective of the study is to assess the impacts on the city of Calgary of climate change and measures in response to climate change. While response measures could include both mitigation and adaptation activities, this study focuses on mitigation activities.

Climate change could impact Calgary in several ways: first, through the direct impacts of global warming; second, through mitigation measures to slow down global warming and their associated costs; and third, through any adaptation measures felt necessary to respond to climate change.

Direct impacts include potential changes in the city's weather, and alterations in water supply; transportation and other infrastructure; health care and outdoor recreation. Mitigation measures might provide significant ancillary benefits such as improvement in local air quality and thereby reductions in air quality related diseases. However, since the Calgary economy depends on oil and gas supply activities (e.g., production, processing, and transportation), the economy will suffer if climate change mitigation measures negatively influence oil and gas supply activities. Adaptation costs, though less likely to be significant in the case of Calgary, might involve massive expenditures on a world scale, thus indirectly affecting us through economic interaction and feedback. Figure 1.1 portrays the interactions of climate change and mitigation measures to human society through various linkages such as natural and built environments and economy.

[1] The term "mega-trends" was coined by futurist John Naisbitt, and became the title of his 1982 best-seller book. The term has entered the popular lexicon to characterize a large social, economic, political, environmental or technological change.

Figure 1.1
Assessing the Impacts of Climate Change



As shown in Figure 1.1, we focus on the impacts of climate change on natural environment (e.g., air, water, soil), built environment (infrastructure, water supply, energy, housing, waste management) and health. In the case of climate change mitigation measures, we discuss the impacts on social, natural environment, built environment and economic.

Our analysis is based mainly on existing literature investigating the impact of climate change on Canadian cities, particularly Calgary. Government departments, research and academic institutions carry out these studies. Both negative and positive impacts of climate change and mitigation measures are assessed.

1.2 Climate Change Trends

1.2.1 Global Trends

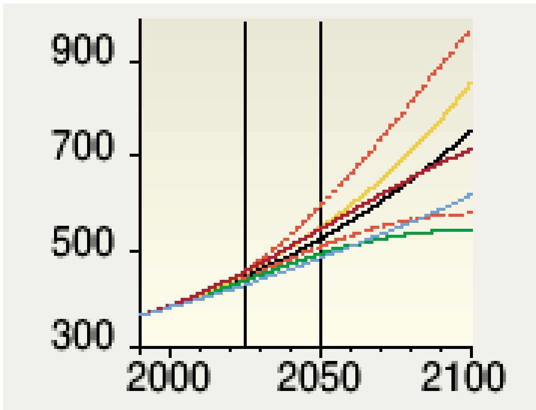
Human activities such as production and consumption of fossil fuels, agricultural activities and land use changes have caused substantial increases in the atmospheric concentrations of greenhouse gases (GHG) such as carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and halocarbons (e.g., HFC, PFC). The increased concentrations of GHGs may enhance the natural greenhouse effect which could result in additional warming of the earth's surface and atmosphere. This in turn may adversely affect both natural ecosystems and humankind

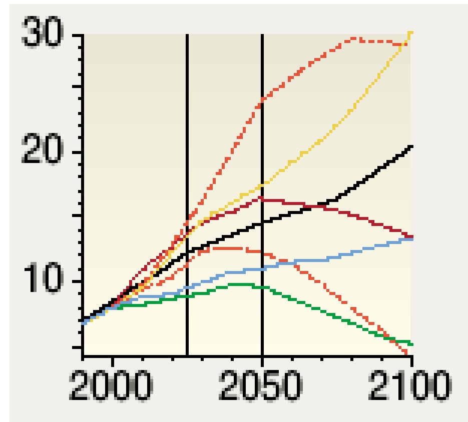
(UNFCCC, 1992). The increase in surface temperature over the 20th century for the Northern Hemisphere is forecast to be greater than that for any other century in the last thousand years (IPCC, 2001). Globally, the 1990s were the warmest decade and 1998 was the warmest year over the last 150 years. There is evidence that most of warming observed over the last 50 years is attributable to human activities (IPCC, 2001).

The increased concentration of GHGs in the earth's atmosphere is believed to be responsible for the increase in the earth's average surface temperature. The atmospheric concentration of CO_2 in the pre-industrialization period (i.e., before 1750) was 280 parts per million (ppm). The concentration increased to 368ppm in 2000. The Intergovernmental Panel on Climate Change (IPCC) believes that the CO_2 concentration in the year 2100 will range from 540ppm to 970ppm. This could lead to an increase in global surface temperatures by 1.4 to 5.8°C by 2100. This is about two to ten times larger than the central value of observed warming over the 20th century.

Figure 1.2 presents annual CO_2 emissions, atmospheric CO_2 concentrations and earth's average surface temperature under various scenarios of economic development, population growth and technological change.

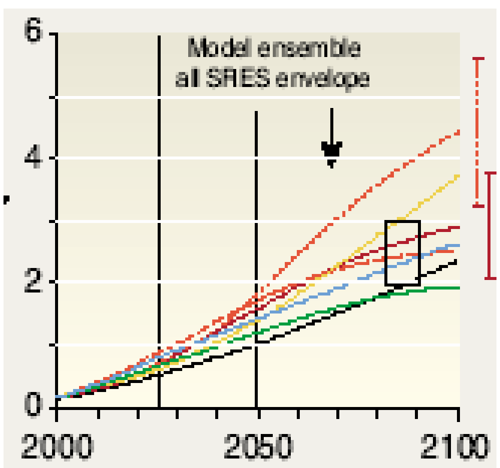
Figure 1.2
CO2 Concentration, Annual Emissions and Resulting Average Temperature

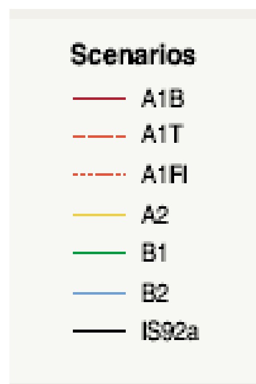




(a) CO_2 concentration (ppm)

(b) Annual CO_2 emissions (Billion tons of Carbon)





(c) Temperature change (^{0} C)

The A1 scenario family describes a future world of very rapid economic growth with global population peaking in mid century and declining thereafter, and rapid introduction of new and efficient technologies. The three A1 cases are distinguished by their technological emphasis: fossil fuel intensive (A1F1); non-fossil source (A1T) and balance across energy sources (A1B).

The A2 scenario family describes a very heterogenous world with continuously increasing population. Economic development would be regionally oriented and per capita economic growth and technological change fragmented and slower than other scenarios.

The B1 scenario family describes a convergent world with population peaking in mid-century and declining thereafter; rapid change in economic structure towards a service and information economy with reductions in material intensity and introduction of clean and resource –efficient technologies.

The B2 scenario family describes a world with emphasis on local solutions to economic, social and environmental sustainability; continuous population increase at a rate lower than A2; intermediate levels of economic development and more rapid and more diverse technological change than in B1 and A1 scenarios.

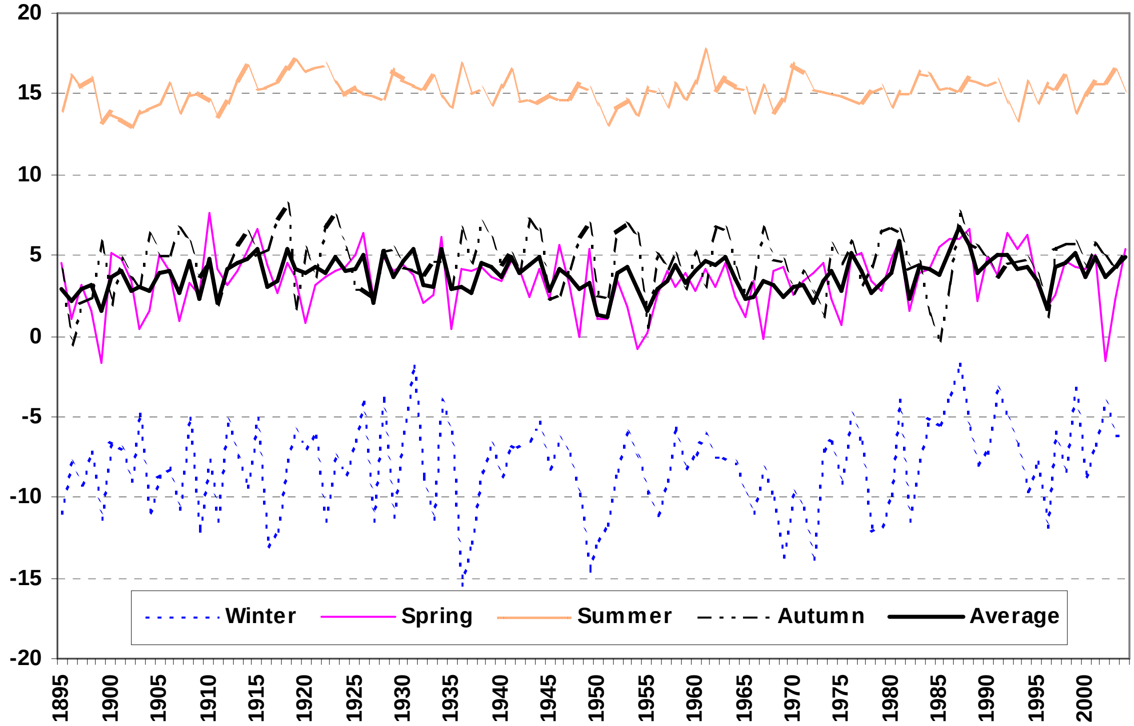
Source: IPCC (2001)

