Water - Vulnerable to Climate Change

Introduction

For thousands of years we have found it necessary to control water -- in order to have it where we want it, when we want it. Nonetheless, some areas still suffer from drought, and some from flood. This is due partly to the natural variability of climate and partly to inappropriate land and water use. Now climate seems to be changing beyond that natural variability, and this is likely to impact on the availability and distribution of water.

At the same time, other stresses on water are increasing. The amount of fresh water is limited, and the easily accessible sources have been developed. Not only do more people than ever before have to share this resource, but the world population is expected to double by 2050, if it continues to grow at the present rate.

A larger population will not only use more water but will discharge more wastewater. Water quality programs are not fully developed even in the industrialized countries and are nonexistent in most developing countries, where they are most needed. Furthermore, the costs for managing water supplies are increasing, as are the demands on limited financial resources.

To sum up, we may now have to consider the effects on water of not only the natural variability of climate and more population pressure but also what appears to be a *change in climate*that is brought about by human activity.

What makes climate?
The climate of a place is the average over a number of years of the day-to-day variations in temperature, precipitation, cloud cover, wind and other atmospheric conditions that normally occur there. Climate also includes the variability of individual climate elements, such as temperature and precipitation, and the frequency with which various weather conditions occur. In other words, climate is the combination of average weather conditions and weather patterns over time for a particular location.

The climate of the earth is a balanced system of interconnected, interacting elements powered by incoming energy from the sun. The main factors affecting climate can be distinguished as either *internal* or *external* processes. The *internal* processes include the circulation of the air and currents of the ocean; the effects of clouds and large masses of snow and ice; the influence of topography, surface soils and vegetation; the impact of processes and activities within the biosphere; and regional, seasonal and daily difference in solar heating. The *external* factors are solar energy output, atmospheric composition, land features, and ocean characteristics.

Global scale climatic changes occur when the balance between the rate at which energy enters or leaves the global climate system is upset by changes in one or more of its major elements. Possible primary causes for such changes include variations in the aerosol and gaseous content of the atmosphere, changes in the reflective properties of the earth's surface, and alterations in the intensity of sunlight reaching the earth's surface. Complex reactions in other factors are likely as the system adjusts to establish a new balance of input and output energy. *Positive feedback* refers to the reactions by climatic factors that increase the initial change, such as additional surface warming due to reduced reflected radiation by less snow cover. *Negative feedback* by other factors would oppose and partially offset change, such as storage by oceans of excess atmospheric heat caused by increased greenhouse gas concentrations.

The change in climate expected within the next four or five decades is believed to be a result of mainly human activities that are causing changes in atmospheric composition (increasing greenhouse gases and aerosols) and changes in land features (reducing natural vegetation).

Source: Henry Hengeveld, March 1995, "Understanding Atmospheric Change", (A State of the Environment (SOE) Report No. 95-2), Atmospheric Environment Service, Environment Canada (pp. 13-18).

How do scientists figure out how climate will change?

How can scientists predict the effects of long-term climate change, when predicting daily weather is still a difficult task? Local variability is what makes weather forecasting seem imperfect: such site-specific and detailed forecasts are not even attempted by climate change models.

There are two main means of predicting possible climate change: one involves working out **analogues** from past climatic and hydrometric records; the other, much more commonly used, uses **mathematical simulations** of climate (on computer programs) known as general circulation models or global climate models (*GCMs*).

How might the climate change?

Overall, results from the GCMs suggest that:

- The greatest increases in temperature will occur in the high latitudes, in winter, and over land;
- The results concerning precipitation are less clear; changes are likely to vary according to the region;

- Sea level is likely to rise, possibly by an average rate of about 5 cm per decade over the next 100 years, primarily due to the thermal expansion of water (steric expansion) and the melting of glaciers. There may be significant regional variations caused by the rise and fall of land masses.
- In addition, evidence suggests that extreme weather events (droughts, storms, floods, forest fires, ice jams, etc.) will be more frequent and more severe. This will have, and indeed may already be having, serious effects on Canadian ecosystems, including economic and social impacts, to which Canadians will have to adapt. While these pages focus on the nature and effects of long-term temperature trends as predicted by the GCMs, the potential effects of increasing extreme events are more fully considered in other Environment Canada publications.

A little goes a long way...

An increase of 3°C may not seem like much, but around 1000 AD a climate slightly warmer than today enabled the Vikings to settle Iceland and Greenland, while generally the mid-latitudes became drier. By about 500 years later, that colony had disappeared, at least in part due to a temperature drop of about one degree.

How will these changes affect our water supply in general?

GCMs simulating a climate that is based on a doubling of CO_2 suggest a global mean increase in precipitation and evaporation of between 3 and 15%. Yet the more useful information, i.e., the location and timing of these changes, is still uncertain.

