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May 7, 2005

Arden L. Bement, Jr., Director
National Science Foundation
4201 Wilson Boulevard
Arlington, Virginia 22230

Dear Mr. Bement:

Thank you for your letter of March 25, 2005 requesting the Denali Commission's assistance in identifying civil infrastructure goals in Alaska to guide the Interagency Arctic Research Policy Committee in their development of the next biennial revision of the United States Arctic Research Plan.

On April 26, 2005 the Commission convened a meeting of state, federal and other parties to identify civil infrastructure goals in Alaska. The agencies and other parties provided a wide array of research goals and methodologies that is assembled as an attachment to this letter.

As you are aware, the agencies working in Alaska on a day to day basis are presented with many challenges of developing civil infrastructure in the Arctic and I am hopeful that the research goals identified in the attached document will receive appropriate review and support.

Thank you for this opportunity and the Denali Commission looks forward to working with you and your agency to further the mutual goal of understanding the Arctic.

Sincerely,

Jeff Staser
Federal Co-Chair

Research Goals and Methodologies

1. Research Goal: Identification, Selection and Monitoring of Basic Indicators for Climate Change to Guide Alaska Community's Future Development

Submitted by: John Warren, Senior Consultant, Alaska Native Tribal Health Consortium

Communities in the circumpolar north will be impacted by climate change in the years to come, and this geographic area may see more pronounced changes than the rest of the world. Retreating sea ice has already had devastating impacts to some arctic coastal communities in the form of accelerated erosion of shore lines. Extreme weather events and thawing permafrost will also impact Arctic infrastructure in the future.

The issue of climate change has been addressed in a number of recent studies (IPCC, 1990). Many of these studies focused on global issues and did not specifically address impacts within the Arctic. One recent study, the Arctic Climate Impact Assessment (ACIA), focused on climate change impacts within the circumpolar north (ACIA, 2004). The study concluded that "[t]he Arctic is now experiencing some of the most rapid and severe climate change on Earth. Over the next 100 years, climate change is expected to accelerate, contributing to major physical, ecological, social, and economic changes, many of which have already begun." Some of the key findings of this study concluded:

- Arctic climate is now warming rapidly and much larger changes are projected.
- Arctic warming and its consequences have worldwide implications.
- Many coastal communities and facilities face increasing exposure to storms.
- Thawing ground will disrupt transportation, buildings, and other infrastructure.

The proposed research goal is to begin the identification, selection, and monitoring of some basic indicators for climate in order for communities to develop a proactive response to these changes. This information can support the community's capacity to know what changes are occurring, what changes are likely to take place in the future, and what impacts these changes may have.

Engineers and community planners must begin considering the potential impacts of climate change in their work and begin to develop approaches to address these challenges. Master plans should be developed or updated with respect to potential climate-induced changes. Engineers must consider aspects such as operational flexibility, infrastructure location, or foundation design to mitigate impacts or avoid disasters.

Proposed Methodologies:

1. Complete a study to evaluate potential climate change impacts to arctic infrastructure, identify communities which are most vulnerable, prioritize those communities that are in imminent danger and begin a monitoring program in the most vulnerable communities.
2. Develop engineering guidelines for basic design parameters. Presently designs are based on historic data such as flood magnitude and frequency, precipitation magnitude and frequency, wind and snow loads, erosion rates, permafrost, etc.

Many of these parameters are changing and will have detrimental affects on civil infrastructure.

3. Prepare or update community master plans to ensure federal funding is used in the most efficient manner for infrastructure improvements.

2. Research Goal: Increase in Wave Data and Ocean Climate
Submitted by: Bruce Sexauer, Plan Formulation Specialist, Alaska District U.S. Army Corp of Engineers

Need for Data:The most significant need for information felt by the Alaska District Corps relates to wave data and ocean climate, the best source being data collection buoys. The Corps coastal projects along the arctic shoreline have had to rely upon sporadic information to generate the predicted wave climate, thus generating a larger level of uncertainty than desired. Because of the uncertainty, projects are designed to handle a much higher range of wave climate than necessary. With an increased amount and more precise wave data, projects can be optimized to reduce the need for "over design" of breakwaters, jetties, and other hard structures typically utilized by the Corps. Better wave data will assist in the development of predictive models, thus aiding planning efforts for future development or protective measures.

