is the supply of water. This has not been a problem in Alaska to date. Water supply has global implications, however, particularly for traditional agriculture (Weller and Lange, 1999).

Reindeer Husbandry

Five potential challenges to the health of reindeer husbandry are related to global climate change: 1) ice-coating of winter forage; 2) poor quality forage in warm and dry summers; 3) caribou range expansion into reindeer areas; 4) tundra fires; and 5) forest expansion into tundra. Four of these trends (1, 2, 4, and 5) are likely to become serious problems following a continuous warming of Alaska's climate. This may well present new challenges to the Native reindeer industry.

The role of recent climate change in a drastic decline of Russia's domestic reindeer stock, which dropped from 2.3 million to about 1.6 million between 1991 and 1997, is still unknown but the impact of climate/weather fluctuations cannot be ignored. During the long arctic winter, reindeer depend on access to range that is rich in lichens. The lichens provide carbohydrates almost exclusively as a source of energy to maintain body temperature in winter. Reindeer can effectively paw through snow to reach the lichens. If warmer than normal temperatures produce freezing rain, the resulting ice cover makes the lichens unavailable and this often causes reindeer to starve to death. Such an event occurred on the Chukchi Peninsula in northeastern Siberia in the fall of 1996, leading to the death of thousands of domestic reindeer.

Subsistence Livelihoods

The harvest of fish and game for direct consumption is critical to indigenous communities throughout the Arctic. Subsistence activities meet nutritional needs, sustain important cultural values, and reinforce social networks of cooperation and sharing. In many indigenous communities, participation in commercial fishing, trapping and reindeer herding also contributes significantly to cash incomes.

Climate change is likely to have significant impacts on key marine and terrestrial species availability for subsistence purposes. At a minimum, salmon, herring, walrus, seals, whales, caribou, moose and various species of waterfowl are likely to undergo shifts in range and abundance. This will entail local adjustments in harvest strategies and allocations of labor and capital (such as boats, snow machines, weapons).

Changes in diet, nutritional health, and exposure to air, water, and food-borne contaminants can also be expected. Adjustments in the balance between the "two economies" of rural areas (subsistence and wage) will occur. This suite of changes will be complex and largely indirect because of the mediating influences of market trends, the regulatory environment, and the pace and direction of rural development.

The following impacts on the subsistence lifestyles in Native villages and communities in Alaska, which depend heavily on fishing and hunting, have been observed in recent years. Most of the impacts listed below come from comprehensive interviews in Alaskan Native communities, for example by Gibson and Schullinger (1998).

- A warmer climate with milder winters and less (or no) shore-fast ice and snow has impeded access to offshore and tundra food resources (-).
- Recent decreases in anadromous fish stocks, which make up 60% of wildlife resources used by subsistence users, have directly affected the latter's dietary and economic well-being (-).
- The availability of marine mammals for subsistence is also lower, due to shifts in oceanographic and sea-ice conditions. While whale catches are normal, walrus harvests are low. Marine mammals are an important food source in many coastal communities (-).

Whitefish seine netting, Kobuk River

- Increases in the frequency and ferocity of storm surges have triggered increased coastal erosion and threatened several villages in the Bering Sea; this has led to plans for relocation of some villages at great expense (-).
- These storm surges have also altered the protection of coastal habitats by barrier islands and spits which are highly vulnerable to erosion and wave destruction (-).
- A warmer climate has also thawed traditional ice cellars in several northern villages in Alaska, making them useless for the storage of meat (-).
- Human health problems may have increased due to new diseases moving north (-).

Other impacts likely to occur in the future include:

- A decrease in the area of pack ice has important implications on primary productivity and the entire food chain (-).
- For example, walrus and bearded seals require sea ice strong enough to support their weight but over water shallow enough so that they can reach the bottom to feed. Changes in ice conditions may adversely affect these species (-).
- Changes in atmospheric and oceanic circulation may bring contaminants from military and industrial installations closer into the food chain and human consumption (-).
- As the boreal forest intrudes further north at the expense of tundra and shrub communities, there will be changes in habitats and the distribution and density of a number of wildlife species on land (+ and -).

Tourism

As the climate changes, the landscape changes with it (e.g., glaciers may disappear, new ecosystems may be created, wildlife will increase or decrease, etc.) and this in turn increases or decreases the attractiveness of the region to tourism. A different but likely impact in Alaska on the environment is due to tourism itself. Tourism is projected to increase steadily in the Arctic, and this will affect the land and its uses. Noise from tourist activities, trampling of vegetation and other impacts are likely to be experienced. In other areas of the world, for example Antarctica, tourism and scientific activities in remote areas constitute the biggest impacts on the environment. The same may apply to remote locations in Alaska, which have so far not experienced much tourist activity. Tourism of course also

has other impacts, for example on the economy of frequently visited regions. Ecotourism is on the rise and tourists may enhance the migration and establishment of invasive dominant species. Finally, tourism may generate both public and political awareness of changes in Alaska.

Transportation, Energy and Infrastructure

Alaska is the supplier and source for a large fraction of the non-renewable resources for the rest of the world. Alaska, as well as Siberia and Northwest Canada, contain large reserves of liquid and gas petroleum and also vast coal resources. Only a portion of these resources have been discovered, explored or exploited so far. The predicted effects of climate change on the production, storage and transportation of petroleum, gas and coal, on mining, and on transportation have important implications, both negative and positive, for the economy of the northern hemisphere.