There are general indications that:

- the present mid-latitude rain belt would shift northward;
- snowmelt and spring runoff would occur earlier than at present;
- evapotranspiration would be greater, as it would start earlier and continue longer;
- the interior continental region in the Northern Hemisphere will, in general, experience drier summers.

More about analogues and GCMs

Analogues

Climatic analogues are developed by choosing warmer-than-average years from the historical record and identifying what conditions were like, to get an idea of the likely effects of global warming. The limitation of this method is that our relatively short period of climatic data does not represent conditions that may come with future climate change, for example, unprecedented long-term increases in temperature, particularly in wintertime.

GCMs

The GCMs simulate atmospheric circulation, the energy exchanges, and other important land/ocean/atmosphere interactions. However, they cannot as yet model well other small-scale processes, such as biological processes, precipitation and cloud cover. These processes have significant effects on the water resource.

GCMs usually project climate over several decades to more than a century ("climate" being based on average weather conditions over 10 years or more), but give only large-scale predictions, not the regional ones needed for planning. This is because grid spacing in most GCMs is between 2 and 5 degrees of longitude or latitude and it takes several grid distances to simulate a physical feature.

The predictions are complicated by difficulty in simulating the lags in the meteorological system, especially in the oceans; the effects of low cloud versus high cloud, and amounts of each; and temporary effects due to solar variability and airborne ash from volcanic eruptions, such as that of Mount Pinatubo.

Also difficult to predict are the results of the*interactions* of cloud cover, soil moisture, vegetation, and ice. How any one of these factors might react to a warmer climate is difficult to predict; when reactions from several such factors might interact, the uncertainty is magnified.

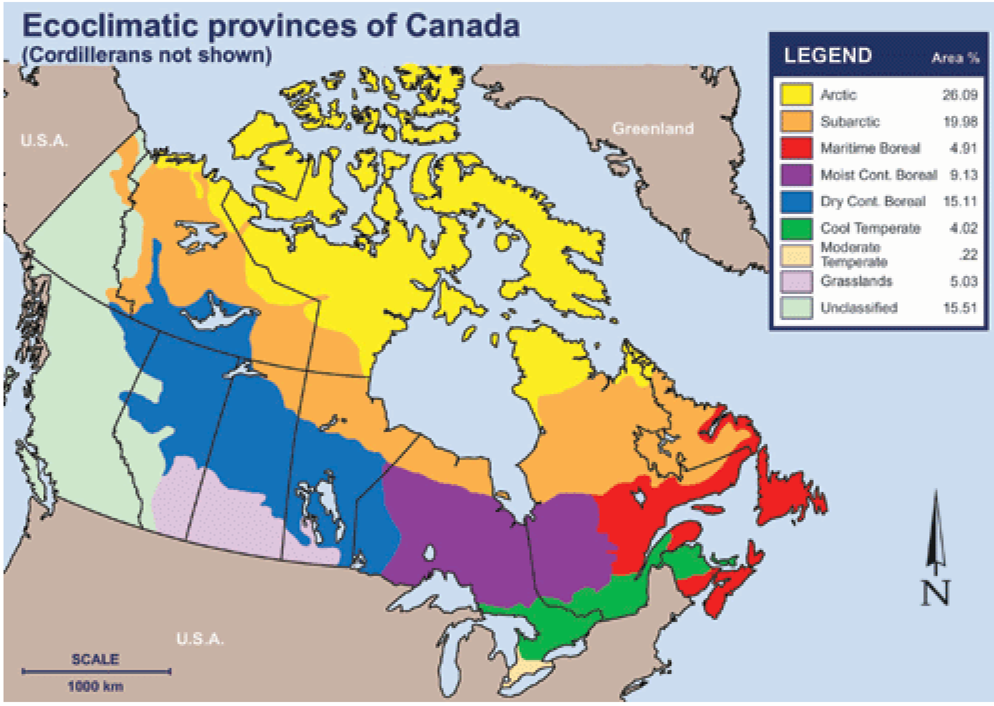
To improve predictions, we need computers with more computing capability. We also need more data on and understanding of the processes affecting climate. These would help us to build more accurate models and to validate model results against observed or measured processes.

To sum up, analogues and GCMs *do not* accurately predict actual future climate; but they can give us some basis for preparing for the future.

How might these changes affect Canada?