Ongoing Corps of Engineers Studies: The Corps has a multitude of studies and projects underway throughout the state related to coastal erosion, Stream bank erosion, flood damage reduction, navigation, and small boat harbors. The Corps has started a statewide erosion assessment in partnership with the state, to identify, assess, and recommend appropriate solutions for erosion issues. The products will be an online database and a priority list of issues and/or projects that require attention.

3. Research Goal: Erosion and Flooding and Its Effect on Aviation Infrastructure
Submitted by: Charlene Derry, Federal Aviation Administration, Alaska District

Background: GAO Report (GAO-04-142), Alaska Native Villages, Most Are Affected by Flooding and Erosion, but Few Qualify Federal Assistance, noted "(A) typical coastal or river Native village has a population of a couple of hundred people and generally contains only basic infrastructure….Most of the villages that are not accessible by roads contain an airport runway that provides the only year-round access to the community. The runways are generally adjacent to the villages or a short distance away." The report contains examples of villages that are planning to relocate (in which case airport infrastructure may have to be re-created) or villages that are serviced by runways subject to flooding and/or risk of erosion. Additional details of the potential effects of erosion and flooding on aviation infrastructure in Alaska can be found on the World Wide Web at http://testimony.ost.dot.gov/test/pasttest/04test/Poe1.htm

Recommendation: Researchers conduction research on civil infrastructure in the Arctic should be cognizant of the importance of airport infrastructure (including the related instrument approaches) when designing studies or creating models that evaluate the potential effects of erosion and flooding on the communities. The FAA point of contact for inquiries is Charlene Derry, Federal Aviation Administration Liaison to the Denali Commission, FAA Alaskan Region, Tel: (907) 271-5534, FAX: (907) 271-3261, E-Mail: charlene.derry@faa.gov

4. Research Goal: Acquisition and Distribution of Arctic Civil Infrastructure Information

Submitted by: Charlene Derry, Federal Aviation Administration, Alaska District

Background: A wealth of information regarding civil infrastructure in the Arctic region has been developed in the past, from basic engineering research to best practices for construction to diffusion of technology. New challenges brought about by changing environmental conditions appear to increase the acquisition of new knowledge. Yet, researchers and other consumers of the information may not be aware of existing information or ongoing or planned research. This lack of awareness could cause duplication of research or foreclose consideration of plausible alternatives in designing and conducting research. Also, creation of infrastructure creates opportunities for additional applications and uses of the technology beyond that originally foreseen. These "lessons learned" need to be recorded and shared. For example, the Capstone/Automated Dependent Surveillance Broadcast airborne navigation system currently under development could make search and rescue efforts much more effective. Similarly the automated aviation weather information systems and weather cameras are finding applications beyond the civil aviation community. Information that could be developed and shared includes but is not limited to monitoring of the use existing and new technology to evaluate its effectiveness, recognize unforeseen uses, and suggest adaptation for future infrastructure development and deployment.

Recommendation: Explore the options for a timely and cost-effect acquisition, management, and distribution network for information on Arctic civil infrastructure research, practices, and outcomes.

5. Research Goal: Foundation System Development

Submitted by John Davies, Research Director, Cold Climate Hosing Research Center Research on Civil Infrastructure

Develop foundation systems that will accommodate expansive soils or melting permafrost. Engineering standards for construction of foundations in permafrost regions are based on research that is 30-40 years old and which assumes that the permafrost régime is stable. The likelihood that the permafrost may entirely melt over the design life of a building requires a new approach to designing foundations of all types in the Arctic. This is especially challenging for low-cost housing. Triodetic foundations are expensive and require that houses are elevated several feet above the ground exposing them to more wind load and requiring significant stairs for entry; we need to develop a low-cost, integrated foundation and heated crawl space or under-floor plenum, in which utilities, ducting, and piping may be located. Standards need to be developed for foundations on different soil types including melting permafrost, expansive soils, river silts, and tundra as examples.

