# Impacts of Climate Change on Transportation Infrastructure in Alaska

By **Orson P. Smith and George Levasseur**

## Introduction

The economy of Alaska is extraordinarily dependent on the efficiency of its limited transportation infrastructure for mineral exports, fisheries, and tourism. Gravel airstrips, many built on permafrost, tenuously uphold the standard of living of the hundreds of Alaskan communities without road connections. Global warming is projected to bring more erratic winter weather, increasing the frequency of freeze-thaw cycles. As this occurs, Alaskan roads, railways, and airport runways will suffer attendant problems and maintenance costs are likely to increase (Figures 1, 2, and 3). This paper is intended to open discussion of these and other potential impacts of global warming in Alaska.

## Changes to Permafrost

Warming and thawing permafrost foundations are the most serious of climate change consequences to land and air transportation services in the 49th state. Extensive evidence exists of permafrost warming and thawing in Alaska over the past several decades (Osterkamp and Romanovsky 1999). Maximum thaw settlement occurs with ice-rich fine-grained frozen ground that is unfortunately common across much of the State. Figure 4 shows the extent of permafrost in Alaska, color-coded by ice content (see Brown et. al. 1997 for detailed explanation of color codes and markings). Figure 5 illustrates the distribution of public infrastructure built on permafrost.

***Figure 1**. Photo of settlement and cracks on an Alaskan roadway due to warming of the permafrost foundation.*

***Figure 2.*** *Photo of Richardson Highway bridge across One Mile Creek in Alaska's interior.*

***Figure 3***. *Photo of channel and bridge repairs after a flash flood at One Mile Creek.*

## The Case of One Mile Creek

Alaska's mountain roads are beginning to feel the effects of receding glaciers and melting permafrost. One Mile Creek crosses Alaska's Richardson Highway in the State's interior near the Alaska Range (Figure 2). The stream is approximately 2.25 miles in length, with headwaters in an ice field at an elevation of about 5,200 feet. The gradient is very steep down to an elevation of approximately 1,800 feet, just upstream of the Richardson Highway bridge. The Alaska Department of Transportation and Public Facilities (ADOT&PF) has spent increasing time and money in recent years to remove alluvial gravel from the stream channel beneath the bridge. Gravel can cover the roadway in less than 24 hours. An ordinary rainfall or even just a spell of warm weather starts the ice melting and the gravel moving. An increased supply of sediment in the drainage basin is deemed to be due to receding glacial ice cover and melting permafrost. The increase in sediment transport to the bridge may also be due to increasingly frequent and intense rainstorms.

On July 11, 2000 a flood washed out the One Mile Creek bridge (Figure 3). The closure of the Richardson Highway lasted 2 days and ADOT&PF spent over $100,000 to make repairs. Since 2000, after each rainstorm maintenance crews remove rock from the bridge channel to a depth of 9 to 12 ft (see Figures 2 and 3). One Mile Creek flooded 6 times in 2001. Each event required a week's work to clear debris and as much as 10,000 cubic yards of gravel from under the bridge.

Melting permafrost on the south side of the Alaska range has also caused several landslides elsewhere, closing roads and isolating rural residents. According to ADOT&PF officials, increased stream sediment loads over the last decade from retreating glaciers and melting permafrost have also led several of Alaska's interior rivers to change channels, resulting in more highway dike and levee projects.

## Views of Alaskans

Historical warming appears to be maximum in North America between 50 and 70° north latitude, as indicated in Figure 6. Evidence of this and other global warming trends has been discussed in Alaska at several meetings in recent years, with a view toward impacts on public and commercial infrastructure. A series of January "Science-to-Engineering" workshops, co-sponsored by federal, State, and commercial interests, including the U.S. Arctic Research Commission, have taken place at the University of Alaska Anchorage (UAA) since 1998. The January 2000 workshop was titled "The

