7 Thawing ground will disrupt transportation, buildings, and other infrastructure.

Transport on Land

Unlike most parts of the world, arctic land is generally more accessible in winter, when the tundra is frozen and ice roads and bridges are available. In summer, when the top layer of permafrost thaws and the terrain is boggy, travel over land can be difficult. Many industrial activities depend on frozen ground surfaces and many northern communities rely on ice roads for the transport of groceries and other materials. Rising temperatures are already leading to a shortening of the season during which ice roads can be used and are creating increasing challenges on many routes. These problems are projected to increase as temperatures continue to rise. Frost heave and thaw-induced weakening are major factors affecting roadway performance; transportation routes are likely to be particularly susceptible to these effects under changing climatic conditions. In addition, the incidence of mud and rockslides and avalanches are sensitive to the kinds of changes in weather (such as an increase in heavy precipitation events) that are projected to accompany warming.

Impacts of Thawing on the Oil, Gas, and Forestry Industries

Because of warming, the number of days per year in which travel on the tundra is allowed under Alaska Department of Natural Resources standards has dropped from over 200 to about 100 in the past 30 years, resulting in a 50% reduction in days that oil and gas exploration and extraction equipment can be used. These standards, designed to protect the fragile tundra from damage, are currently under review and may be relaxed, raising concerns about potential damage to the tundra. Forestry is another industry that requires frozen ground and rivers. Higher temperatures mean thinner ice on rivers and a longer period during which the ground is thawed. This leads to a shortened period during which timber can be moved from forests to sawmills, and increasing problems associated with transporting wood.

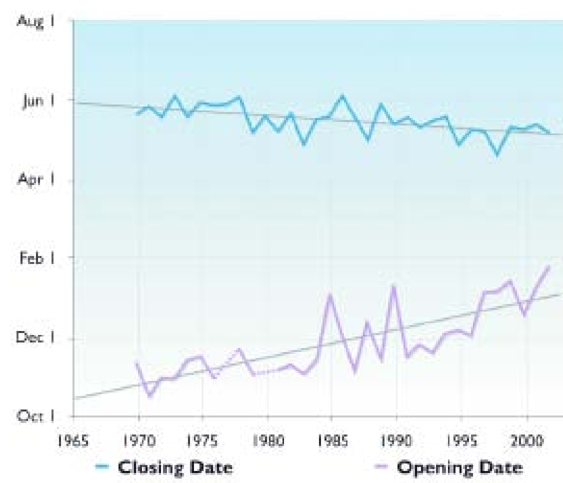
A Shrinking Ice Road Season

In January 2003, winter road construction in Canada's Northwest Territories was badly behind schedule. Les Shaw, superintendent of transportation for the Fort Simpson region, said the warm weather and lack of snow put winter road and ice bridge construction behind by several weeks. The ice bridge across the Mackenzie River at Fort Providence provided a good example. *"These last two years we've had the ice form across the channel between Christmas and New Year's, which is really strange. Normally it would be doing that at the beginning of December,"* Shaw said. This causes major problems for the territory's mining and oil and gas industries, which rely on the frozen roadways to truck in hundreds of tonnes of supplies for the year.

Alaska Winter Tundra Travel Days
(1970–2002)

The number of days in which oil exploration activities on the tundra are allowed under Alaska Department of Natural Resources standards has been halved over the past 30 years due to climate warming. The standards are based on tundra hardness and snow conditions and are designed to protect the tundra from damage.