6. Research Goal: Develop Standards Frost protected Shallow Foundations

Submitted by John Davies, Research Director, Cold Climate Hosing Research Center Research on Civil Infrastructure

Develop standards for the use of frost-protected shallow foundations (FPSF). These foundations require less materials and excavation and can therefore reduce the cost of a building by about 15%. Standard building codes provide guidance for the design of FPSF for regions with air freezing indexes of 4000 degree-days or less. These codes are based on limited research and don't apply to much of the Arctic where the air freezing indexes exceed 4000 degree-days. It is important to develop guidance both for the design of the FPSF and the soil types on which its use is appropriate.

7. Research Goal: Efficient, Durable and Health Arctic Housing
Submitted by John Davies, Research Director, Cold Climate Hosing Research Center Research on Civil Infrastructure

Develop more energy efficient, durable, and healthy housing that uses 50% of the energy of older housing and maximizes the use local materials and labor. If we can reduce the energy (both for heating and electrical use) by about half, we can impact the need for both bulk fuel storage and PCE and improve the local economies.

- Evaluate the economics of regional SIPs plants.
- Evaluate low-power, efficient ventilation systems.
- Demonstrate benefits of energy star lighting and appliances.
- Develop locally appropriate energy sources including wind, wood, small-scale hydro and PV.
- Evaluation of alternative energy strategies for rural housing.
- Demonstrate specific solutions.
- Develop integrated community infrastructure strategies that are sustainable. Elements of these strategies must include power, waste treatment, potable water, transportation, housing and communication systems that create local jobs, utilize local resources and are culturally and economically appropriate. Develop village-level strategies for energy self sufficiency (how to deal with power outages or heating system failures without freezing pipes).

8. Research Goal: Develop Efficient and Safe Potable Water Systems in Rural Communities
Submitted by John Davies, Research Director, Cold Climate Hosing Research Center Research on Civil Infrastructure

Develop new and sustainable options for wastewater treatment in rural communities. We need to explore the options for water treatment systems on the scale of 1 to 4 units that include at least gray water reuse.
Evaluation of existing sewer system strategies and local options
Demonstrations of new systems for waste treatment in rural communities.

9. Research Goal: Health of Arctic Residents and Civil Infrastructure
Submitted by John Davies, Research Director, Cold Climate Hosing Research Center Research on Civil Infrastructure

Develop village transportation, power production, and housing options that reduce the incidence of asthma and other upper respiratory disease. Asthma is nearing epidemic proportions in rural Alaska (as well as much of the Nation). We know that it is a multifactorial disease the causes of which probably include tobacco smoke, wildfire and woodstove smoke, particulates from road dust and power production, as well as many particulate and organic compounds generated inside of homes. CCHRC was the project manager for a HUD and AHFC funded study of ways to mitigate housing-induced asthma. We found that we could augment the usual weatherization protocol to improve the indoor air quality and consequently the health of those living in the targeted housing. We have also funded a project that demonstrated cost-effective techniques for filtering outside air that contains hazardous levels of particulates from wildfires so that the inside air was much safer to breath. These finding need strengthening and cost-effective technologies need to be developed to implement them.

- Evaluate the production of particulate mater and VOCs from existing roads, power plants, and homes as well as sources such as wild fires and dust storms.
- Demonstrate cost-effective strategies to reduce or filter harmful emissions.
- Explore the economics and emissions of clean-burning wood stoves and masonry heaters. These can be cleaner than oil-fired plants, and use local wood products.

10. Research Goal: Research Infrastructure Facility
Submitted by John Davies, Research Director, Cold Climate Hosing Research Center Research on Civil Infrastructure

There is a need in Alaska for a facility in which to conduct research and testing of building-related materials, equipment, products, systems, and infrastructure. This need has been recognized by the Alaska State Home Building Association, Cold Climate Housing Research Center, Alaska Delegation in Congress, University of Alaska, State of Alaska, US Dept. of Agriculture- Rural Development, Golden Valley Electric Association, and many other public and private partners who have committed funds, materials, or other in-kind support to building a Cold Climate Building and Infrastructure Research and Testing Facility. This research and testing facility (RTF) will be built and operated by the CCHRC and located on the campus of UAF. It will be an important venue in which to advance many of the above research goals, educate the next generation of arctic engineers, and transfer new technology to the marketplace. Appropriate research, testing and demonstration projects of the various federal agencies should help develop, partner with, and make use of this facility.