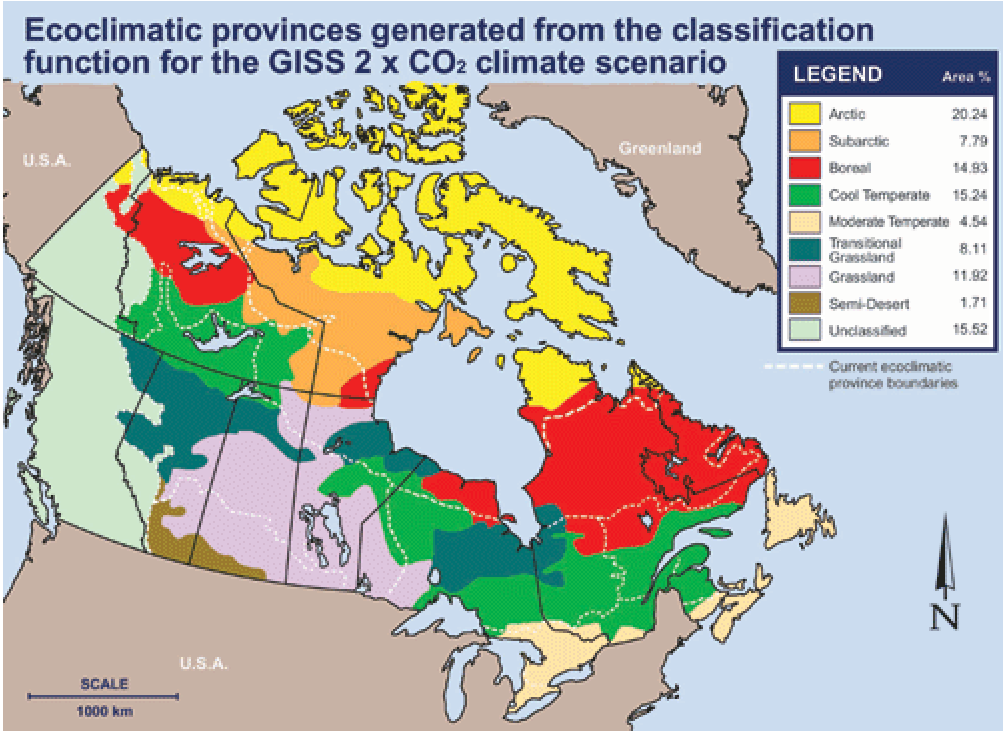
Researchers, through the use of GCMs and other methods, develop "scenarios" of possible future climates of a region. These scenarios are then applied to the ecosystem or economic region to determine how it would be affected by climate change. Impacts of climate change are expected to be greater in some regions than in others; these have been looked at in greater detail. At the same time, it must be noted that there is greater uncertainty for scenarios at the regional scale than at the global one.

One such investigation is based upon an ecological framework that expresses regional climate through the development of vegetation and soils.



The "unclassified" area is composed of Subarctic Cordilleran, Cordilleran, Interior Cordilleran, and Pacific Cordilleran.

The underlying premise is that if all factors are held constant in sites that are affected by extremes, the vegetation and soil development over time will reflect the influence of climate. Using the data generated by a general circulation model for doubled atmospheric CO_2concentrations, (i.e., a possible future climate), a scenario was generated illustrating how the location and quantity of existing ecosystems might change with time.



As Canada is a large land mass in the northern mid to high latitudes, its interior is expected to experience a larger than average increase in temperature and a decrease in summer soil moisture. The north would have a greater increase in winter temperatures and more precipitation than now, particularly in winter.

Pacific coast

A rise in sea level would threaten low-lying coastal lands, such as the Fraser River delta, with possible increases in flooding and erosion. The increased precipitation considered likely in winter could promote landslides and local flooding.

Warmer river temperatures could cause severe prespawning mortality in some fish that go up rivers to spawn (anadromous), such as the Pacific salmon. However, warmer ocean temperatures could create favourable conditions for species such as tuna, hake, and squid to migrate from the south.

West Coast forest ecosystems could become more stressed as a warmer climate allowed insect pests and disease to migrate northward. Forests in the drier areas would become more vulnerable to fire.

Prairie provinces

The Prairies, the breadbasket of Canada, already suffer from periodic drought, especially in the south. With higher temperatures and increased evapotranspiration, drought would probably become more frequent. An increase in irrigation, if water was available, could bring more soluble salts to the surface, degrading the soil.

With a warmer climate, agriculture could move northward, into more humid (although still dry) areas. The poor northern soils would be more likely to limit its northern expansion than climate. Conflict between agricultural and industrial or aboriginal interests could arise as a result of the spread of farming into new territory.

The forests could also expand to the north, although more slowly, as trees take much longer to mature than field crops. Some of the areas presently under forest may not be able to support trees, if the soil moisture, already low, is reduced much more. Low soil moisture stresses trees, making them more susceptible to pests, disease, and fire. It has been suggested that 170 million hectares of forest could be lost in the south and only 70 million hectares gained in the north, as they would be limited by poor soil or rock.

Great Lakes - St. Lawrence basin

Over 42.5 million people live in the Great Lakes - St. Lawrence basin. Over 29 million of them (including 8 million Canadians) depend on the lakes for drinking water. The quality of the water is already under stress as the region is a major centre of North American manufacturing.