Opening and Closing Dates for Tundra Travel on Alaska's North Slope

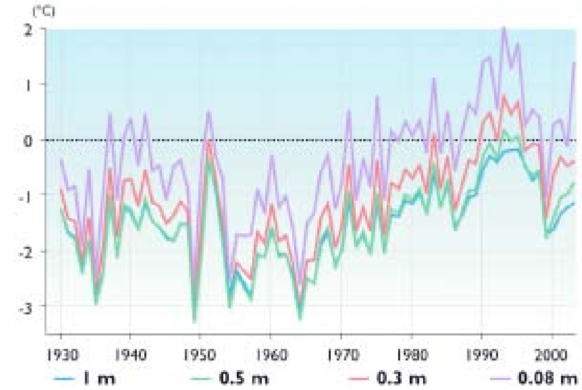


The number of travel days for oil exploration on the Alaskan tundra has been decreasing over recent decades as the opening dates come later and the closing dates come earlier.

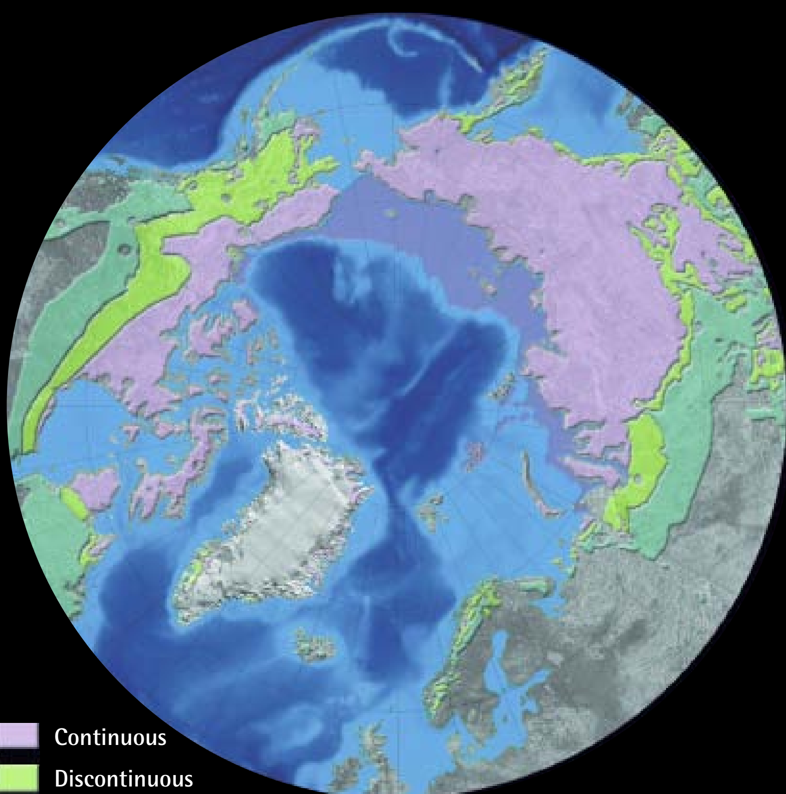
Degrading Permafrost

Air temperature, snow cover, and vegetation, all of which are affected by climate change, affect the temperature of the frozen ground and the depth of seasonal thawing. Permafrost temperatures over most of the sub-arctic land areas have increased by several tenths of a °C up to 2°C during the past few decades, and the depth of the active layer is increasing in many areas. Over the next 100 years, these changes are projected to continue and their rate to increase, with permafrost degradation projected to occur over 10-20% of the present permafrost area, and the southern limit of permafrost projected to shift northward by several hundred kilometers.