11. Research Goal: "Polar Models of Excellence"
Submitted by John Doyle, President, 64th Parallel International LLC

This project is an inquiry into "who does what best" in high-latitude and -altitude civil infrastructure and related matters. Not an engineering science or research project *per se*, "Polar Models" is an international compilation of knowledge about successful models, technologies, methodologies, standards, data and information. Known gaps in U.S. data, information or knowledge might be targeted in certain economic and professional sectors.

The project's timelines and costs would be minimal compared to the potential benefits listed below. During approximately two years, a small team would design and implement "Polar Models." Each sector would be managed by an appropriate lead investigator.

Results would include electronic databases containing model summaries, contact information, implementation recommendations, bibliographies, graphics, legal parameter summaries, etc. Results would also include selected linguistic translations and suggestions for institutional and/or cultural adaptation. A website would be developed and users would be encouraged to supply updates to enhance the effort's value over time.

"Polar Models" would help people trying to address increasing rates of change in the Arctic: engineers, policy makers, scientists, researchers, contractors, holders of intellectual property, indigenous peoples and others. Benefits would include:

- Savings in time, money, energy and materials in the development of more sustainable Arctic civil infrastructure;
- Simple, cross-sectoral and dynamic databases;
- Single locus summary data, information and knowledge of specific, proven and "state of the art" models—as well as unsuccessful models;
- Promotion of learning across disciplines and shortened R&D timelines for emerging ideas;
- Strengthened international, institutional and professional relationships and networks; and
- Improved survivability and economic synergies for remote Alaskans and others.

12. Research Goal: Multiple Goals Presented by Cold Regions Research and Engineering Laboratory

Submitted by: Dr. Jon Zufelt, Research Civil Engineer, US Army Engineer Research and Development Center, Cold Regions Research and Engineering Laboratory, Anchorage, Alaska and Peter Smallidge, Project Engineer, US Army Engineer Research and Development Center, Cold Regions Research and Engineering Laboratory, Hanover New Hampshire

It is important to continue efforts to contend with the effects of climate change, particularly as it impacts Arctic and Alaskan infrastructure. The effects of infrastructure problems on human life in the Arctic have been well documented in reports such as the recent "Arctic Climate Impacts Assessment", an international project of the Arctic Council and the International Arctic Science Committee (IASC). Strong support of infrastructure engineering research in the Arctic and Alaska in particular is needed to address problems with destabilization of structures by changes in permafrost, changes in coastal communities caused by changing in sea conditions and in the frequency and strength of storm induced wave action. The US Army Engineer Research and Development Center (ERDC) laboratories and their predecessor Corps of Engineer organizations have a long history of supporting infrastructure R&D in Alaska ranging from applying lessons learned from construction of the Alaska Highway in World War II to supporting construction of the Trans-Alaska oil pipeline and recent construction of missile defense facilities at Fort Greely. The ERDC laboratories also have been heavily involved in support of environmental remediation efforts and coastal process research in Alaska.

Key to the success of these efforts has been the laboratories' collaboration with other DOD, Federal, state agencies, academia and industry in Alaska, especially the Corps' Alaska District and the University of Alaska in Anchorage and Fairbanks. The ERDC's Cold Regions Research and Engineering Laboratory (CRREL) has offices in Anchorage and Fairbanks as well as Hanover, New Hampshire that interact regularly with other agencies in Alaska. CRREL is recognized around the world as an international center of expertise in Arctic engineering. CRREL and its sister ERDC laboratories in Vicksburg, Mississippi, Alexandria, Virginia, and Champaign, Illinois also have very strong ties to world-wide cold regions and related infrastructure engineering resources that can be leveraged to address these challenges in Alaska.