Depending upon the scenarios, the CO_2 concentration in 2100 would be 540ppm (B1 Scenario) to 970ppm (A1F1 Scenario). CO_2 emissions in 2050 would range between 9 billion tons (B1 Scenario) and 23.5 billion tons (A1F1 Scenario). The increase in earth's average surface temperature in 2100 would vary from 1.8^0C (B1 Scenario) to 4.5^0C (A1F1 Scenario).

1.2.2 Local Trends

Calgary has a dry continental-type of climate, which is primarily controlled by the geographic setting, the Rocky Mountains. Since there are no physical barriers to air masses crossing Alberta from the north or south, moist and warmer air from the US Midwest affects southern Alberta throughout the year and may lead to large regional precipitation events. During the winter, frigid Arctic air flows southward across the Prairie Provinces, with associated migratory weather disturbances frequently producing blowing snow and/or high wind-chill conditions. Like other prairie cities, Calgary also enjoys predominately sunny skies throughout the year, considerable fall and spring cloudiness occurs due to the oscillation of the migratory storm track across the region (Wittrock et al 2001).

Figure 1.3
Temperature Pattern in Calgary (1895 – 2004)



Winter: Dec., Jan., Feb.
Spring: Mar., Apr., May
Summer: June, July, Aug.
Autumn: Sept., Oct., Nov.

Source: Environment Canada, www.ec.gc.ca

Climatic change in a region is related to global climate change. A small change in mean global climates can produce relatively large changes in regional climates and in the frequency of extreme events. Regional and global climate models are used to predict future climate patterns. Table 1.1 presents the average temperature in the prairies as predicted by the Canadian Global Climate Model.

Table 1.1
Changes Average Temperature (°C) Across the Prairies for the 2020s, 2050s and 2080s Time Slices as Compared to the 1961-90 Simulation

Season	(2010-2039)	(2040-2069)	(2070-2099)
Annual	2 to 3	4 to 5	5 to 8
Spring	2 to 3	4 to 7	5 to 9
Summer	2 to 3	3 to 5	5 to 7
Fall	1 to 2	2 to 4	3 to 5
Winter	2 to 4	5 to 8	5 to 9

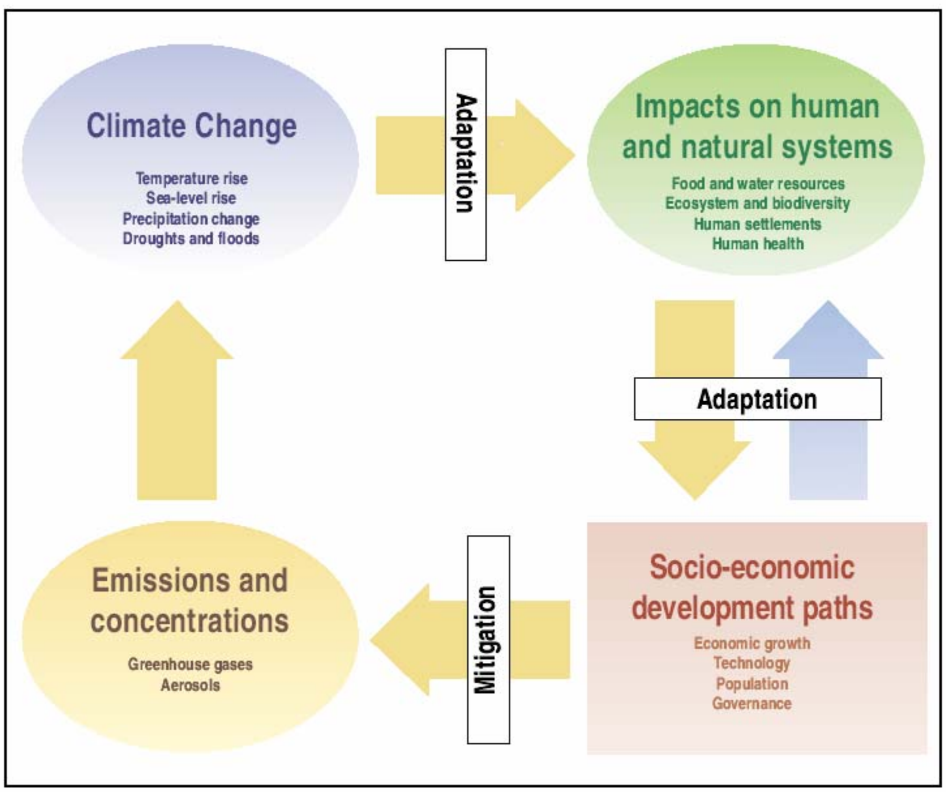
Source: CCIS (2000).

As can be seen from the table, the future prairie climate is forecast to be warmer. The fall season is expected to experience the least warming and least variability. Warming in summer would be smaller than winter and spring.

1.3 Climate Change – Interactive Framework

Figure 1.4 presents a simplified representation of an integrated assessment framework for climate change. As can be seen from the figure, the accumulation of GHG emissions through burning of fossil fuels, agricultural activities, and land use change, increases concentrations of GHG emissions in the earth's atmosphere. The increased concentrations could increase the natural greenhouse effect thereby resulting in global warming or climate change. The indicators of climate change include the increase in earth's average temperature, rise in average sea level and change in precipitation. Both human and animal populations would have to adapt to the changed climate as food and water supplies, natural resources, the ecosystem, and eventually, the degree of biodiversity would be different in the changed climate. The adaptation process would affect economic growth, technological change, and social development.

Figure 1.4
An integrated Framework of Climate Change



Source: IPCC (2001)

CHAPTER 2
IMPACTS OF CLIMATE CHANGE

2.1 Impacts on Natural Environments

2.1.1 Vegetation

Climate change is predicted to exacerbate the heat island effect[2], a major phenomenon that affects treecover (or greenery) in cities. Many trees in the cities already suffer from the heat island effect (International Council for Local Environmental Initiatives 2000). This is likely to result in either fewer trees or large expenditures for more tolerant species for shade and recreation. Because natural plant species are migrating northward, there may be some surprising changes in cities' natural ecosystems. For example, species, now native to Montana could appear in Calgary after some years. Warmer temperatures would benefit unwanted plants (i.e., weeds) as well as desired vegetation (e.g., garden plants). The relative advantage to weeds depends on competing species and other environmental factors besides temperature and precipitation such as attractiveness and susceptibility to insects (Patterson et al. 1999). Another potential impact of higher temperatures is the increased risk of grass fires with warmer temperatures and drier landscapes. Forest fire potentials are expected to increase about 20 to 30 percent in prairie regions over the next 60 years (Flannigan et al. 2000). The length of the fire season is also estimated to increase by over 20 days during the next 50 years or so (Wotton and Flannigan 1993).

The City of Calgary, like other cities, uses sprinkle irrigation to help maintain green spaces along with roadways and pathways. Higher air temperature will expand lawn-watering activities (Hofmann et al. 1998). This would obviously increase water consumption and costs for lawn-watering.