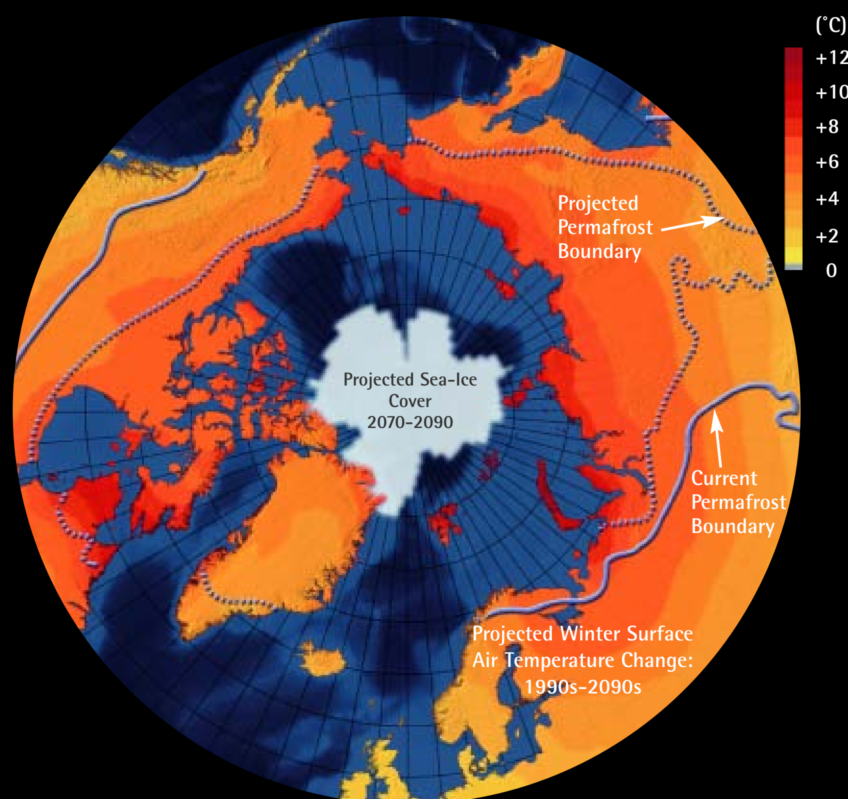
Average Annual Ground Temperature
Fairbanks, Bonanza Creek 1930-2003



Observed Permafrost Regions



Projected Change in Permafrost Boundary



A PERMAFROST PRIMER

Permafrost is soil, rock, or sediment that has remained below 0°C for two or more consecutive years. Permafrost underlies most land surfaces in the Arctic, varying from a few meters to several hundred meters thick.

Continuous permafrost zones are those in which the permafrost occupies the entire area, and can reach up to 1500 meters in depth, for example, in parts of Siberia.

Sporadic or discontinuous permafrost zones are those in which the permafrost underlies from 10% to 90% of the land and may be only a few meters thick in places.

Active layer refers to the top layer of permafrost that thaws each year during the warm season and freezes again in winter.

Degradation of permafrost means that some portion of the former active layer fails to refreeze during winter.

Thermokarst refers to a place where the ground surface subsides and collapses due to thawing of permafrost. This can result in new wetlands, lakes, and craters on the surface.