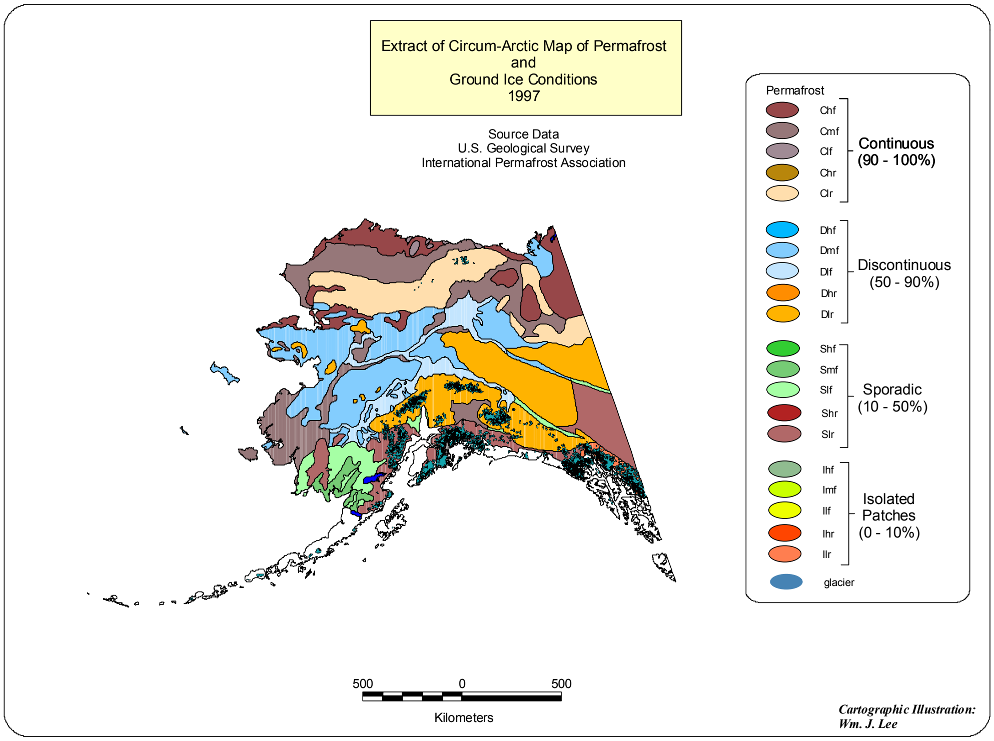
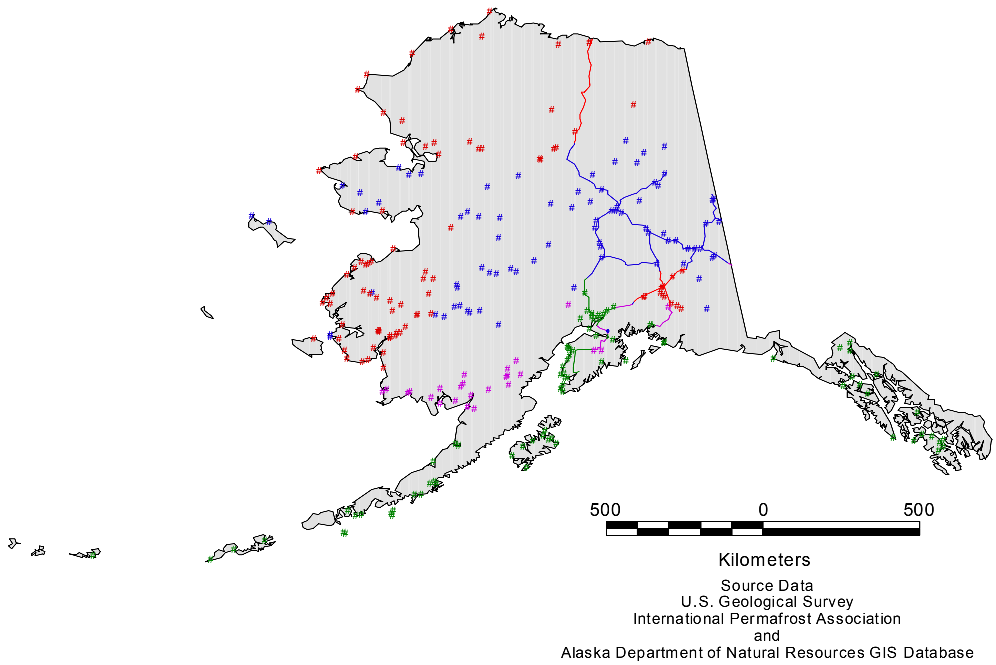



***Figure 4.*** *Map showing extent of permafrost in Alaska. Permafrost can be found to varying extents in most parts of Alaska. Source: Brown et al 1997.*

Warming World: Effects on Alaska Infrastructure" (Smith and Johnson 2000). This workshop attracted over 100 researchers, practicing engineers, educators, and leaders of public agencies and commercial businesses with Alaska interests. Attendees agreed that roads, airports, and critical infrastructure in Alaska would be adversely affected by long-term warming.