2.1.2 Pest Management

Climate change will have both positive and negative impacts on pest management (e.g., management of insects, rodents, and disease). The risk of damage from plant fungal and bacterial pests depends on temperature, rainfall, humidity, solar radiation, and dew. Climatic conditions affect the survival, growth and spread of pathogens, and the resistance of their hosts to infections (Patterson et al. 1999). Mild winters have been associated with rapid and strong outbreaks of plant diseases (Patterson et al. 1999). A mild winter combined with warm spring and summer conditions may allow for certain types of disease to form. Hot and dry summers

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[2] Urban heat island effect is a phenomenon that causes higher temperatures in the cities as compared to the surrounding rural areas. It is a result of replacing "natural land cover" (e.g., grasslands, trees) with urban land surfaces (e.g., buildings, pavement). This land surface alteration changes the way solar radiation is absorbed and distributed across the land with the ultimate result an increase in air temperature (Quattrochi et al. 2000).

generally result in a reduction of infestations of most fungal diseases. Warmer temperatures are probably going to shift the occurrence of diseases into areas that are currently too cold to support them (Patterson et al. 1999). Higher atmospheric carbon dioxide may affect insect feeding activity through the effects on host plant physiology and chemical composition. Climatic changes will also affect the distribution and degree of infestation of the insect pests by changing their life cycle or by affecting their hosts, predators, competitors or insect pathogens (Patterson et al. 1999). There is generally an increase in beetle activity with hot dry spring, weather, and this will likely be exacerbated under climate change.

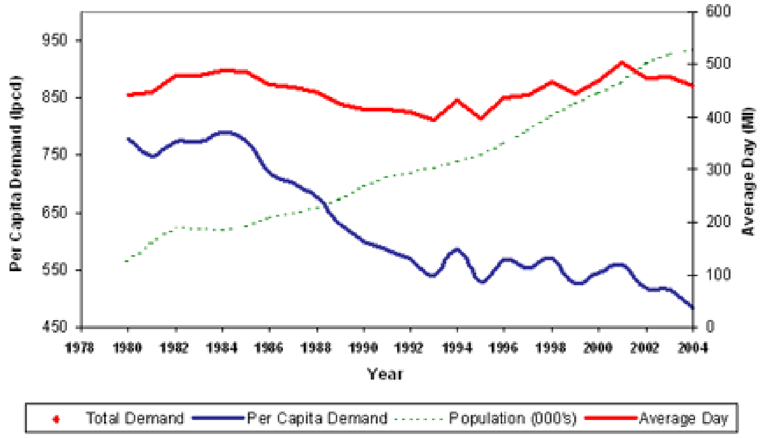
2.1.3 Water Supply

Before discussing the potential impacts of climate change on water supply, it is relevant to briefly review Calgary's water supply systems.

Currently, Calgarians use more water than the average user in many other North American and European cities. According to City of Calgary Environmental Management, on average, Calgarians use approximately 84,000 litres of water annually (City of Calgary – EM, 2005). While the Waterworks provides safe and reliable water to over 950,000 citizens–including customers in surrounding communities of Airdrie and Chestermere–and over 20,000 industrial, commercial and institutional customers, Calgary's current water use patterns are not likely sustainable in the long-term future (City of Calgary - WEP, 2005).

Figure 2.1 illustrates water consumption in Calgary over the past twenty-five years. The average day demand, which is the water system's average daily use over a one-year period, continues to increase at an average rate of five percent annually based on a ten-year average since 1996. This increase is largely due to economic and population growth. Calgary's population has increased dramatically over the past quarter of a century. Unprecedented urban and upstream developments are putting pressure on the current water and wastewater infrastructure.

Figure 2.1
Water Consumption in Calgary



Source: City of Calgary Waterworks (2005)

As demonstrated in the figure, the per capita water demand[3] continues to drop, from its peak of 800 litres per day in 1979. It is speculated that technological advancements in various household appliances, such as dishwashers and clothes washers, have impacted water usage. In addition, water is supplied and used more efficiently now than 25 years ago.

According to the City of Calgary's, *Water Efficiency Plan*, residential customers account for over 50% of the total annual water treated and distributed in the city. ICI customers, industrial, commercial and institutional, use 34% of the total. Figure 2.2 shows Calgary's water use profile across sectors.

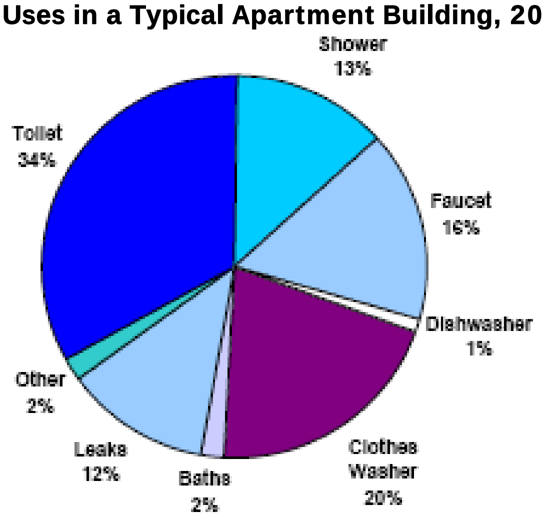
[3] Per capita demand is defined as the average amount of water used per person per day includes total water use for the city including industrial, commercial, and institutional use as well as residential consumption divided by the total population.

Figure 2.2
Calgary's Water Demand by Sector, 2003

Source: City of Calgary Waterworks (2005)

Figure 2.3 illustrates the various uses of water in a typical apartment building in Calgary. While Calgarians have very high-quality water, only a small portion of it is actually consumed. Perhaps surprising to some, most of it, in fact, is flushed down the toilet. According to Waterworks, 34% of water in an average Calgarian household is used when we flush our toilets and nearly 60% of residential indoor water use is used in our bathrooms.

Figure 2.3
Water Uses in a Typical Apartment Building, 2003



Source: City of Calgary Waterworks (2005)

While total water use is increasing at a slower rate than the population rate of growth, The City is still trying to curb Calgarians water-hungry practices. The *Water Efficiency Plan* provides the framework for water conservation efforts. Its goal is to reduce GHG emissions produced from the consumption and production of potable water. Calgary has to start planning for that period when the rivers may not be supplying as much water as they are now.

From a climate change perspective, hot water consumption is an important issue. Hot water accounts for approximately 30% of household natural gas consumption in Calgary. That is equivalent to between 1,500 and 2,500 kg of green house gases annually (City of Calgary – EM, 2005). The treatment, production and transportation of potable water and wastewater require large amounts of natural gas and electricity.

Climate change would impact water supply (both quality and quantity) by affecting water temperatures, flows and runoff rates (Gleick 2000). Changes in climatic variables (e.g., temperature and precipitation) affect runoff and evaporation patterns as well as the volume of water stored in glaciers, snowpacks, lakes, wetlands, soil moisture and groundwater. Although Canada has a relative abundance of water, it is not evenly distributed across the country. The greater Calgary area (Calgary, Cochrane, Airdrie, Bragg Creek) relies solely on water supply from two rivers: the Elbow and Bow. Climate change models predict river discharge in the future will drop due to decreased precipitation and decreased glacial coverage in the headwaters of the basin. Moreover, there would be less runoff, higher evaporation amounts, and increased water consumption (Bruce et al. 1999). As the cities would likely have to share water shortages with other major users (industry, agriculture), this places a high degree of uncertainty on the upper limit of population that can be supported solely by the river system.

The Bow and Elbow rivers which supply water to Calgary are glacier-fed rivers. It is predicted that in the next 30 to 100 years, reduced melt volumes from glaciers would result in reduced river flow, particularly in the summer (Demuth 1997). While population and activities in the city increases thereby increasing water demand, water supply would decrease. The timing of the snow pack melt and glacier runoff is also a crucial factor for water supply. If there is an early and rapid melting of the mountain snow pack that produces runoff in excess of reservoir capacities, the water will have to be released in an uncontrolled flood.

Climate change also has negative impacts on the quantity of groundwater resources. This is because precipitation is one of the main factors affecting groundwater levels and climate change significantly affects precipitation.