Key Finding #7

7 Thawing ground will disrupt transportation, buildings, and other infrastructure.

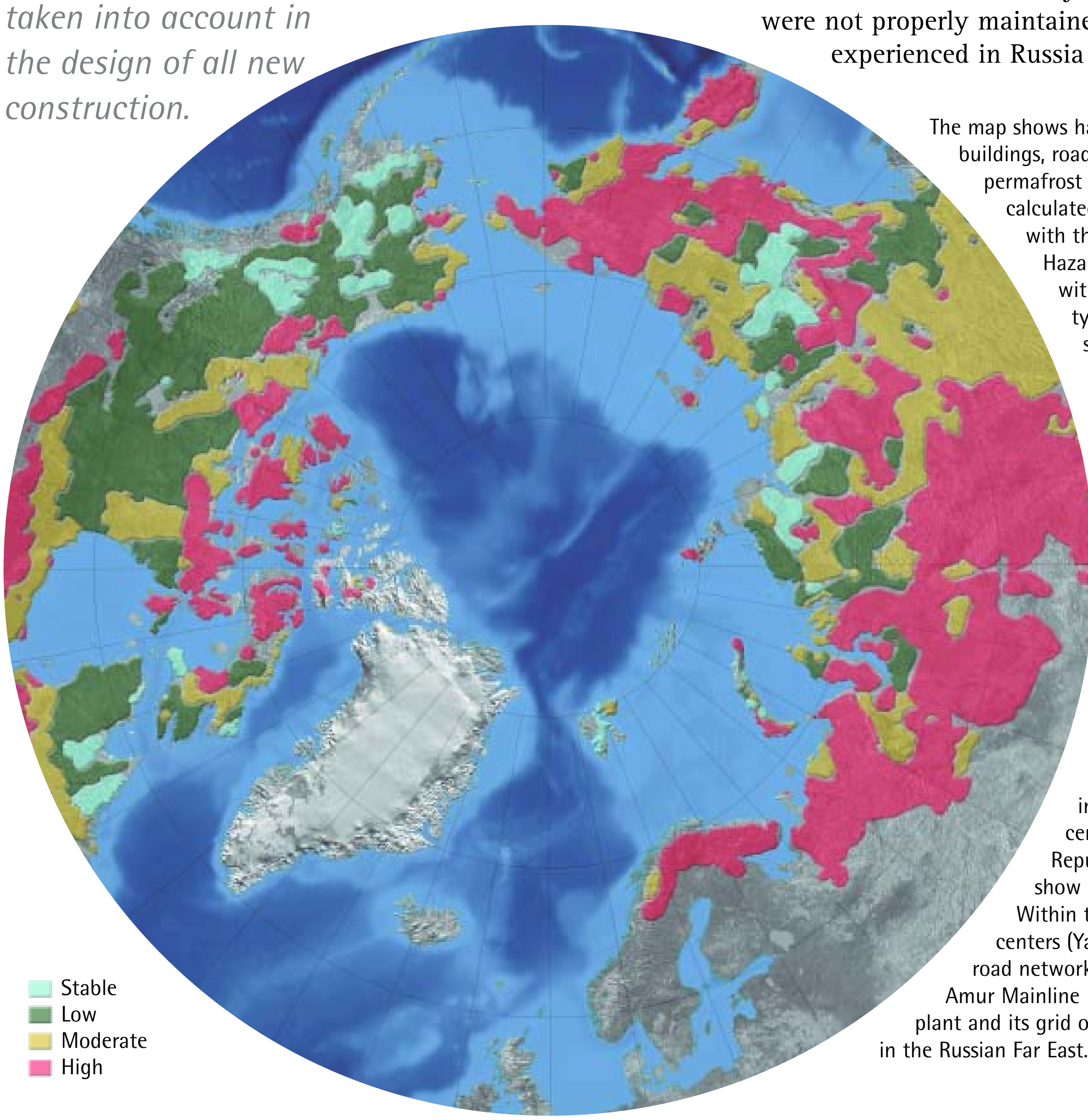
The projected rate of warming and its effects will need to be taken into account in the design of all new construction.

Impacts on Infrastructure

Projected increases in permafrost temperatures and in the depth of the active layer are very likely to cause settling, and to present significant engineering challenges to infrastructure such as roads, buildings, and industrial facilities. Remedial measures are likely to be required in many cases to avoid structural failure and its consequences. The projected rate of warming and its effects will need to be taken into account in the design of all new construction, requiring deeper pilings, thicker insulation, and other measures that will increase costs.

In some areas, interactions between climate warming and inadequate engineering are causing problems. The weight of buildings on permafrost is an important factor; while many heavy, multi-story buildings of northern Russia have suffered structural failures, the lighter-weight buildings of North America have had fewer such problems as permafrost has warmed. Continuous repair and maintenance is also required for buildings on permafrost, a lesson learned because many of the buildings that failed were not properly maintained. The problems now being experienced in Russia can be expected to occur