Experienced engineers pointed out at the January 2000 UAA workshop that tested solutions are available, given warning of changes, reliable local information, and funding. Arctic engineers are accustomed to dealing with warming, since the structures they build tend to cause warming of frozen foundations. New works can be located over gravelly thaw-stable permafrost to avoid the worst consequences, but expensive investigations are required for optimum site selection. Widely used Alaskan engineering references on climate and ground conditions are outdated, some based on measurements from the 1950s. Project site measurements reveal current conditions, but don't foretell the future unless they are part of a monitoring sequence. Environmental monitoring and global warming research were supported by a consensus of workshop attendees. Public works agencies that fund projects only for the duration of design and construction, such as the Alaska Department of Transportation and Public Facilities (ADOT&PF) and the U.S. Army Corps of Engineers, should leave in place means for monitoring infrastructure status. ADOT&PF has subsequently increased its efforts to monitor existing roadway foundations (ADOT&PF 2002).

## Alaska Community and Highway Permafrost Exposure




**Suseptible Roads**

- Continuous (90 - 100%)
- Discontinuous (50 - 90%)
- Sporadic (10 - 50%)
- Less than 10%

**Suseptible Communities**

- # Continuous (90 - 100%)
- # Discontinuous ( 50 - 90%)
- # Less than 10%
- # Sporadic ( 10 - 50%)

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GEOMATICS

Summary of Alaska Highways Susceptible to Permafrost

| Permafrost Extent | Road Distance (km) |
|---|---|
| Continuous (90 - 100%) | 734 |
| Discontinuous (50 - 90%) | 1950 |
| Sporadic (10 - 50%) | 307 |
| Less than 10% | 452 |

Summary of Alaska Communities Susceptible to Permafrost

| Permafrost Extent | Total Communities | Population |
|---|---|---|
| Continuous (90 - 100%) | 87 | 40811 |
| Discontinuous (50 - 90%) | 79 | 47140 |
| Sporadic (10 - 50%) | 26 | 5235 |
| Less than 10% | 129 | 396821 |