Climate change could change quality of water through temperature increases and changes in precipitation patterns (Gleick 2000). Increases in the frequency or magnitude of extreme precipitation causes increased loading from sediments, nutrients, and contaminants from agricultural and urban areas (Auld 1999). Moreover, higher water flows could increase erosion of land surfaces and stream channels leading to higher sediment, chemical, and nutrient loads in rivers (Frederick and Gleick 1999; Arnell 1998). On the other hand, lower water flows also affects water quality (EPA, 2000b), particularly by elevation of water temperatures through increased rates of biogeochemical processes (Arnell 1998). Lower water flows reduce dissolved oxygen concentrations and reduce the dilution of pollutants (Gleick 2000; Sauchyn 2000).

2.2 Impacts on Built Environment

2.2.1 Infrastructure

Climate change would have both negative and positive impacts on infrastructure such as roads, buildings, and bridges. An increase in temperature would affect the structural integrity of pavement through increased pavement deterioration. On the other hand, increased temperature reduces damage to pavement from freeze-thaw events and also reduces costs and accidents associated with winter storms. Climate change would affect precipitation patterns, which in turn could increase the intensity and frequency of heavy rainfall events. Consequently, costs associated with constructions and maintenance of roads, highways, bridges and culverts (storm water management) would increase. Deterioration of transportation infrastructure, such as bridges and parking garages, accelerates in areas where precipitation events become more frequent. In summer 2005, flooding resulting from heavy rainfall damaged infrastructure in the Calgary and High River areas.

Climate change scenarios project increased frequencies of high intensity rainfall events that could result in flash flooding (Bruce 1999; Etkin et al. 1998; Maksimovic 2000; Minnery and Smith 1996). This would obviously have implications for infrastructure, such as more frequent overflow of storm drainage facilities. Calgary depends upon a single large water-supply system. Vulnerability of such a system to flash flooding is well known. In summer 2005, flash flooding on the Elbow River created extreme pressure on the dam at Glenmore Reservoir, the source of Calgary's water supply.

Traditionally infrastructure has been built using the assumption of a static climate (Jacob et al. 2000) and it may have difficulties dealing with a changed climate. The construction of new infrastructure should take into account extreme climatic events observed recently and likely in the foreseeable future. Infrastructure costs may rise because of climate change.

2.2.2 Transportation

Existing studies on the impact of climate change on transportation (see e.g., Jackson 1992) suggest that there is a likelihood of a reduction in winter maintenance and snow removal costs in the populated areas of southern Canada. It is predicted that winters will be shorter and have variable precipitation amounts. A shorter winter could lengthen the period available for road maintenance and construction. A shorter winter accompanied by continually less snow may result in cities reducing their stocks of snow-removal equipment (Auld 1999). If winters are accompanied by more extreme snowfall events, there will be more equipment breakdowns resulting in the need to maintain a higher inventory of replacement parts. If winters are accompanied by more freezing rain, cities will have to keep more sand and salt inventory in stock and carry out more sanding and salting. Salt mixtures work effectively at or above -6°C, but below -12°C they cannot melt and break down the ice-pavement bond. Calcium chloride and/or calcium magnesium acetate, which are more environmentally benign but more expensive, could be needed in such an event (Samuels 1989).

High temperatures cause damage to roadway materials' heat tolerance levels because they depend upon the type of material, duration of the temperature, and the loading upon the material (Zimmerman and Cusker 2000). In the southern United States, asphalt roads soften and concrete roads have been known to "explode", lifting three to four-foot pieces of concrete (Adams 1997).

Climate change may affect driving habits. Warmer winter temperatures would cause less warming up of vehicles in the winter months; leading to savings to the cities' and residents' vehicle operations. Because of easier starting, gasoline specifications could be altered to lower the maximum amount of volatile organic compounds such as isobutane, resulting in a decline in emissions (boiling off) taking place when filling up during winter months. Since climate change has the potential for more extreme weather hazards, there could be major short-term impacts on transportation systems and on the risk of accidents (MacIver and Auld 2000).

2.2.3 Waste Management

Calgary has invested millions of dollars in waste management infrastructure. However, climate change would have enormous impacts on the infrastructure that was designed and installed more than 30 years ago (Watt et al.1998).

According to Waste & Recycling Services' 2004 Annual Report, total waste collected in 2004 by civic crews was 264,000 tonnes, including 215,000 tonnes of waste collected by civic hand collection and 49,000 tonnes of waste collected by civic container crews. Waste collected by civic hand collection increased by 5.4% from 2003 while waste collected by civic container crews increased 11.4%. Both figures are the highest recorded for The City.

In 2004, 685,000 tonnes of waste were disposed in Calgary's three landfill sites. This represents a slight decrease of 0.88% from the previous year's total. Forty two per cent (or 285,000 tonnes) of waste was disposed at East Calgary landfill, while the Spyhill and Shepard facilities each disposed of 29% (or 200,000 tonnes) of waste. Total disposal is significantly less than the city's capacity of just under 800,000 tonnes. This may be a result of the City's serious recycling efforts[4] begun in 1985. However, it is interesting to note that Calgary's population at that time was 629,000.

Climate change would impact waste management in both possible scenarios of precipitation: high and low. Increased frequency of high intensity rainfall could increase the amount of urban runoff, to a point that exceeds the capacity of storm sewer systems, thereby leading to localized

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[4] In addition to maintaining landfills and garbage collection, the goal of Waste & Recycling Services is that Calgarians will recycle 80% of our waste by the year 2020.

flooding. In the event of low precipitation, there may be lower water flow in rivers. Treatment of raw water, its distribution and the treatment of sewage effluent depend upon volume of water flow in rivers where the effluents are released (Arnell 1998). Sewage effluent needs adequate water-supply levels to allow it to be effectively assimilated. Rivers with declining water flow have reduced wastewater assimilation capability (Yulianti and Burn 1998).

2.2.4 Energy Consumption

Since climate change is projected to result in warmer temperatures, there would be shifting of some energy demand from winter to summer because of a decrease in winter heating and an increase in summer air conditioning. This shift would result in higher demand for electricity and lower demand for natural gas in the residential and commercial sectors. However, if natural gas is used to generate electricity in response to increased demand, total consumption of natural gas might increase.

Most of the energy consumption in Calgary is for water & space heating, lighting and transportation (i.e., cars, trucks, SUVs). An average household in Calgary spends over $3,000/year on energy consumption. Moreover, the average household emits nearly 20,000 kg of GHG emissions from fuel consumption. The following figure illustrates the energy consumption of a typical household in Calgary and the various levels of GHG emissions associated with the energy use.

Table 2.1
Energy Consumption for a Typical Calgary Household

Energy Use	Avg. Annual Use	Cost ($)	Greenhouse Gas Emissions
Electricity (lights, appliances, etc.)	7200 kWh	$504*	6,700 kg
Heating (space & water)	150 gigajoules (GJ)	$960**	7,500 kg
Vehicle	2,200 litres	$1,540***	5,300 kg
TOTALS		$3,004	19,500 kg

*Electricity cost of $0.07/kWh.
**Natural gas prices are extremely variable. Data is based on September 2003 1-year fixed rate of $6.40/GJ.
***Based on a gasoline price of $0.70/litre, vehicle use of 20,000 km/yr and fuel economy rating of 11L/100 km.

Source: City of Calgary Environmental Management (infosheets)

2.3 Impacts on Social Development

2.3.1 Health Care

Climate change could impact health in two ways: (i) direct (e.g., changes in temperature-related morbidity and mortality) and (ii) indirect (e.g., shifts in vector-borne diseases). Higher temperatures are expected to increase the occurrence of heat-related illnesses such as heat exhaustion and heat stroke, and exacerbate existing conditions related to circulatory-, respiratory- and nervous system problems. Higher temperatures combined with high pollution levels could increase respiratory disorders, such as asthma. Higher concentrations of airborne particulates would cause nasal, throat, respiratory and eye problems. Higher temperatures and heavier rainfall are associated with a significant number of waterborne disease outbreaks, an example of which was the *E. coli* outbreak in Walkerton, Ontario in 2000. Warmer temperatures also increase bacterial levels and encourage the growth of toxic organisms.

Warmer weather fosters the establishment and proliferation of vector-borne diseases as it encourages the northward migration of species of mosquitoes, ticks and fleas. Moreover, climate change could enhance the seasonal abundance of vector-borne diseases as changes in temperature, precipitation, humidity and wind patterns affect vector species' reproduction, development, and longevity (Martens et al. 1999). Diseases such as West Nile virus, malaria, Lyme disease, eastern and western equine encephalitis are likely to increase.