Specific ERDC research initiatives, proposals, and programs that contribute to improving civil infrastructure in Alaska include:

- **<u>Coastal Processes Impacting Infrastructure</u>**
  - **Arctic climate change effects on coastal storm surge and wave conditions.** Western and northern coasts of Alaska are experiencing a decrease in winter sea ice cover and later development of ice cover in early winter when severe storms can occur. Exposure of coastal infrastructure and communities to storm surge and wave damage is increasing. There is a need to more accurately quantify wind driven storm surge and wave generation in waters with partial ice cover, and need for research to determine how surge and wave generation varies with changing degrees of ice cover. Research is needed to investigate how the coastal surge and wave climate will change as the trend for decreasing ice cover continues. Is the frequency and severity of storms changing with the warming trend, or is the increased open water fetch the major problem? The former issue compounds the problem.
  - **Quantifying coastal beach and bluff erosion and sedimentation rates.** As this trend for decreasing ice cover continues, and storm surge and wave conditions increase, the following symptoms will worsen: 1) Fine-grained, ice-rich permafrost soils along shores, and in bluffs, are especially susceptible to erosion as the depth to permafrost increases and exposure to storm wave energy increases, 2) Granular (sand and gravel) beaches will experience increased erosion (many Native Alaskan villages are situated right on the coast just landward of these beaches, 3) Sedimentation of coastal harbors and channels, which is driven by episodic storm events, will increase as will maintenance dredging costs. There is also a need for research and better design tools to describe sediment erosion and transport in regions characterized by bluffs and gravel beaches. Do theories and beach fill design methods developed for sand beaches apply to the types of coastline that are typically found in Alaska?
  - **Arctic climate change effects on coastal structures.** Existing coastal structures were designed for an assumed wave level and wave exposure. In areas where the sea is ice-covered for a portion of the year, risk of wave damage is reduced. However, if climate trends indicate longer seasons of open-water exposure, waves larger than expected may damage the structures. Similarly, a rise in sea level will allow larger waves to impact the structures, and wave overtopping will become excessive. Research is needed to quantify expected changes in the environmental forcing and evaluate existing (and planned) coastal structures for potential vulnerability. Design life expectancy of coastal structures and risk of damage should be re-examined.
  - **Ice effects on coastal projects.** Previous efforts have initiated research into understanding how ice, ice breakup, and freeze/thaw cycles affect coastal projects. Generally, special provisions must be taken to assure revetments, breakwaters, and gravel beach fills can survive more than one season without significant damage. With better understanding of the

interaction of ice and coastal structures, better projects could be designed and constructed with higher reliability and optimized cost.

  - **Design guidance for coastal engineering in arctic zones.** The Corps of Engineers has compiled state-of-the-art design guidance for coastal engineering into the widely-accepted Coastal Engineering Manual. Unfortunately, little coverage is given to the unique problems facing coastal engineering projects in the arctic. Experience gained in numerous projects sited in cold regions has been published in various forums, but no effort has been made to draw all the hard-earned information and design guidance into a single reference volume to assist coastal engineers faced with designing coastal projects in this harsh environment. A new manual focused on cold-weather coastal engineering is needed.
  - **Hydrodynamic, meteorological, and beach/bluff characterization and response measurements.** Measuring hydrodynamic parameters for use in validating wave and storm surge hindcasts, establishing design wave heights at project sites, and quantifying river and stream flows are challenging in the arctic environment, as is characterizing the response of beaches and bluffs to coastal storms. New techniques, instrumentation, and deployment tactics would greatly augment many of the tasks related to the arctic research initiative.

- **<u>Design and Construction in the Arctic</u>**
  - **Building design criteria.** Agencies that establish design criteria for strategic facilities are considering revising these standards to increase consideration of snow and other environmental loads on seismic designs of buildings. If not applied rationally, these proposed changes to seismic design criteria for critical DOD facilities in Alaska could significantly increase construction costs.
  - **Changes in permafrost regimes.** Roads, airfields, buildings, and pipelines founded on permafrost are at risk of damage when the ground warms or thaws. Roads and foundations that were designed twenty or more years ago may be at risk. Permafrost degradation causes frozen ground to lose its strength, with consequences ranging from a reduced service life to outright structural failure. The thawing of ice-rich permafrost produces irregular settlement and slope instabilities that permanently alter the terrain and have catastrophic consequences on the infrastructure. The issue of permafrost degradation impacts virtually all elements of the existing infrastructure and future Arctic building programs. Since ecosystems are dramatically altered and wetlands are frequently created by such changes in the thermal regime, permafrost degradation also impacts land use policy and management practices on military installations in Alaska. A reliable methodology for evaluating the rate and extent of permafrost degradation and quantifying the resulting damage to the northern infrastructure should be developed. This will require an understanding of the factors affecting permafrost degradation, an ability to predict the state of the ground under various climate scenarios, and an understanding of the fate of engineered structures subjected to permafrost degradation.