***Cartographic Illustration: Wm. J. Lee***

***Figure 5.** Map of Alaska infrastructure on permafrost foundations.*

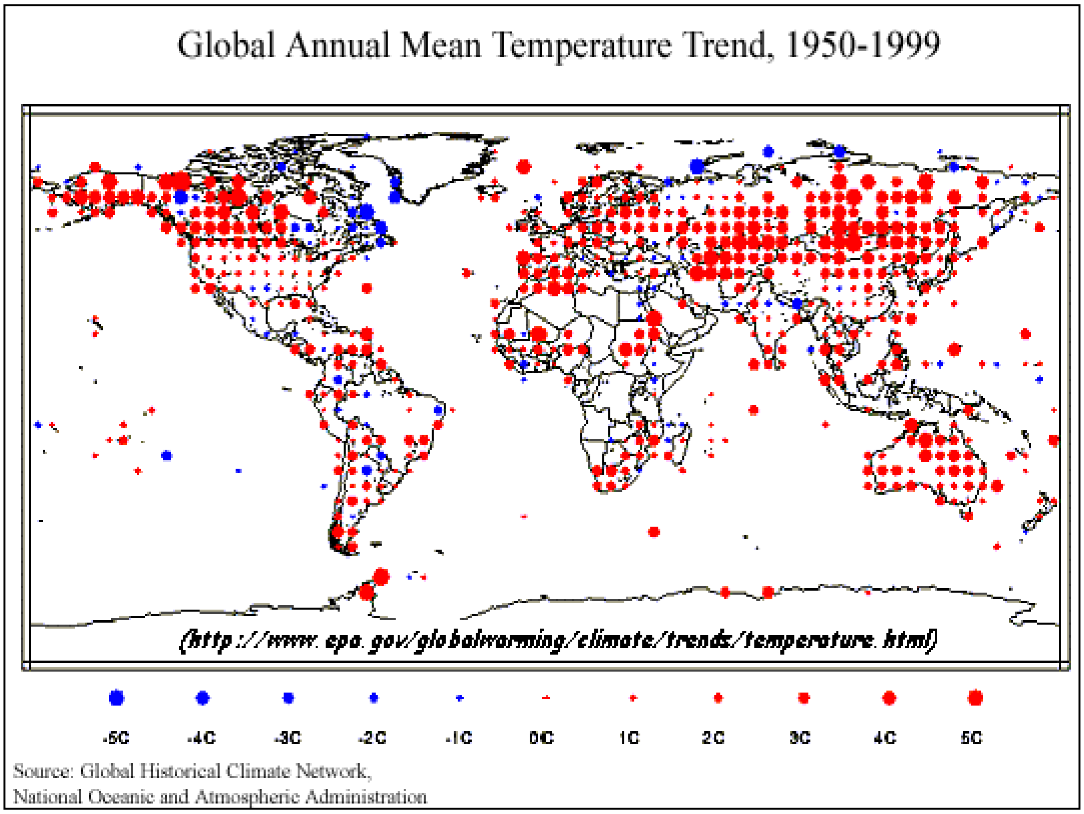


***Figure 6.*** *Map of annual mean temperature trends worldwide, 1950-1999. Historical temperature trends show the most warming in Canada and Alaska.*

A January 2001 workshop at UAA focused on "Cold Regions Port and Coastal Engineering," with discussions of science and engineering needs related to coastal problems and engineering solutions. The following excerpt from the workshop report (Smith and Johnson 2001) summarizes conclusions regarding permafrost shorelines:

> "…Wise decisions must be made with regard to the life of new infrastructure in the face of erosion threats. Bluff shoreline retreat rates of up to 5 meters or more per year are common in Arctic Alaska, Canada, and Russia, due to thawing of permafrost. The International Permafrost Association has proposed a circum-Arctic coastal monitoring system to quantify coastal erosion, as part of an international Arctic Coastal Dynamics initiative. Remote sensing is of great utility in this regard, both for the extent and nature of erosion trends and associated sea waves, currents, water levels, and for ice conditions. Satellite-borne sensors include RADARSAT, AVHRR and SSM-I, from which processed data is available from the University of Alaska Fairbanks and the National Weather Service. Regular monitoring of survey profiles across the shore at selected representative sites is important ground truth and provides the best information for site-specific studies and

> erosion control designs. Globally, Arctic coastal erosion seems to average about 1 - 2 meters a year, according to recent regional analyses. Local residents can be trained and equipped to accomplish valuable objective measurements of coastal change..."

The U.S. Senate Appropriations Committee convened a hearing in Fairbanks, Alaska on 29 May 2001 with focus on climate change research needs. Testimony of Orson Smith (2001), University of Alaska Anchorage, included the following remarks:

> "…Permafrost coasts are especially vulnerable to erosive processes as ice beneath the seabed and shoreline melts from contact with warmer air and water. Thaw subsidence at the shore allows even more wave energy to reach these unconsolidated erodable materials. Alaska's permafrost coasts along the Beaufort and Chukchi Seas are most vulnerable to thaw subsidence and subsequent wave-induced erosion…
>
> …Thawing permafrost and freeze-thaw cycle changes in the active layer of soils across Alaska may bring adverse impacts to existing foundations of all types. New foundations can be designed to accommodate these changes, if site conditions are known and predictions are accurate…
>
> …Climate change began some time ago and problems of warming permafrost and other environmental changes have occurred throughout the careers of cold regions engineers in practice today. Their fears for northern infrastructure relate to lack of site information and reliable prediction of future change..."