According to researchers, the average temperature in the Great Lakes basin could go up by about 4.5°C by 2055, with slightly larger increases in winter than in summer. Higher rates of evaporation and drier soils would reduce runoff, and water levels in the Great Lakes could fall by an average of between 0.5 m and 1.0 m, according to typical scenarios. The St. Lawrence River outflow could be reduced by 20%.

Water is used intensively by industries such as primary metals, chemicals, food processing, and timber products. Water is also important, particularly to the grain and metal producers, for shipping. However, the biggest single user of Great Lakes water is the electric power industry. All of these industries would be affected by a significant change in the quantity and quality of the water supply.

While lower water levels would decrease the flow available for the generation of hydroelectric power, a warmer winter would also slightly lower the demand for electric power for heating. This might be counter-balanced by an increase in summer demand for power to run electric fans and air conditioners. Lower water levels would reduce the amount of cargo that ships could carry per trip, but a shorter ice season (by 5 to 12 weeks) might provide for a longer shipping season, allowing more trips per year.

Agriculture is the largest industry in the region, and forestry is a major one in the northern parts of the basin. Although the growing season would be longer, the reduction in soil moisture would be likely to decrease crop yields over time unless adaptive measures were taken. Higher temperatures and drier soils could also reduce the extent and health of forests of the basin, and the drying out of marshes would cut back on wildlife habitat. Some of the present fish species could disappear from the lakes due to warmer temperatures, while other species could migrate northward from southern parts of the region.

An unreliable "cold" season and a projected decrease in snowfall of from 20 to 80%, with the biggest change to the north of the lower Lakes, would substantially reduce the ski season for southern Quebec and virtually eliminate it in southern Ontario.

Water quality might also be affected in the following ways:

- the dredging needed to offset lower water levels could resuspend toxic chemicals;

- higher water temperatures could decrease dissolved oxygen levels and increase the growth of algae and bacteria;
- less runoff and stream discharge would reduce the flushing out of bays and dilution of organic matter and chemicals;
- lower water levels could cause the disappearance of wetlands, which are valuable habitats;
- agricultural and urban expansion would continue to contaminate runoff with fertilizers and toxic chemicals.

The impacts of climate change on water quantity and quality might also increase external pressures on the Great Lakes water supply. For instance, lower water levels in the Mississippi River system might create an increased demand for diversion of Lake Michigan water. Infiltration of salt water into the New York City water supply due to rising sea levels might result in a request for a diversion of Lake Ontario water.

Atlantic coast

A rise in sea level would threaten residential, transportation, and industrial facilities with flooding in low-lying communities along the coast, such as Charlottetown. The threat to a given area would be lesser or greater depending on whether the land itself was rising or subsiding. For instance, the Gaspé Peninsula is rising, while that of Newfoundland is subsiding.

The rise in sea level would increase the incidence of flooding, especially during storms. The serious storm surge and river flooding that may now affect Saint John, for instance, once in 100 years might in future occur once in 20 years.

Salt water intrusion could contaminate groundwater aquifers (the main source of regional water supplies), disturb sensitive estuary ecosystems, and displace freshwater fish populations. On the other hand, freshwater fisheries and aquaculture could benefit from the longer season resulting from a higher average annual temperature.

A rise in ocean temperature could affect the distribution and makeup of the fish population, limiting some species, encouraging others.

While higher temperatures would reduce the extent of sea ice, some scientists think that greater snow accumulation on Arctic ice caps and longer, warmer seasons at their edges might increase the calving of icebergs. It is not clear what effects the warmer temperatures would have on ocean circulation, wave patterns, and the frequency of tropical storms.

The North

A rise in sea level would also flood low-lying areas in northern Canada, such as the Mackenzie River delta, erode shorelines, and change near-shore ecosystems. However, higher temperatures would lessen the extent and duration of sea ice and facilitate shipping in the far north.

Inland, milder winters and longer summers would shorten the season for ice roads in many areas, reducing access to remote communities and to stands of timber. Gradual melting of the southern permafrost would change water drainage patterns and destabilize the land, affecting roads, pipelines, and buildings. The season for barge transport on the rivers would lengthen.

A longer growing season would allow agriculture to expand northward from its present limits, where soils and moisture permitted. The boreal forest would become more productive in the south, although its northward expansion would be limited by poor soils and slowly thawing permafrost. Fire could become more of a threat as well.

An expected increase in precipitation, particularly in fall and winter, would result in a greater accumulation of snow, although over a shorter season, and the possibility of extensive and earlier flooding in spring. The higher precipitation could increase the net water supply in northern watersheds, expanding the potential for hydroelectric power. For instance, that potential in northern Quebec could increase by 15%.

Wetlands

Wetlands are permanently or temporarily submerged or permeated by water, and characterized by plants adapted to saturated soil conditions. Wetlands include fresh and salt water marshes, wooded swamps, bogs, seasonally flooded forest, sloughs -- any land area that can keep water long enough to let wetland plants and soils develop.