Health impacts on the elderly, the very young and low income families could be severe (Scheraga 1998; Kilbourne 1997; Guest et al. 1999; Gaffen and Ross 1998; Kinney et al. 2000). Since governments are responsible to provide health care, their health care costs would increase. The baby-boom generation in Canada, including the Prairie Provinces, is aging and soon will become the most vulnerable population (Mortsch and Quinn 1998). Climate change could also have other impacts such as an extended flu season because of the fluctuating temperatures (Beaulieu 2001).

2.3.2 Outdoor Recreation

The number of days suitable for golfing could increase due to climate change. For example, Lamothe and Périard (1989) estimates that number of days suitable for golfing in Quebec could increase by 20 to 50 percent. This change would obviously affect the golfing industry. On the other hand, shorter winters would negatively impact ski and outdoor skating activities. One impact of climate change might be to increase demand for outdoor sports activities such as soccer and football as compared to indoor sports activities such as ice hockey.

2.4 Impacts on Economic System

Although climate change might have both positive and negative impacts, the negative impacts are likely to outweigh the positive ones. Climate change would incur additional cost to the city through the followings:

- Additional maintenance costs and adaptation costs for transportation and infrastructure facilities
- Additional costs to maintain water supply and waste management
- Possible additional costs to maintain recreation (e.g., public park and play grounds) facilities, although milder winters may lessen the weather-related deterioration of equipment
- Additional costs to maintain care-giving facilities (care for elderly population)

2.5 Impact on Governance

Climate change is expected to affect activities mostly falling under municipal jurisdiction such as water supply, waste management, local transportation and infrastructure, parks and recreation. Since the city is responsible for these services, it may need more budget to maintain the services affected by climate change. The city might need to demand more financial resources from the provincial and federal governments to cope with situations that would be created by climate change.

CHAPTER 3
IMPACTS OF CLIMATE CHANGE MITIGATION MEASURES

The United Nations Framework Convention on Climate change (UNFCCC) signed in Rio, Brazil in 1992 during the first Earth Summit defines its ultimate objective as stabilization of GHG concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system (UNFCCC, 1992). The atmospheric concentration of carbon dioxide (CO_2), the main GHG was 280 ppm (part per million) in the pre-industrial era and about 368 ppm in the year 2000. Under various scenarios, the Intergovernmental Panel on Climate Change (IPCC) projects that concentration of CO_2 in the atmosphere would vary between 540 ppm to 970 ppm by the end of this century. These increased GHG concentrations could cause the earth's average surface temperature to increase by 1.4 to 5.8^{o}C over the period 1990 to 2100. This is about two to ten times larger than the central value of observed warming over the 20th century (IPCC, 2001). This change in temperature would be reflected through an increase in average annual global precipitation of from 5 to 20 percent and an associated increase in global mean sea levels of from 0.09 to 0.88 meter during the 21st century.

Future climate change may be determined by historic, current and future emissions of GHGs. The IPCC projects that if the present rate of CO_2 emissions continues, its concentration in the atmosphere would reach 450ppm within 2 decades and 1000ppm by the end of the century (IPCC 2001). The projected global warming would be slower and its effects on earth's climatic system would be lowered if higher level of GHG reductions could be achieved in earlier dates. To stabilize the atmospheric CO_2 concentration at 450ppm level, which is believed to be essential to avoid climate change, global CO_2 emissions would have to be reduced below the year 1990 levels within a few decades.

Table 3.1 presents CO_2 concentration stabilization profiles and corresponding concentrations in years 2050 and 2100. The table also presents annual CO_2 emission to be maintained in order to achieve the stabilization profiles.

Table 3.1
CO_2 concentration stabilization profiles and corresponding CO_2 emissions

CO_2 concentration stabilization	Year of Concentration stabilization	Concentrations (ppm)		CO_2 emissions (Billion tons of Carbon)		% reductions from 1990 in year
				Annual for year	Cumulative for period	
Profiles		2050	2100	2050	2001 to 2100	2050
450 ppm	2090	445	450	3.0 –6.9	365 - 735	-61.5
550 ppm	2150	485	540	6.4 – 12.6	590 – 1,135	-17.9
650 ppm	2200	500	605	8.1 – 15.3	735 – 1,730	3.9
750 ppm	2250	505	640	8.9 – 16.4	820 – 1,500	14.1
1000 ppm	2375	510	675	9.5 – 17.2	905 – 1,620	21.8

1990 emissions are taken to be 7.8 billion tons of carbon.

[a] Lower number of 2005 emissions are taken to calculate percentage reductions.

Source: IPCC (2001)

There is no agreement as to the level of CO_2 concentration needed to meet the ultimate objective of the UNFCCC. However, most climate models predict irreversible damages if CO_2 concentration doubles from the present level of 368ppm as earth's mean surface temperature could increase by 2.6 to 5.8 degrees Celsius and global mean sea level could rise 0.32meter to 0.88 meter. To avoid catastrophic damage from climate change, many countries favor stabilization of CO_2 concentration at 450ppm by the end of the century. If that is the case, global CO_2 emissions should be reduced more than 60% from 1990 levels by 2050.

It is uncertain, whether or not Canada will adopt a policy to reduce GHG emissions by 60 percent or so by 2050, therefore, we will discuss in general terms only, the major impacts of climate change mitigation measures on Calgary. We focus our climate change mitigation impact assessment on a few key variables. These are natural and built environments and economic and social developments.

3.1 Impacts on Built Environment

3.1.1 Transportation

Before discussing the impacts of GHG reduction efforts, it is useful to review some relevant transportation statistics for Calgary. The average distance traveled per person within the city has increased by nearly 3,000 km per year between 1991 and 2001 (City of Calgary - CTP, 2005). It is interesting to note that Calgary has a relatively higher proportion of its labour force using public transportation as compared to other cities in Western Canada (Please see Table 3.2).

Table 3.2
Employed Labour Force by Mode of Transportation (2001 Census)

	Saskatoon	Calgary	Edmonton	Vancouver	Victoria
Total Employed Labour	106,025	499,045	469,220	905,995	140,515
Car, truck or van, as driver	80%	72%	78%	72%	68%
Car, truck or van, as passenger	7%	7%	7%	7%	6%
Public transit	4%	13%	9%	11%	10%
Walked to work	6%	6%	5%	6%	10%
Bicycle	3%	1%	1%	2%	5%
Motorcycle	0%	0%	0%	0%	1%
Taxicab	0%	0%	0%	0%	0%
Other method	1%	1%	1%	1%	1%

Source: Statistics Canada, Census of Population

There is a positive trend with regard to the increased use of public transit and the number of individual that either walk or bicycle to work. LRT station expansions to Canyon Meadows, Fish Creek-Lacombe, Shawnessy and Somerset-Bridlewood in the south and Dalhousie in the north, connect distant suburbs to the downtown center. According to the City of Calgary's *Calgary Transportation Plan,* there have been significant improvements to transit networks, including a 36% increase in the number of buses, a 30% increase in C-Trains and 9 more kilometers of LRT track. There has been almost a tripling of the number of people using the city's pathway and bikeway system, making it a genuine mode of travel for Calgarians getting to work. Walking, cycling and transit use indicate less auto dependency in Calgary.

GHG emissions from transport can be reduced through:

- Reductions in levels of transport activity
- Modal shift
- Improvement of vehicle engine efficiency
- Fuel switching

In the first case, transportation service demand in the city would be lowered and operation of vehicles would be discouraged. The positive impacts of this policy would be cost reductions in maintenance and repair of existing transportation infrastructure as well as avoidance of part of new transportation infrastructure demand. This policy could however, negatively impact the economy of the city as well as the welfare of individuals or households.

The second case is a shift from private transportation such as car, SUV, truck and mini van, to public transportation such as bus, and LRT. A typical characteristic of a big city with a good transportation system is that the city is based more on public transportation (commuting) than private transportation. Big cities such as Paris and Tokyo have a very large public transportation network. Singapore has discouraged private transportation by imposing a vehicle-licensing fee, which is almost equal to the cost of vehicle itself. One of the key implications of climate change mitigation measures for Calgary in the long-term could well be a modal shift of transportation.

Switching fuels is another way to reduce transportation sector GHG emissions. Alternative fuels such as ethanol, bio-diesel, fuel cells, hydrogen, compact natural gas (CNG) are already available in the market place. Solar cars are also in the demonstration phase. Cities in California have already begun significant initiatives to switch over to these alternative fuel vehicles. In the long term, the City of Calgary could also encourage fuel switching in the transportation sector to reduce GHG emissions. As a result, the city would have more alternative fuel vehicles running on the road.