**Native Alaskan Concerns.** Caleb Pungowiyi, President of the Robert Aqqaluk Sr. Memorial Trust and a respected spokesman on native Alaskan issues, also testified at the May 2001 hearing. His testimony included the following statements (Pungawiyi 2001):

> "…More wind causes wave action and wave action along with rising waters causes erosion. In the past 20 years we have lost much land to beach and shore erosion. Many subsistence camps have lost land to erosion, especially in areas like Cape Espenberg and Cape Krusenstern. As you mentioned the other day, Senator, some of the communities like Shishmaref [see Figure 7] and Kivalina will have no choice but to relocate…
>
> …Most people take change too lightly and do not think that people are being affected directly. It is not the severe events, such as hurricanes, floods, drought, and unseasonable snowfall that are major effects from climate change, but small changes that will or are having dramatic effects…

***Figure 7.*** *Photo of coastal erosion leaving buildings at the edge of the sea at Shishmaref, Alaska.*

> …We need to document and record the economic and other effects of the warming on the coastal residents of Western and Northern Alaska..."

## International Interests

International efforts are also bringing attention to bear on climate change impacts to Alaska infrastructure. The Arctic Council, a forum of the eight Arctic national governments (Canada, Denmark/Greenland, Finland, Iceland, Norway, Russia, Sweden, and the U.S.) is sponsoring an assessment of the consequences of climate change in the Arctic region. The Arctic Climate Impact Assessment (ACIA 2001) project is under the purview of the Arctic Council and the non-governmental International Arctic Science Committee (IASC). The ACIA Secretariat is located at the International Arctic Research Center at the University of Alaska Fairbanks. The U.S. National Science Foundation and National Oceanic and Atmospheric Administration provide funding for the Secretariat. ACIA will focus on projections for the years 2020, 2050, and 2080, applying an intermediate scenario of global warming from climate model projections investigated by the Intergovernmental Panel on Climate Change (Leggett et al 1992 and IPCC 2000). Chapter 15 of the ACIA report is titled "Infrastructure: Buildings, Support Systems, and Industrial Facilities" and will include a summary of anticipated impacts in Alaska. The report will also propose research, education, and other measures in response to climate change impacts.

## Coastal Erosion

Alaska is bounded by over 50,000 km of diverse Arctic and sub-Arctic coastline, most of which is uninhabited. Over 90% of its population lives within 20 km of the coast, however, so coastal development is critical to the economy and social well being of nearly all Alaskans. Fisheries and oil and gas developments are concentrated along the coast. Markets for minerals and other resources from the hinterland are constrained by export through widely scattered seaports. Tourism aboard cruise ships is growing rapidly.

Alaska's coastal zone includes a broad range of temperate, sub-Artic, and Arctic characteristics. Coastal dynamics of the northern half of the State are affected directly or indirectly by the presence of permafrost (Figure 4). Sea level rise and thaw subsidence of permafrost shores are projected to exacerbate problems of increased wave energy at the coast from extended periods of broad ice-free fetches. More energetic waves would be generated by more frequent and intense storms that may accompany global warming.

The southern half of the State has coastal characteristics complicated by erodable glacial deposits and high tides. Cook Inlet, in south-central Alaska, has a 10-m tidal range at its northern extreme and an eroding shoreline of glacially deposited bluffs (Figure 8, Smith et al 2001). Freezing of brackish water at the northern end and ice deposition on broad tidal flats create huge blocks of "beach ice" that carry coarse sediments for distances over 100 km (Figure 9, Smith 2000). These sediment-laden ice blocks are most dangerous of all Cook Inlet ice to ships in winter. The complex dynamics of bluff erosion and ice-borne sediment transport will become even more difficult to forecast with sea level rise and a more erratic storm climate.

The history of coastal erosion studies in Alaska is one of isolated site-specific efforts aimed at design of erosion control works. Erosion control measures in place are mostly small expedient works that run the gamut of low-cost alternatives. Exceptions to this rule occur where protection of critical transportation justifies larger investments of State and federal funds. Erosion problems at rural locations, such as Kivalina and Shishmaref (Figure 7), are not associated with the same scale of tangible economic loss.