They are the only ecosystem designated for conservation by international convention. They have been recognized as particularly useful areas because:

- they absorb the impact of hydrologic events such as large waves or floods;
- they filter sediments and toxic substances;
- they supply food and essential habitat for many species of fish, shellfish, shorebirds, waterfowl, and furbearing mammals;
- they also provide products for food (wild rice, cranberries, fish, wildfowl), energy (peat, wood, charcoal), and building material (lumber);
- they are valuable recreational areas for activities such as hunting, fishing, and birdwatching.

As a frontier-type ecosystem, *wetlands are particularly vulnerable to climatic variation and extreme events*. Many, especially coastal ones, are unstable to start with, and are easily or frequently changed by erosion, flooding, or the invasion of salt water.

But water supply is the main concern. In arid and semi-arid areas, the occurrence of hotter, drier summers and the increased use of water for irrigation could reduce the supply of water for wetlands, either directly or indirectly (through the effect on the water table), or both. A lower volume of water would increase the concentrations of the pollutants that tend to settle in wetlands (agricultural chemicals, naturally occurring salts, atmospheric pollutants).

Small changes in temperature or water supply could have significant effects on wetland biota. A rise in temperature could allow an undesirable plant species (purple loosestrife, for example) to expand northward. High temperatures and low concentrations of oxygen favour the growth of the botulism bacterium. A change in the seasonality of precipitation could harm plants or animals whose life cycles require certain amounts of water at specific times of the year. Such a change could cause a decline in a plant on which waterfowl depend.

In the past, wetlands were considered wasteland, and many of southern Canada's wetlands were drained or filled in so that they could be farmed or built upon. Recently the value of wetlands has been recognized and efforts have been made to protect these ecosystems. However, they are still disappearing under the pressure of human activity, and now are threatened by air pollution and climate change as well.

Options to prevent further loss of wetlands include the following:

- adding sediment to coastal wetlands to keep up with rising sea levels;
- planting grasses to protect coastal sands from erosion;
- building dikes or barrier islands;
- controlling water levels artificially;
- developing a national policy of protection.

The greenhouse effect is natural, but...

The earth benefits from a certain natural heat-trapping system, the so-called greenhouse effect. The atmosphere allows most solar radiation to come through to the earth's surface, which then heats up and sends radiation back outward. Certain gases in the atmosphere absorb the outward radiation and re-radiate much of it back to earth, keeping it warm, like a greenhouse. This raises the global average temperature to about 15°C; without those gases, the average surface temperature would be about -18°C.

Now, however, human activity has affected the composition of the atmosphere by adding to the greenhouse gases, particularly carbon dioxide. The increase in atmospheric carbon dioxide was first noticed in the nineteenth century. However, regular and accurate measurements were first begun in Hawaii in the International Geophysical Year of l957-58.

According to studies of Antarctic ice cores, the concentration of carbon dioxide in the atmosphere remained relatively constant for 10 000 years, until the mid-1800s, at approximately 280 parts per million (ppm). Today that concentration is about 360 ppm and continues to rise.

Among the other greenhouse gases caused by human or anthropogenic activity are low-level ozone, methane, nitrous oxide, and chlorofluorocarbons (CFCs). These gases are found in lower concentrations than carbon dioxide, but they may be more effective in trapping heat. CFCs are some of the most heat absorbant of the greenhouse gases: oneCFC molecule may have from 10 000 to 13 000 times the impact of a CO_2 molecule. However, these effects are at least partially offset by surface cooling due to depletion of ozone in the lower stratosphere, also caused by these gases.

Scientists usually estimate that the doubling of pre-industrial levels of atmospheric CO_2, expected by about 2080, would cause an average global warming of two or three degrees Celsius. If they add the effect of the other greenhouse gases, increasing at their present rates, they expect an effective doubling by mid-century.

Water vapour, a natural greenhouse gas and the most abundant one, will also increase with global warming, as warmer temperatures would cause more evaporation and increase the atmosphere's ability to hold moisture.