Infrastructure at Risk by 2050 Due to Permafrost Thaw



The map shows hazard potential by risk level for buildings, roads, and other infrastructure due to permafrost thaw by the middle of this century, calculated using the Hadley climate model with the moderate B2 emissions scenario. Hazard potential is partitioned into areas with high, moderate, and low susceptibility to thaw-induced settlement. Areas of stable permafrost, which are not likely to change, are also shown. A zone in the high and moderate risk category extends discontinuously around the Arctic Ocean, indicating high potential for coastal erosion. Also within these bands are population centers (Barrow, Inuvik) and river terminals on the Arctic coast of Russia (Salekhard, Igarka, Dudinka, Tiksi). Transportation and pipeline corridors traverse areas of high hazard potential in northwestern North America. The area containing the Nadym-Pur-Taz natural gas production complex and associated infrastructure in northwest Siberia also falls in the high-risk category. Large parts of central Siberia, particularly the Sakha Republic (Yakutia), and the Russian Far East show moderate or high hazard potential. Within these areas are several large population centers (Yakutsk, Noril'sk, Vorkuta), an extensive road network, and the Trans-Siberian and Baikal-Amur Mainline Railroads. The Bilibino nuclear power plant and its grid occupy an area of high hazard potential in the Russian Far East.

elsewhere in the Arctic if buildings are not designed and maintained to accommodate future warming.

Structural failures of transportation and industrial infrastructure are also becoming more common as a result of permafrost thawing in northern Russia. Many sub-grade railway lines are deformed, airport runways in several cities are in an emergency state, and oil and gas pipelines are breaking, causing accidents and spills that have removed large amounts of land from use because of soil contamination. Future concerns include a weakening of the walls of open pit mines, and pollutant effects from large mine tailing disposal facilities as frozen layers thaw, releasing excess water and contaminants into groundwater.

The effects of permafrost thawing on infrastructure in this century will be more serious and immediate in the discontinuous permafrost zone than in the continuous zone. Because complete thawing is expected to take centuries, and benefits (such as easier construction in totally thawed ground) would occur only after that time, the consequences for the next 100 years or so will be primarily negative (that is, destructive and costly).

Building damaged due to permafrost thawing in Chersky (low Kolima River), Russia.

Yakutsk, Russia Experiences Infrastructure Failure as Permafrost Thaws

In Yakutsk, a Russian city built over permafrost in central Siberia, more than 300 buildings have been damaged by thaw-induced settlement. The infrastructure affected by collapsing ground due to permafrost thaw includes several large residential buildings, a power station, and a runway at Yakutsk airport. Some ascribe a large proportion of the city's recent problems to climatic warming, though others believe that better construction practices and maintenance could have prevented much of the trouble.

BP operations center, Prudhoe Bay, Alaska, built on pilings to resist damage from thawing permafrost.

Research on the impacts of warming on infrastructure indicates that even small increases in air temperature substantially affect building stability, and that the safety of building foundations decreases sharply with increasing temperature. This effect can result in a significant decrease in the lifetime of structures as well as the potential failure of structures.

As global warming continues, detrimental impacts on infrastructure throughout the permafrost regions can be expected. Many of these impacts might be anticipated, allowing structures to be re-designed and re-engineered to withstand additional pressures under changing climatic conditions. This will certainly incur costs, but can avoid the dramatic infrastructure failures being experienced in Yakutsk and elsewhere in the Arctic.

Floods and Slides

Another set of climate-related problems for arctic infrastructure involves floods, mudslides, rockslides, and avalanches. These events are closely associated with heavy precipitation events, high river runoff, and elevated temperatures, all of which are projected to occur more frequently as climate change progresses. Soil slopes are also made less stable by thawing permafrost, and this is expected to result in more slides. Some transportation routes to markets are sensitive to the types of weather events that are expected to increase as climate continues to warm. Protecting or improving these routes will be required.