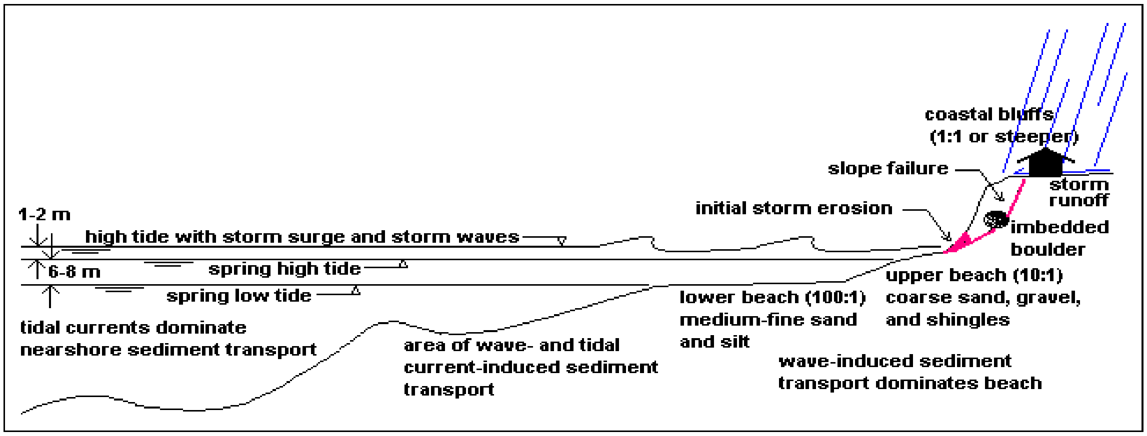


***Figure 8.*** *Diagram of bluff erosion of glacial deposits in macro-tidal Cook Inlet in southcentral Alaska. Storm waves initially undercut steep coastal bluffs. Combined with storm runoff, this triggers slope failure and erodes the coast farther inland.*

Through the Alaska Department of Transportation and Public Facilities, the State government relies a great deal on technical resources of the federal government, primarily the U.S. Army Corps of Engineers, to investigate coastal erosion concerns and to design erosion control measures. Other State agencies, such as the Department of Natural Resources, generally only involve themselves in erosion control problems from a regulatory versus a problem-solving perspective. The net effect is that severe constraints on federal appropriations for coastal erosion also apply to the State government and large-scale trends of coastal change in Alaska are poorly understood.

***Figure 9.*** *Photo of beach ice on a beach in upper Cook Inlet. Beach ice in macro-tidal zones of Alaska is a significant agent of sediment transport and hazard to navigation.*

## Marine Transportation Considerations

**Ocean Navigation.** Continuing trends of lesser ice extent and thickness (Smith and Lee 2001) will provide an opportunity for export of natural resources and other waterborne commerce over new northern shipping routes. Prospects for increased international trade through Alaskan waters via the Northern Sea Route along the Russia's northern coast will improve if Arctic Ocean ice conditions continue to become less severe. Few ice-breaking cargo ships exist with a capacity to make the distance advantage of the Northern Sea Route more profitable than use of larger ships through the Panama and Suez Canals or southern cape routes (Smith 1995). Ice-capable commercial cargo vessels specifically suited for Alaskan coastwise service have not been built. Marine transportation remains critical to Alaska's economy; so, early attention to these opportunities will save time and money getting valuable products to market.

**River Transportation.** Global warming is also changing Alaska's rivers as transportation routes, water sources, and habitats. Projected precipitation increases will induce higher stream flows and more flooding. Associated improvement of bridges and culverts may prove to be a particularly expensive impact of global warming. Erosion of thawing permafrost banks will accelerate with increased inundation, threatening hard-won infrastructure of rural Alaska river communities, such as Bethel and Noatak. River ice breakup may continue to occur earlier and be more difficult to predict in terms of ice jam flooding risks. Prediction and prevention of ice jam flooding in Alaska warrant further study. Conditions for commercial river navigation may improve for transport of minerals and bulk exports to tidewater. Since no State or federal agency is presently responsible for either charting or marking river channels, this prospect will be difficult to quantify. A program to survey river navigation routes would provide a baseline from which to monitor change and evaluate improvements for waterborne commerce.

## Design Criteria Development

Scientific research findings are only occasionally tailored to fit the practice of engineers in design criteria development and structural computations. Conventional historical extrapolations now appear to be incomplete bases for predicting future permafrost characteristics during a projected accelerating global warming trend. A non-linear trend and maxima and minima bounds for a naturally variable parameter are shown in Figure 10 as dashed lines. Linear extrapolation of any portion of this hypothetical time series will underestimate future means and extremes (Smith 2002).