The main greenhouse gases

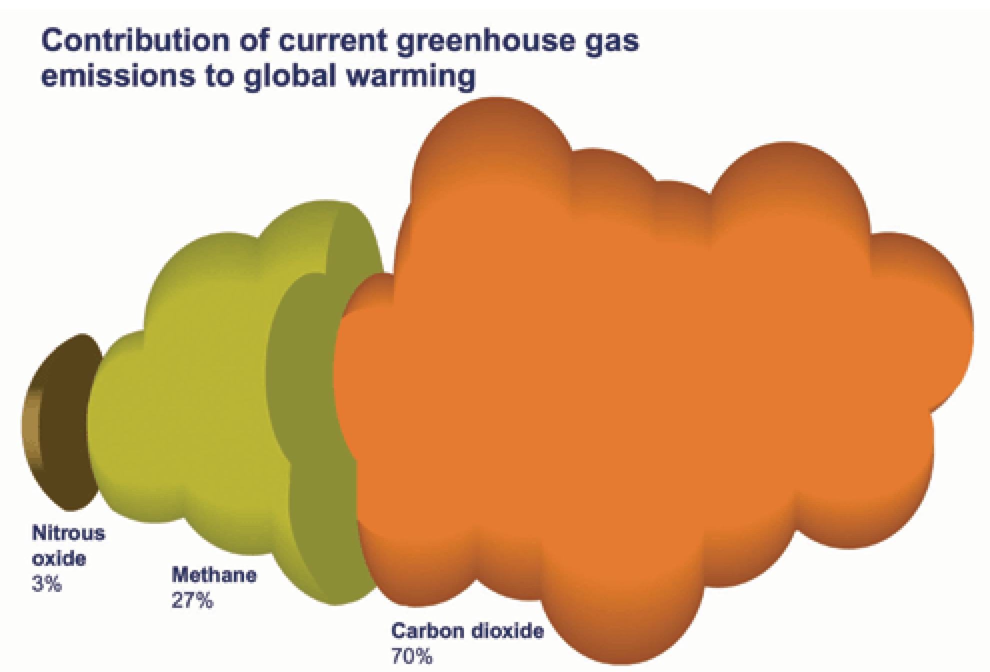
Carbon dioxide (CO_2)

Human source: Comes mostly from burning fossil fuels (oil, gas, and coal) for electricity and in cars and factories. Also from forest burning.
Annual increase: 0.5%
Life span: 50-200 years

Methane (CH_2)
Human source: Bacterial decomposition of organic matter (without oxygen) in rice paddies, swamps, garbage dumps, and intestines of ruminants like cows and sheep. Also from buning wood, mining coal.
Annual increase: 1%
Life span: 10-12 years

Chlorofluorocarbons (CFCs)
Source: Chemically synthesized for use as coolants in refrigerators and air conditioners. Also in foam insulation, aerosol sprays.
Annual increase: 4%
Life span: up to 10 000 years

Nitrous oxide (N_2O)
Human source: Bacterial reactions in soil and water and from the breakdown of nitrogen-based chemical fertilizers. Also from burning fossil fuels and wood (deforestation).
Annual increase: 0.4%
Life span: 150 years



Note: Man-made greenhouse gases include those manufactured and those released due to processes controlled through human activity (e.g., the burning of fossil fuels). Some greenhouse gases, such as chlorofluorocarbons (CFCs), are entirely man-made, while only a small percentage of others, such as carbon dioxide, are man-made. Although man-made greenhouse gases are a small percentage of the overall total, they are changing the balance.

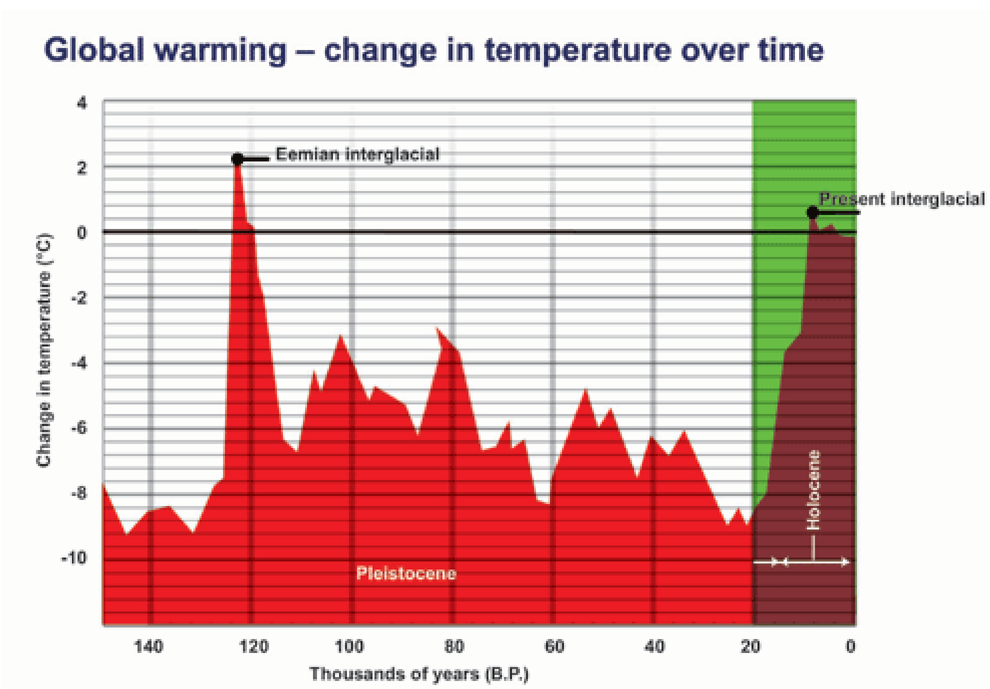
What is global warming?