Besides the policy instruments discussed above, an important issue emerging is the long-term city plan. The design of the city, as such, is inefficient in terms of public transportation system. Most office buildings are concentrated in the downtown area. During peak hours of transportation (7:00 – 9:00 AM and 4:00 to 6:00PM), busses and LRT cars to and from the downtown are over crowded in one direction and nearly empty in the other. This implies a greater number of vehicles is needed in the peak hours, poor utilization of vehicles and unnecessary emissions of GHGs as vehicles consume fuel even though they operate with few passengers. This issue is not important from the perspective of climate change only, but also as it affects overall planning for the city. Calgary continues to grow, and the continually increasing population could lead to public transportation problems unless the city has an efficient plan to manage that growth. The city will need a transportation plan that is compatible with climate change and its sustainable development goals. This may require provincial and federal support, possibly under current and future climate change programs. A transportation plan with a ring LRT system (like a ring road) with a number of feeders connecting to downtown could be a vision for the city. Moreover, instead of adding more office buildings in the downtown core, the city could have a policy to diversify office buildings into the four corners: NW, SW, NE and SE.

3.1.2 Energy Consumption

GHG mitigation efforts could significantly affect energy consumption in Calgary. Since, energy consumption is the main source of GHG emissions, most GHG mitigation efforts will focus on reducing GHG emissions associated with energy consumption. The key strategies reducing GHG emissions from energy consumption are as follows:

- Energy efficiency improvement/energy conservation/demand side management
- Fuel switching
- Demand reduction through pricing

Energy Efficiency Improvements: Most energy efficiency improvement options, such as replacement of inefficient light bulbs (e.g., incandescent lamps) with their efficient counterparts (e.g., compact fluorescent lamps); replacement of low or mid efficiency furnaces with high efficiency furnaces; and replacement of low efficiency refrigerators, ranges, washers & dryers with their efficient counterparts, are being considered to reduce GHG emissions from urban areas. These options not only reduce GHG emissions but also result in net economic benefits through savings in energy bills. A study conducted by the Canadian Energy Research Institute (CERI) for the Clean Air Strategic Alliance of Alberta (CASA) in 2004 shows that if existing electrical appliances are replaced by their best practice counterparts, significant energy consumption would be saved (please see)

Table 3.3
Technical Potential for Electricity Savings Through the Best Practice End-use Appliances in Alberta

Device/Technology	% Savings
Residential Sector	
Lighting	67 - 75
Refrigerator	61
Electric Range	5
Electric Dryer	15
Dishwashers	63 - 77
Clothes washers	67 - 87
Commercial and Institutional Sector	
Lighting	33 - 56
Residential type refrigerator	50
Packaged refrigerator	45
Central Chiller	50-70
Packaged AC	10-15
Industrial Sector	
Chemical Industry	
Electric Motor	2 – 8
Electrolyzer	15
Pulp & Paper	
Electric Motor	1 – 5
Oil sands Industry	
VAPEX technology for in-situ bitumen production	80
Electric motors in oil sands mining	2.5
Conventional oil & gas extraction	
Electric Motor	4-8

Source CERI (2004)

Fuel switching, for example, switching over to gas fired cooking stoves (range) from electric fired stoves is another instrument to reduce GHG emissions from residential and commercial establishments in Calgary, as the electricity system in Alberta is coal dominated. Natural gas emits about 40% less CO_2 than coal, while providing the same amount of heat. Moreover, when electricity is generated from fossil fuels, only about 30 to 40% of the heat content of the fuel is converted to electricity (i.e., thermal efficiency of power plants are around 30 to 40% depending on plant type). Accounting for all factors (i.e., thermal efficiency, emission coefficients and stove efficiency), natural gas stoves emits 75% less CO_2 than electric stoves if electricity is produced from anthracite coal. Even if electricity is produced from natural gas, gas stove emits CO_2 emissions almost a half of electric stove.

Demand reduction through pricing: One of the negative consequences of GHG mitigation policies could be higher energy prices. Climate change policies are likely to increase energy prices directly or indirectly. Consumers will experience lower economic welfare because of higher energy prices resulted from climate change mitigation policies.

3.1.3 Housing

GHG mitigation policies could lead to energy efficient housing in the city. Both residential and commercial buildings are expected to have better insulation, efficient energy appliances (e.g., refrigerators, washers & dryers, lamps, furnace etc.). Some new houses might use geothermal (earth) energy. Houses with solar roofs might be also a possibility considering the relatively good solar energy profile in Calgary.

3.2 Impacts on the Economic System

One of the key concerns of climate change mitigation measures for Alberta and Calgary economies is the potential negative economic impacts of mitigation measures. Calgary's economy is highly sensitive to the service sector supplying oil and gas industries in Canada. Stabilization of CO_2 concentration at the 450ppm level to meet the ultimate objective of the UNFCCC would lead to significant reductions in global fossil fuel demand. Significant reductions in global oil demand could discourage investments in the oil sands sector in Alberta. Any reductions in oil and gas activities in Alberta would obviously impact the economy of Calgary through losses in jobs, revenues, transactions of goods and services and other economic activities. However, even though global oil demand decreases due to climate change mitigation policies, it is not necessary that oil and gas production activities in Alberta will slow down. This is because there might be a shift from the Middle East to North America in supplying North American demand for oil. This scenario is increasingly likely because of the growing emphasis on energy security.

Whether or not cuts in global oil demand resulting from climate change policies affect oil production in Alberta, these policies are likely to increase the costs of oil production from Alberta oil sands. If the federal government adopts a policy to reduce GHG emissions in line with the 450ppm stabilization scenario, the price of fossil fuel would increase dramatically. As the production of bitumen through in-situ processes is very energy intensive, any increase in energy costs could discourage oil sands investors and production from the oil sands industry might grow more slowly or even decline. As mentioned earlier, any reduction in oil and gas activities would significantly affect the economy of Calgary.

A recent CERI study 'Economic impact of Alberta's Oil Sands' (CERI 2005) reveals that the oil sands industry is expected to invest more than $100 billion through 2020, translating into crude bitumen production and SCO outputs worth approximately $571 billion. These investment and production activities lead to an increase in GDP of $634 billion and to 3.6 million person-years of employment in Alberta during the 2000-2020 period. Since, Calgary is one of the largest components of Alberta's economy, its share in those impacts would be significant. Moreover, municipalities in Alberta including Calgary would receive about $10 billion through property taxes due to oil sands development and production activities during the 2000-2020 period. A reduction in oil sands investment and production for any reason would obviously impact Calgary economy.

3.3 Impacts on Natural Environment

Most GHG mitigation activities help directly or indirectly improve the quality of the natural environment (e.g., air, water, soil, plant animals).

3.3.1 Air Quality

An improvement in air quality is one of the most important ancillary benefits of GHG mitigation measures, particularly in urban areas. This is because the source emissions with local impacts (e.g., particulate matters, carbon monoxide, and volatile organic compounds), with regional or trans-boundary impacts (e.g., oxides of sulfur (SOx) and nitrogen (NOx) and with global impacts (e.g., CO_2, N_2O) are mainly the common, burning of fossil fuels. A reduction in use of fossil fuels would reduce all of these emissions. Hence, GHG mitigation measures in residential, commercial, transportation and industry sectors in Calgary would significantly help reduce local air pollution and thereby improves air quality of the city.

3.3.2 Water Quality

GHG mitigation measures would contribute indirectly to improved water quality. Acid rain resulting from SOx and NOx concentration in air, is a prime culprit for deteriorating water quality in reservoirs. GHG mitigation measures, by reducing SOx and NOx emissions, mitigate the acid rain problem.

3.6 Impacts on Social Development

3.6.1 Health Care

Climate change mitigation measures would impact the health care system positively in several ways such as reduction of Criteria Air Contaminants (CAC), improving indoor air quality, and reducing vehicular noise pollution.