7 Thawing ground will disrupt transportation, buildings, and other infrastructure.

Impacts of Thawing Permafrost on Natural Ecosystems

Important two-way interactions exist between climate-induced changes in permafrost and vegetation. As permafrost thaws, it affects the vegetation that grows on the surface. At the same time, the vegetation, which is also experiencing impacts due to climate change, plays an important role in insulating and maintaining the permafrost. For example, forests help sustain permafrost because the tree canopy intercepts the sun's heat and the thick layer of moss on the surface insulates the ground. Thus, the projected increase in forest disturbances such as fire and insect infestations can be expected to lead to further degradation of permafrost, in addition to what is projected to result directly from rising temperatures.

Water levels in many rivers and lakes in Nunavut (eastern Arctic Canada) have been falling for four decades, with the most dramatic drops in the past decade. Native people have long relied on both drinking water and fish from these waters. Rivers also provided access by boat to hunting grounds that can no longer be reached.

In some northern forests, certain tree species (notably black spruce) utilize the ice-rich permafrost to maintain the structure of the soil in which they are rooted. Thawing of this frozen ground can lead to severe leaning of trees (sometimes referred to as "drunken forest") or complete toppling of trees. Thus, even if a longer, warmer growing season might otherwise promote growth of these trees, thawing permafrost can undermine or destroy the root zone due to uneven settling of the ground surface, leading instead to tree collapse and death. In addition, where the ground surface subsides due to permafrost thaw, even if the trees do not fall over, these sites often become the new lowest points on the landscape. At least seasonally, these places fill with water, drowning the trees.

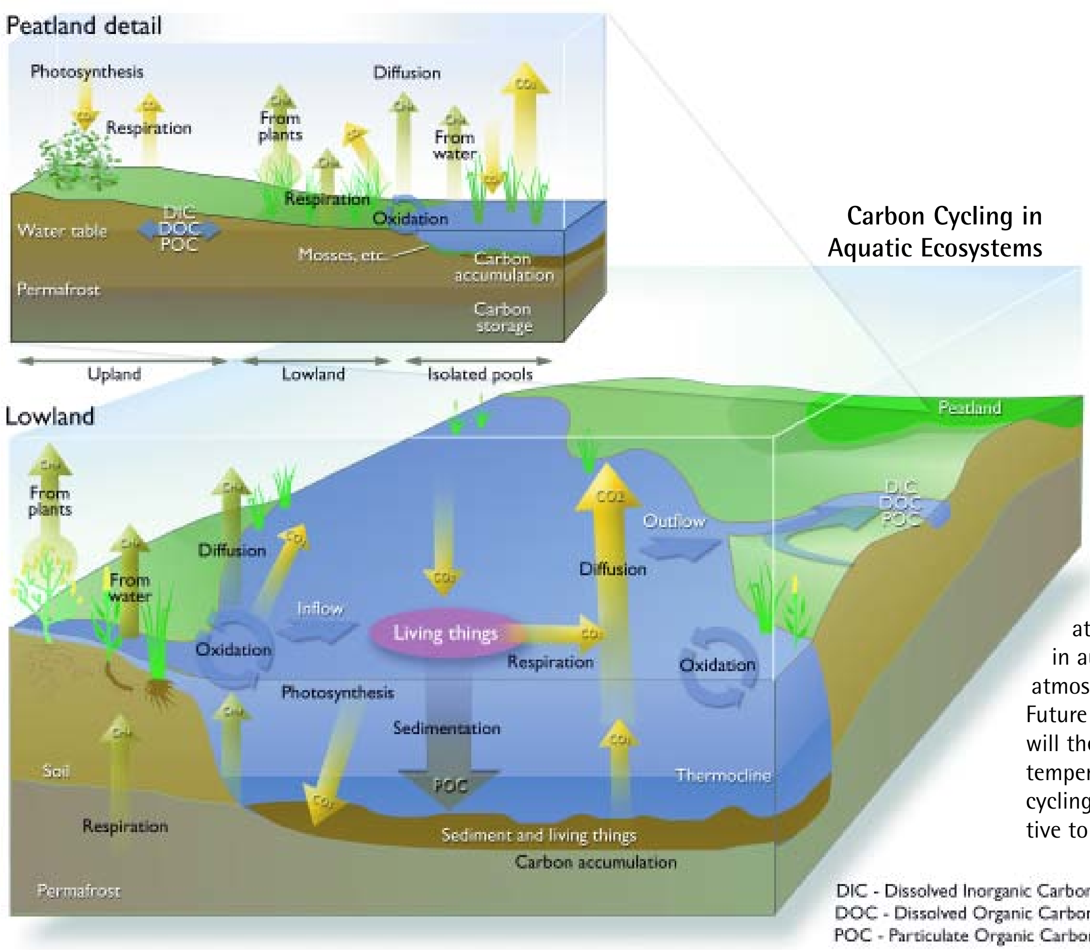
The potential for many shallow streams, ponds, and wetlands in the Arctic to dry out under a warming climate is increased by the loss of permafrost. As permafrost thaws, ponds connect with the groundwater system. They are thus likely to drain if losses due to downward percolation and evaporation are greater than re-supply by spring snowmelt and summer precipitation. Patchy arctic wetlands are particularly sensitive to permafrost degradation that links surface waters to groundwater. Those along the southern limit of permafrost, where increases in temperature are most likely to eliminate the relatively warm permafrost, are at the highest risk of drainage. Indigenous people in Nunavut (eastern arctic Canada) have observed recently that there has been increased drying of rivers, swamps, and bogs, to the extent that access to traditional hunting grounds and, in some instances, migration of fish, have been impaired. There is also a high risk of catastrophic drainage of permafrost-based lakes, such as those found along the western arctic coast of Canada.