Although our own climate records cover only about 100 years, we can infer climatic conditions from the pollens found in layers of mud and from the gas bubbles in ice cores bored through major ice sheets (including an ice core from the Antarctic that gives a record going back well over 200 000 years). These ice cores enable scientists to identify correlations between the composition of the atmosphere and regional climatic conditions in the past. Recent and predicted increases in concentrations of greenhouse gases in the atmosphere are expected to cause additional warming of average surface air temperatures.

These increases in greenhouse gas concentrations have been related to human activities such as the burning of fossil fuels and the reduction of forests. Combustion changes the composition of the atmosphere by adding carbon dioxide and other gases. The large-scale destruction of forests releases large amounts of carbon stored in trees and forest soils.

These human-induced changes to the greenhouse effect of the earth's atmosphere are expected to result in *global warming* and other changes in climate. Most scientists agree that the threat of climate change is real: what is debatable is the extent of change and how it will vary from place to place.

The models used by climatologists generally agree that the temperature increase, as a global annual average, might be from 1 to 4°C by the year 2100. They also agree that the effect would be greater in the high latitudes, especially during the winter months and over large land masses. The warmer temperature would trigger other changes, such as a change in global precipitation patterns, a decrease in snow and ice coverage, and a rise in sea levels.



Permafrost

Permafrost is the term used to describe permanently frozen ground. It is said to underlie from one fifth to one quarter of the world's land. As the melting caused by a warmer climate could release some of the large amounts of methane now locked into the frozen soil, this might add substantially to the concentrations of greenhouse gases in the atmosphere.

The surface layer above the permanently frozen ground can become very mobile during the melt season, making an unstable base for construction. This layer is also vulnerable to melting when built on, driven over, or even walked on. Such traces of human activity remain visible for many years in this delicate environment. A warmer climate might increase the depth of the surface layer.

Mackenzie River Basin

Much of the Mackenzie Basin is underlain by permafrost. This is a particularly interesting part of Canada when we talk about climate change and water supply.

Geographically, it is large; it covers about one sixth of the area of the country. Its settlement pattern is unusual in that the majority of its population and development is located in the upstream part of the basin. Oil and gas and pulp and paper are the main industries. Because the aboriginal inhabitants downstream live almost entirely off the land, a clean and regular water supply is particularly important to them, both for drinking and for the animals they depend on. As well, the rivers are vital transportation links, as routes for boat travel in summer and as ice roads in winter.

Canadian scientists are monitoring the current situation in the Mackenzie Basin to discover possible effects of global warming on northern hydrology, including its impacts on permafrost. They are looking at possible changes in runoff patterns, snow and ice cover, ice jam flooding, water quality, and water levels. Although it is too early for predictions, they suspect that:

- drainage patterns in low-lying areas *might* change due to the melting of frost sills, which direct or impede water flow;
- water levels in some areas might drop in late summer and autumn due to increased evapotranspiration (with an impact on ecosystems in wetlands, small lakes, and deltas);
- runoff in other areas *might* increase due to the loss of permafrost;
- an increased sediment load might lead to erosion in some rivers;
- higher temperatures might make some water bodies more productive;
- certain slopes might become unstable and vulnerable to landslides (due to permafrost thaw).

What can we do?

Different people give different answers.

Some argue that since we cannot be sure how climate will react to changes in the atmosphere and the biosphere, we cannot know the outcome of global warming. Why worry if it might not happen?

Others say that because we do not know how the water supply will be affected at the regional level, there's no point in spending time and resources on what is only a possibility.

Experts have recommended two general strategies:

- One has to do with preventing or *limiting* the cause of climate change, by cutting back on production of greenhouse gases and planting more forests.
- The other has to do with anticipating and *adapting* to change (as it comes), for instance, moving from low-lying coasts or planting crops suited to a warmer, drier climate.

It would make sense to follow both of these strategies. Even a concerted effort to limit the greenhouse effect will not entirely stop the changes in climate: there are time lags between greenhouse gas accumulation and climate change, and between climate change and its impacts on natural resources. While this time lag makes it all the more important to reduce greenhouse gas emissions immediately, it also means that we shall have to adapt to some change in climate.

Adaptive measures include conservation and efficiency strategies that are beneficial even without climate change. These include using less water, making regional water management more efficient, and instituting realistic water pricing. They include reviewing levels of protection from hazards such as floods, droughts, and forest fires. They also include conserving energy, using alternative energy sources and changing agricultural practices; these would all help to *limit* future climate change.

We need to manage the water resource more effectively for other reasons -- to accommodate to its natural variation and to cope with the demands of a fast-growing population. More effective management would also help us to be prepared for changes in the water supply induced by climate change. Further, a strategy for conserving water quality and quantity, as well as reducing atmospheric pollution makes environmental sense, regardless of the presence or absence of a specific climatic crisis.