- Reduction of local air pollutant

  Combustion of fossil fuels are a source not only of GHG emissions but also of CACs such as particulate matters (PM), ozone (O_3), volatile organic compounds (VOC), carbon monoxide (CO), oxides of sulphur (SOx) and oxides of nitrogen (NOx). Among these PM2.5, PM10 and ground level O_3 are the most toxic to human health. There is a large body of literature (Pope et al., 1995; Schwartz et al., 1996; Ostro et al., 1989; Abbey et al., 1993; Ostro et al., 1991) confirming that higher levels of these pollutants are associated with increased mortality and morbidity. These pollutants increase the risks of chronic bronchitis and asthma (Burnett et al., 1997; Stieb et al., 1995; Krupnick et al,. 1990; Whittemore et al., 1980). This leads to more emergency room visits and hospital admissions for respiratory illness and cardiovascular complications. Reducing fossil fuel combustion to reduce GHG emissions also results in significant reductions in CAC emissions and their negative health effects. Any activities aimed to reduce GHG emissions from fossil fuel combustion such as energy efficiency improvements on both the demand and supply side, modal switching in transportation (i.e., from private to public) and fuel switching would provide health care benefits through reductions of CAC emissions.

- Improvement in in-door air quality

  Some GHG mitigation measures for buildings such as improved ventilation systems also reduce indoor air pollutants such as VOC's, particulates, etc. The reduction of these indoor air pollutants result in decreased eye irritation, headaches, fatigue, and respiratory diseases.

- Reduction of vehicular noise pollution

  As mentioned earlier, reduction of vehicular kilometer travel (VKT) is one of the key strategies to reduce GHG emissions from the transportation sector. Reductions in VKT would also lead to lower vehicular noise pollution.

3.6.2 Sense of Community

Climate change mitigation initiatives are likely to enhance the sense of community. For example, car pooling is one of the options to reduce GHG emissions from the transportation sector. Car pooling could help strengthen neighborhoods and local communities. Climate change mitigation may eventually lead to shifts in transportation from private mode (e.g., car, truck, SUV, van) to public mode (e.g., bus, LRT). Public transportation would provide greater opportunities for personal interaction and the sharing of information. This result could be an enhancement in the sense of community.

CHAPTER 4
CONCLUSIONS

This study presents long term effects on Calgary of climate change and climate change mitigation measures on the city of Calgary. The effects highlighted in the study are related to built environment (e.g., water and energy supply, infrastructure and transportation), natural environment (e.g., vegetation, and air & water quality) and economic and social development.

Climate change would affect the city's weather, vegetation, water supply, infrastructure, transportation, health care and recreation. Climate change is also predicted to affect tree cover (or greenery) through exacerbation of the heat island effect. It is likely that there will be some surprising changes in the city's natural ecosystems. For example, species currently native to Montana, could also appear in Calgary after some years. Water consumption and costs for lawn-watering would increase. Climate change is expected to affect the quantity and quality of water in the Elbow and Bow rivers, the City's only sources of water. River discharge is likely to drop due to decreased precipitation, decreased glacial coverage and high rate evaporation. There could be shifting of some energy demand from winter to summer because of the decrease in winter heating and increase in air conditioning.

Climate change would impact health directly (e.g., through changes in temperature-related morbidity and mortality) and indirectly (e.g., through shifting in vector-borne diseases). Circulatory, respiratory, and nervous system problems are expected to increase. Waterborne disease outbreaks (e.g., *E. coli*), vector-borne diseases and parasitic disease (e.g., West Nile virus, malaria, encephalitis) are likely to rise. Health impacts on the elderly, the very young and low-income families could be severe. Climate change might increase summer recreation/sport activities (e.g., golfing, soccer and football etc.), whereas it could negatively affect winter recreation/sport activities such as ski and outdoor skating.

Climate change would have both negative and positive effects on infrastructure such as roads, buildings, and bridges. An increase in temperature would affect the structural integrity of pavement through increased pavement deterioration. On the other hand, increased temperature reduces damage to pavement from freeze-thaw events and also reduces costs and accidents associated with winter storms. Frequencies of high intensity rainfall events might increase thereby resulting in flash flooding, which would obviously impact infrastructure. Climate change could reduce winter maintenance and snow removal costs as winters are expected to be shorter.

Climate change mitigation measures could affect the population's approach to transportation as well as energy consumption, and air quality. This would, in turn, lead to health effects, need for changes to infrastructure, and general impacts on the economy. The implications for transportation include switching from private vehicles such as cars, SUVs, trucks and mini vans to public transportation such as bus and LRT; more alternative fuel vehicles (e.g., solar and ethanol cars; bio-diesel, fuel cells, hydrogen and compressed natural gas (CNG) buses).

Climate change mitigation efforts could also result in significant energy savings through improvements of energy efficiency in buildings, machinery and vehicles in the city. Both residential and commercial buildings are expected to incorporate better insulation, more efficient energy appliances (e.g., refrigerators, washers & dryers, lamps, furnace etc.) and specific improvements such as solar roofs and geothermal heating systems.

GHG mitigation measures in residential, commercial, transportation and industrial sectors in Calgary would significantly reduce local air pollution and thereby improve the quality of air in the city. Moreover in-door air quality is also expected to improve as some GHG mitigation measures improve ventilation systems, reduce indoor air pollutants such as VOC's, particulates, etc. Improved air quality would have positive impacts on the health care system. Modal shifts in transportation (i.e., from private to public) and fuel switching would also provide health care benefits through reductions of CAC emissions.

Climate change mitigation measures could negatively affect Alberta and city economies in two ways. First, global oil demand might fall implying cuts in investments in the oil sands sector in Alberta and losses in jobs, revenues, transactions of goods and services and other economic activities. Secondly, costs of production could increase leading to competitive problems in many industries. This could affect important sectors in Alberta such as production from the oil sands, which would be affected by rising natural gas prices and other costs attributable to stringent climate change mitigation policies. The City has an interesting and significant planning requirement related not only to its natural evolution but also affected very much by potential changes in climate.

REFERENCE

Abbey, D.E., F. Petersen, P.K. Mills, and W.L. Beeson. 1993. *Long-term Ambient Concentrations of Total Suspended Particulate, Ozone and Sulphur Dioxide and Respiratory Symptoms in a non-smoking Population*. Archives of Environmental Health 48(1):33-46.

Adams, C.R. 1997. Impacts of Temperature Extremes. *In*: *Workshop on the Social and Economic Impacts of Weather*, April 2 to 4, 1997, Boulder, Colorado.

Arnell, N.W. 1998. Climate Change and Water Resources in Britain. *Climatic Change*, 39:83-110.

Auld, H. 1999. Adaptation to the Impacts of Atmospheric Change on the Economy and Infrastructure of the Toronto-Niagara Region. *In*: Mills, B. and L. Craig (Editors), *Atmospheric Change in the Toronto-Niagara Region - Towards an Integrated Understanding of Science, Impacts and Responses*, May 27 to 28, 1998, Toronto, Ontario, pp. 103-121.

Beaulieu, C. 2001. *A Community Climate Change Workshop Series for the Canadian Prairie Provinces - Summaries of the Workshops and Round Tables Discussions in Regina, Winnipeg and Edmonton*. Saskatchewan Research Council [SRC], Saskatoon, Saskatchewan. SRC Publication No. 11332-3E01. 10 pp.

Bruce, J., I. Burton, H. Martin, B. Mills, and L. Mortsch. 1999. Water Sector: Vulnerability and Adaptation to Climate Change. *In*: *Regional Workshop*, 1999.

Burnett, R.T., J.R. Brook, W.T. Yung, R.E. Dales, and D. Krewski. 1997. *Association between Ozone and Hospitalization for Respiratory Diseases in 16 Canadian Cities*. Environmental research 72:24-31.

Canadian Energy Research Institute (CERI). 2004. Study on the Electrical Efficiency of Alberta's Economic Sectors, CERI, September 2004.

Canadian Energy Research Institute (CERI). 2005. Economic Impacts of Alberta's Oil Sands, CERI, August 2005.

The City of Calgary, Environmental Management, "Introduction to Energy Consumption & Climate Change", Infosheet #1 of 6.

The City of Calgary, Environmental Management, "Rethink Your Water Use – Reduce the Flow!", Infosheet #3 of 6.

The City of Calgary, "See for Yourself…Transportation in Calgary: Dramatic Changes, 1995 to 2005", 2005.

The City of Calgary, Waste & Recycling Services, 2004 Annual Report, 2005.

The City of Calgary, Waterworks, "Water Efficiency Plan", September 2005

Demuth, M.N. 1997. Challenges Facing Surface Water Monitoring in Canada: Discussion. *Canadian Water Resources Journal*, 22(1).