In other places, warming of surface permafrost above frozen ground and associated collapsing of ground surfaces could increase the formation of wetlands, ponds, and drainage networks, particularly in areas characterized by heavy concentrations of ground ice. Such thawing, however, would also lead to dramatic increases in sediment being deposited into rivers, lakes, deltas, and coastal marine environments, resulting in significant impacts to aquatic life in these bodies of water.

Changes to the water-balance of northern wetlands are especially important because most wetlands in permafrost regions are peatlands, which may absorb or emit carbon (as carbon dioxide or methane) depending on the depth of the water table. There are many uncertainties in projections of these changes. One analysis suggests that an increase in temperature of 4˚C would reduce water storage in northern peatlands, even with a small and persistent increase in precipitation, causing peatlands to switch from emitting carbon dioxide to the atmosphere to absorbing it. It is also possible that the opposite could occur, whereby warming and drying could cause the rate of decomposition of organic matter to increase faster than the rate of photosynthesis, resulting in an increase in carbon dioxide emissions. A combination of temperature increase and elevated groundwater levels could result in increased methane emissions. Projections based on doubling of pre-industrial carbon dioxide levels, anticipated to occur around the middle of this century, suggest a major northward shift (by 200-300 kilometers) of the southern boundary of these peatlands in western Canada and a significant change in their structure and vegetation all the way to the coast.

"There is a lot less water, around all these islands [in Baker Lake]... There used to be a lot of water. We could go through with our outboard motors and boats, but now there is getting to be less and less water all over... There's been a lot less fish because there's not as much water anymore... The fish were more plentiful and they used to be bigger. Now you hardly get char anymore at Prince River or any of these fishing places."

L. Arngna'naaq
Baker Lake, Canada



Carbon Cycling in Aquatic Ecosystems

Simplified schematic of the cycling of carbon in high-latitude aquatic ecosystems. Arctic wetlands typically emit carbon to the atmosphere during spring melt and as plants die in autumn. They then absorb carbon from the atmosphere as plants grow during the warm season. Future changes in the release and uptake of carbon will therefore depend on changes in vegetation, temperature, and soil conditions. Similarly, carbon cycling in lakes, ponds, and rivers will also be sensitive to direct and indirect effects of climate change.