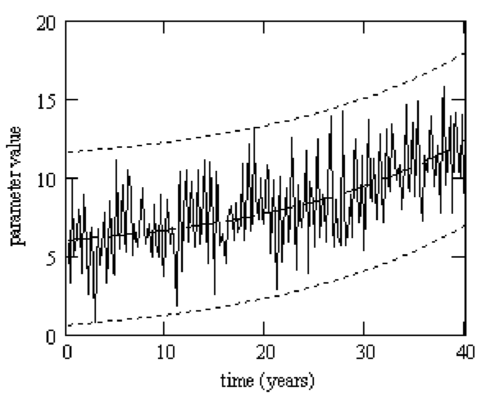


*Figure 10. Chart showing a hypothetical accelerated increase in the time series of a naturally variable parameter. Although the value of the parameter varies up and down considerably in the short run, in the long run the parameter trends upwards at an increasing rate.*

Decisions regarding new infrastructure on permafrost foundations are likely to be wiser if they consider accelerated warming, as predicted by global circulation models (GCM's), weighted by associated probabilities (Vinson and Bae, 2002). Design criteria that make use of projections of GCM's will better predict the full range of possible permafrost thawing rates and other climate change effects on infrastructure. A rational approach to development of design criteria using GCM results should be more affordable than applying an arbitrarily large factor of safety to conventional design criteria. Adaptation of conventional statistical analyses of trends and of extremes to apply GCM projections of accelerated change is a challenging topic for research and development. Once available, engineers may develop rational design criteria for future conditions with global warming.

**Data Access.** Data application doesn't automatically follow expansion of the archives. Storage and accessibility of engineering site data are improving, but more old data can be saved and new data must be measured. The World Wide Web provides means for quick access to modern GIS-based atlases of linked environmental databases, complete with common engineering computations. One such effort is the Alaska Engineering Design Information System (AEDIS), now in its first stage of development at the U.S. Army Cold Regions Research and Engineering Laboratory in cooperation with the University of Alaska. The AEDIS program will provide online information to replace outdated printed atlases of engineering information, but needs additional resources to achieve its goals.

## Conclusions and Recommendations

Environmental monitoring, though universally favored by researchers, is difficult to fund by infrastructure agencies whose budgets revolve around construction projects. A comprehensive monitoring program is warranted. Instituting a "one percent for monitoring" federal funding policy for large public works projects could finance a consolidated monitoring, data analysis, and dissemination program well within the confidence bounds of construction cost estimates and contract bids.

Alaska is the U.S. Arctic, where projected effects of global warming are most pronounced in the entire nation. The State will probably undergo expansive development in the 21st century as the world turns to the north for natural resources. Applied research and development of engineering methods to account for climate change are best tested in Alaska where the signal of global warming is strong and new applications will be economically and strategically crucial to America.

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Orson Smith received a B.S. in Mechanical Engineering in 1971 from the University of Kentucky, a graduate Diploma in Coastal Engineering and Port Planning in 1979 from the International Institute of Hydraulic and Environmental Engineering in Delft, the Netherlands, an M.S. in Civil Engineering in 1986 from Mississippi State University and a Ph.D. in Physical Oceanography in 1989 from North Carolina State University. He is a registered Professional Civil Engineer in the State of Alaska. Orson accumulated 20 years' experience with the U.S. Army Corps of Engineers as a Project Manager of dredging, hydrographic surveying, port, harbor, coastal erosion control, flood control, and other civil works projects, primarily in Alaska, but extending to coastal areas of the lower 48 and a number of overseas locations. He presently teaches undergraduate and graduate civil engineering courses and is Arctic Engineering Program Chair at the University of Alaska Anchorage, School of Engineering. Orson is now involved in several research projects related to sea ice, ice navigation, shoreline resources, and climate change in Alaska.

George Levasseur is a graduate of the University of Minnesota. He began his career with the Alaska DOT in 1974 and manages the maintenance and operations efforts for much of Southcentral Alaska. This area contains the geography in Alaska most affected by the warming trend. His greatest challenges are dealing with the melting permafrost on the highway and airport system and handling the bridge problems associated with the increase water flows and bedload deposition.