Environmental Protection Agency. 2000b. *Water Resources.* wysiwyg://119/http://www.epa.gov/globalwarmning/impacts/water/index.htm.

Etkin, D. 1998. Climate Change and Extreme Events: Canada. *In*: Mayer, N. and W. Avis (Editors), *The Canada Country Study: Climate Impacts and Adaptation - National Cross-Cutting Issues Volume*, pp. 31-80. Environment Canada, Ottawa, Ontario.

Flannigan, M.D., B.J. Stocks, and B.M. Wotton. 2000. Climate Change and Forest Fires. *The Science of the Total Environment*, 262:221-229.

Frederick, K.D. and P.H. Gleick. 1999. *Water & Global Climate Change: Potential Impacts on U.S. Water Resources.* Pew Center on Global Climate Change, Arlington, Virginia.

Gaffen, D.J. and R.J. Ross. 1998. Increased Summertime Heat Stress in the US. *Nature*, 396:529-530.

Gleick, P.H. 2000. *Water: The Potential Consequences of Climate Variability and Change for the Water Resources of the United States.* Pacific Institute for Studies in Development, Environment, and Security, Oakland, California.

Guest, C.S., K. Willson, A.J. Woodward, K. Hennessy, L.S. Kalkstein, C. Skinner, and A.J. McMichael. 1999. Climate and Mortality in Australia: Retrospective Study, 1979-1990, and Predicted Impacts in Five Major Cities in 2030. *Climate Research*, 13:1-15.

Hofmann, N., L. Mortsch, S. Donner, K. Duncan, R. Kreutzwiser, S. Kulshreshtha, A. Piggott, S. Schellenberg, B. Schertzerand, and M. Slivitzky. 1998. Climate Change and Variability: Impacts on Canadian Water. *In*: Koshida, G. and W. Avis (Editors), *The Canada Country Study: Climate Impacts and Adaptation - National Sector Volume*. Environment Canada, Toronto, Ontario.

Intergovernmental Panel on Climate Change (IPCC). 2001. Climate Change 2001: Synthesis Report. Cambridge University Press.

Jackson, C.I. 1992. *Global Warming: Implications for Canadian Policy.* Environment Canada, Ottawa, Ontario. 17 pp.

Jacob, K.H., N. Edelblum, and J. Arnold. 2000. *Climate Change and a Global City: An Assessment of the Metropolitan East Coast Region - Risk Increase to Infrastructure Due to Sea Level Rise.* 58 pp.

Kilbourne, E.M. 1997. Heat Waves and Hot Environments. *In*: Noji, E. (Editor), *The Public Health Consequences of Disasters*, pp. 245-269. Oxford University Press, New York, New York.

Kinney, P.L., D. Shindell, E. Chae, and B. Winston. 2000. *Climate Change and Public Health: Impact Assessment for the NYC Metropolitan Region*.

Krupnick, A.J., W. Harrington, and B. Ostro. 1990. "Ambient Ozone and Acute Health Effects: Evidence from Daily Data." Journal of Environmental Economics and Management 18(1):1-18.

Lamothe & Périard. 1989. *Implications of Climate Change on Municipal Water Use and the Golfing Industry in Québec.* Environment Canada, Ottawa, Ontario. 6 pp.

MacIver, D.C. and H. Auld. 2000. Weather Hazards and Changing Road Conditions in Ontario, Canada. *In*: *Third Symposium on the Urban Environment*, August 14 to 18, 2000, Davis, California.

Maksimovic, C. 2000. Mitigation of Flood Hazards in Urban Areas. *Stockholm Water Front Forum for Global Water Issues*, 1(February).

Martens, W.J.M., T.H. Jetten, J. Rotmans, and L.W. Niessen. 1995. Climate Change and Vector-Borne Diseases - A Global Modelling Perspective. *Global Environmental Change*, 5(3):195- 209.

Minnery, J.R. and D.I. Smith. 1996. Climatic Change, Flooding, and Urban Infrastructure. *In*: Bouma, W.J., G.I. Pearman, and M.R. Manning (Editors), *Greenhouse: Coping With Climate Change*, pp. 235-247. CSIRO Publishing, Collingwood, Victoria, Australia.

Mortsch, L. and F. Quinn. 1998. Great Lakes-St. Lawrence Basin Project: What Have We Learned? *In*: Mortsch, L.D., S. Quon, L. Craig, B. Mills, and B. Wrenn (Editors), *Adapting to Climate Change and Variability in the Great Lakes-St. Lawrence Basin - Proceedings of a Binational Symposium*, May 13 to 15, 1997, Toronto, Ontario, pp. 52-66.

Ostro, B.D., M.J. Lipsett, M.B. Weiner, and J.C. Selner. 1991. *Asthmatic Responses to Airborne Acid Aerosols*. American journal of Public Health 81:694-702.

Ostro, B.D., and S. Rothschild. 1989. *Air Pollution and Acute Respiratory Morbidity: An Observational Study of Multiple Pollutants*. Environmental Research 50:238-247.

Patterson, D.T., J.K. Westbrook, R.J.V. Joyce, P.D. Lingren, and J. Rogasik. 1999. Weeds, Insects, and Diseases. *Climatic Change*, 43:711-727.

Pope, C.A.,III, M.J. Thun, M.M. Namboodiri, D.W. Dockery, J.S. Evans, F.E. Speizer, and C.W. Heath, Jr. 1995, *Particular Air Pollution as a Predictor of Mortality in a Prospective Study of U.S. Adults*. American Journal of Respiratory and Critical Care Medicine 151:669-674.

Quattrochi, D.A., J.C. Luvall, D.L. Rickman, M.G. Estes, C.A. Laymon, and B.F. Howell. 2000. A Decision Support Information System for Urban Landscape Management Using Thermal Infrared Data. *Photogrammetric Engineering & Remote Sensing*, 66(10):1195-1207.

Samuels, J. 1989. To Salt or Not to Salt. What Are the Alternatives? *Civic Public Works*, 41(9):12-20.

Sauchyn, D. 2000. Synopsis. *In*: *Water Sector Vulnerability and Adaptation to Climate Change*, May 17, 2000, Winnipeg, Manitoba.

Scheraga, J.D. 1998. What Is the Issue? *In*: Mortsch, L.D., S. Quon, L. Craig, B. Mills, and B. Wrenn (Editors), *Adapting to Climate Change and Variability in the Great Lakes-St. Lawrence Basin - Proceedings of a Binational Symposium*, May 13 to 15, 1997, Toronto, Ontario, pp. 40-51.

Schwartz, J., D.W. Dockery, and L.M. Neas. *Is Daily Mortality Associate Specifically with Fine Particles?* Journal of the Air & Waste Management Association 46:927-939.

Stieb, D.M., R.C. Beveridge, J.R. Brook, R.T. Burnett, A.H. Anis, and R.E. Dales. 1995. The Saint John particle health study: measuring health effects, health costs and quality of life impacts using enhanced administrative data. *In* Particulate Matter: Health and Regulatory Issues: Proceedings of an International Specialty Conference. Air and Waste Management Association, Pittsburgh, PA. 131-142.

United Nations Framework Convention on Climate Change (UNFCCC). The Text of UNFCCC, Climate Change Secretariat, Geneva, 1992.

Watt, E., M. Van Buren, and D. Sellars. 1998. *Hydrological Science Research in Canada: The Practitioners' View.* Canadian Water Resources Association, Cambridge, Ontario. 33 pp.

Whittemore, A., and E. Korn. 1980. *Asthma and Air Pollution in the Los Angeles Area*. American Journal of Public Health 65:365-72.

Wittrock, V., E.E. Wheaton and C.R. Beaulieu (2001). Adaptability of Prairie Cities:The Role of Climate Current and Future Impacts and Adaptation Strategies. Saskatchewan Research Council, Publication No. 11296-1E01

Wotton, B.M. and M.D. Flannigan. 1993. Length of the Fire Season in a Changing Climate. *The Forestry Chronicle*, 69(2):187-192.

Yulianti, J.S. and D.H. Burn. 1998. Investigating Links Between Climatic Warming and Low Streamflow in the Prairies Region of Canada. *Canadian Water Resources Journal*, 23(1):45-60.

Zimmerman, R. and M. Cusker. 2000. *Climate Change and a Global City: An Assessment of the Metropolitan East Coast Region - Institutional Decision-Making Sector Report.* 52 pp.

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