Options for action

- Everywhere:
  conserve water and energy; repair leaky systems; plan for strength and flexibility in new structures; regulate land use to avoid building on areas vulnerable to flooding; establish water metering and realistic pricing; include water-efficient technology in building codes.
- In drylands:
  choose appropriate crops; irrigate less wastefully; design new criteria for adjustable, retrofitable storage structures; consider interbasin transfers and/or recharge of aquifers.
- In flood-prone areas:
  continue to improve forecasting and warning systems, and evacuation and relief plans; evaluate and improve present flood-control structures; design new structures to handle more frequent and extreme events.
- On the coasts:
  look at building barriers to erosion and salt-water invasion; consider desalinization technologies.
- In navigable waterways:
  dredge shallows; lighten barge loads; use other means of transport during dry

times.

Publications of general interest include the fact sheets on climate change published by Meteorological Service of Canada, the Freshwater Series provided by the Environmental Conservation Service (also Environment Canada), and Great Lakes Facts (The Centre for the Great Lakes, Toronto). The Climate Change Digests and the CO_2/Climate Reports (both from the Meteorological Service of Canada) are particularly useful.

Bardecki, Michal J. 1991. "Wetlands and climate change: a speculative review." *Can. Water Resour. J.* 16(1): 9-22.

Bolin, Bert, Bo Döös, Jill Jäger, and Richard Warwick, (Eds). 1986. *The greenhouse effect, climatic change and ecosystems.* Chichester: Wiley.

Bruce, J., Hoesung Lee and E. Haites (Eds.). 1996. *Climate change 1995- Economic and social dimensions of climate change*. Cambridge University Press.

Canadian Climate Centre and U.S. National Oceanic and Atmospheric Administration. 1989. *Impacts of climate change on the Great Lakes Basin.* Downsview, Ont. 210 pp.

Cohen, S.J. 1991. "Possible impacts of climatic warming scenarios on water resources in the Saskatchewan River Subbasin, Canada." *Climatic Change*, 19: 291-317.

Cohen, S.J., L.E. Welsh, and P.Y.T. Louie. 1989. *Possible impacts of climatic warming scenarios on water resources in the Saskatchewan River Subbasin.* Canadian Climate Centre Report 89-9, Environment Canada.

Environment Canada. 1991. *Climate change and Canadian impacts: the scientific perspective.* Prepared for the Climate Change Digest, Atmospheric Environment Service, by the Canadian Climate Program Board. CCD 91-01. 30 pp.

Gleick, P.H. 1989. "Climate, hydrology, and water resources." Reviews of Geophysics, 27: 329-344.

Government of Canada. *The state of Canada's environment-1991.* Chapters 22 and 26.

Hall, J. Peter. 1991. "How will the projected changes in Canada's climate affect the sustainability of forests?" *Winter Cities Symposium*, Sault Ste. Marie, 3 Jan. 1991.

Hall, J. P., and L.W. Carlson. 1990. *Forestry Canada's perspectives on climate change.* Dep. Geogr. Publ. Ser. Occasional Paper No. 11. University of Waterloo, Waterloo, Ont.

Harrington, J.B. 1987. "Climatic change: a review of causes."*Can. J. Forest Res.* 17(11): 1313-1339.

Hengeveld, H. 1995. *Understanding atmospheric change.* A State of the Environment (SOE) Report No. 95-2. Atmospheric Environment Service, Environment Canada.

Houghton, J.T., L.G. Meira Filho, B.A. Callender, et al. (Eds). 1996. *Climate change 1995 - The science of climate change.* Cambridge University Press.

Lewis, G.D., D. Milburn, and A. Smart. 1992. "The challenge of interjurisdictional water management in the Mackenzie River basin."*Can. Water Resour. J.* 16(4): 381-390.

Lewis, J.E. 1989. "Climatic change and its effects on water resources for Canada: a review." *Can. Water Resour. J.* 14: 34-55.

Shaw, J., R.B. Taylor, D.L. Forbes, et al. 1994. *Sensitivity of the coasts of Canada to sea level rise*. GSC Open File Report 2825.

Sinclair, Jan. 1991. "Global warming: a vicious circle." *Our Planet, magazine of the United Nations Environment Programme.* Vol. 3(1): 4-7.

Wall, G., and M. Sanderson (Eds). 1990. *Proceedings of an International Symposium/Workshop on Climate Change: Implications for Water and Ecological Resources.* Department of Geography Publication Series, Occasional Paper No. 11, University of Waterloo. 342 pp.

Watson, R.T., M.C. Zinyowera and R.H. Moss (Eds.). 1996.*Climate change 1995 - Impacts, adaptations and mitigation of climate change: scientific-technical analyses*. Cambridge University Press.

Freshwater Series A-9

Note: A resource guide, entitled Let's Not Take Water For Granted, is available to help classroom teachers of grades 5-7 use the information from the Water Fact Sheets.