Energy production by means of hydroelectric systems, fossil fuel, and other less-standard techniques, and impacts on the infrastructure of power generation, and on transportation will be affected by changes in the seasonal temperatures, precipitation, wind and solar radiation, and by glacial melt, permafrost thawing, river flow, and snow accumulation. Climate effects on the river systems, port facilities, and hindrances or improvements in ocean transportation (e.g., reduction in sea ice thickness and extent) will have vital impacts on regional energy needs, as well as on transportation of materials both into and out of the Arctic.

Examples of likely impacts on infrastructure and the geophysical cause for these impacts, the availability of any remedial action and the time frame of predictions most useful to put remediation into effect, the decisionmakers and stakeholders involved in this, and the recommended remedial action are shown in Table 3, based on experience in Alaska from 1992 to the present.

The following impacts on infrastructure have been observed in recent years (BESIS 1997; 1998; 1999):

- Failure of buildings has occurred due to a change in the properties of permafrost that is warming (-). For examples see Chapter IV.
- Accelerated permafrost thawing has also led to costly increases in road damage and road maintenance in Alaska (up to $3 million to replace 1 mile [1.6 km] of road system) (-).
- Increased slope instability, landslides and erosion have occurred in thawing permafrost terrain in the Mackenzie Basin, threatening roads and bridges, and causing local floods (-).
- The disappearance of permafrost reduces construction problems in the long run; in some areas permafrost boundaries have moved north by tens of miles in the last century (+).
- Reductions in sea ice extent and thickness have allowed easier access to villages and industrial installations in some regions of the Arctic (e.g., Bering Sea) (+).

Other impacts likely to occur if climate warming continues include:

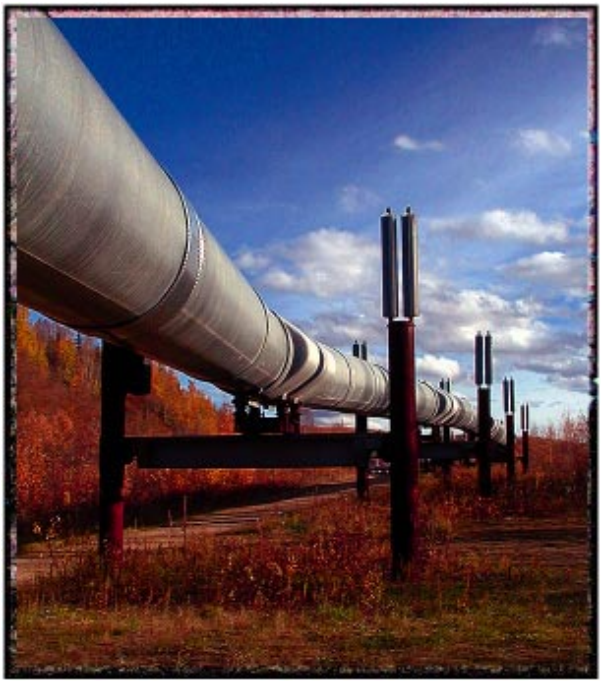
- The mechanical properties of permafrost will decrease further with warming, resulting in possible failure of pilings for buildings and pipelines, and of roadbeds (-).

Table 3. Examples showing infrastructure affected by climate change and extreme weather events, whether remediation exists, the stakeholders involved, and remediation efforts, based on experience in Alaska from 1992 to present (modified from Weller and Lange, 1999).

Infrastructure (geophysical cause)	Time Frame of Prediction	Does Remediation Exist?	Decisionmaker/ Stakeholder	Remediation Efforts
Roads & airports (permafrost)	Long term	Yes and No	State and Federal agencies, Community	Plan ahead or fix it later
Housing & construction (permafrost)	Long term	Yes	Owner, Contractor, Community, Government	Fix it before
All Infrastructure (extreme weather events)	None	Yes and No	State, Federal, Private sector, Community	Engineer it correctly or fix it later
Pipelines (permafrost)	Long term	Yes	Private sector, Government	Engineer it correctly
Hydro power (ice, hydrologic cycle, extreme weather)	Long term	Yes	State, Private, Federal energy regulatory committee	First inspections required, Plan ahead
Non-hydro power	Long term but less critical	Generally	State, Private	Less affected, remediation less important
Power lines (ice, extreme weather, permafrost)	Long and short term	Yes	State, Private	Plan ahead, Fix at once
Barge ocean traffic (ocean ice, storm surges)	Long term and less of problem	—	Private	No problem, so no remediation needed
Barge river traffic (ice, freezing temperatures)	Seasonal	No	Private, Community	Adjust schedules
Ice roads (early thaw, permafrost, lack of snow)	Immediate	No	Private, Community, Governmental regulators	Adjust schedules

- Ice and snow roads, frequently used by the oil industry to reduce environmental damage to the tundra, may not be thick enough or last long enough in the future. (-).
- Power outages due to more severe winter snow storms could lead to threats to human life and safety, as well as increased repair costs (-).
- Ship and barge traffic on rivers and in the ocean will benefit from a longer ice-free season and thinner ice (+).
- Higher temperatures will lead to cost savings in power generation in remote arctic towns and villages (+).

Permafrost problems deserve some special attention. There is great concern that the impact of global warming on permafrost and reduction of permafrost bearing capacity can exceed the safety factor that is incorporated in the design of existing structures. This has become a particularly serious problem in northern Russia (see also Chapter IV).



An exposed section of the trans-Alaskan pipeline on thaw-unstable permafrost ground near Fairbanks. The pipe is insulated and jacketed and rests on supports equipped with cooling fins.