- **Shallow Insulated Foundations in Cold Regions** A Shallow Insulated Foundation (SIF) design allows a building's foundation footing to be placed at a much shallower depth by incorporating the use of strategically placed insulation around the foundation. This frequently is a good design alternative in areas of high groundwater and other geotechnical problems and has the potential to save on building material and construction costs. The insulation utilizes heat from the building and surrounding soil, redirects it to the area around the foundation, and thus reduces the frost penetration. While current accepted design guidance is focused on temperate cold regions, the SIF concept has been demonstrated in Galena, Alaska by CRREL. Criteria should be adapted and extended for acceptance and use in more regions in Alaska.

- **Super Durable Concrete** The number one problem of concrete in cold climates is deterioration caused by freezing and thawing. During the development of advanced cold weather concrete technology at CRREL, it was discovered that admixtures can greatly enhance the freeze-thaw durability of concrete. The need exists to exploit the potential role of chemicals to enhance to service life of concrete on cold regions. It is expected that the life of concrete exposed to freezing and thawing can be extended by at least 30%. Applications include highway pavements and bridges, dams, and port and harbor structures.

- **Ice roads for resource exploration** Ice roads are an accepted method for access where gravel roads are lacking or environmental concerns preclude construction of standard design temporary or permanent roads for resource exploration. Changes (decreases) in snow cover distribution and timing is affecting permitted off-road travel on the North Slope of Alaska. This can have large adverse impacts on oil exploration and development as the winter season is shortened. Additional studies are needed to confirm how much snowcover and what depth of frozen ground is needed to support off-road travel for exploration and oilfield development without adverse environmental impact. Other research on ice road construction is needed to assess the volume, rate, location and methods of withdrawal from river and lake systems to avoid adverse impacts on over-wintering fish.

- **Utilities services for rural villages** Utilities delivery in rural arctic communities is most often accomplished via trucked systems or above ground piping systems. These systems are not always acceptable or sufficient. Many diverse designs have been installed with varied success but no accepted standard design process has emerged. The primary reason that aqueous utility pipes are not placed in thaw sensitive permafrost soils is the inability to design a conservative solution that will both maintain foundation stability and prevent freezing of the pipe contents. In order for buried utilities to be considered as an alternative an accepted standard design procedure must be developed. The overarching considerations for the development of such a standard must be low maintenance and low energy requirements and must address the rural culture and constructability issues.

- **Application of Geographic Information Systems (GIS) Techniques to Rural Village Infrastructure Planning and Design** The USACE Remote Sensing/GIS Center at CRREL provides assistance to a variety of civil and military agencies, helping them maximize the benefits from new and emerging remote sensing and GIS technologies. These developing technologies are typically used to measure and monitor environmental conditions over land and water surfaces and often serve as decision support systems. The Center applies a wide range of automated geospatial data technologies to perform operational activities and support military base planning and environmental monitoring. Deficiencies exist with systems not meeting the full range of customer needs including: linkages to operational models; applications specific to Corps' missions; and, full integration of the related geospatial data technologies including GPS, remote sensing, CADD, and GIS. Development of spatial data management tools and linkages is vital to enabling these customers to effectively operate and manage their facilities and bases. These systems are frequently designed for interaction with the public and can be used to record lessons learned and accept other input from users. This technology is directly applicable to the challenges faced by rural villages as they plan, design and operate their infrastructure. Potential applications include identification of village and other environmental changes in response to adjustments in traditional hunting/gathering patterns and movement to other village activities. Climate change will potentially further affect this along with village growth and changes in local transportation methods. Also, satellite data has been used to identify tundra lakes that do not completely freeze during the winter; a potential water source identification application. We have also seen information describing changes over time of tundra lake areas; evidence of the permafrost thawing and tundra lakes draining or filling.

- **Climate Change Impacts on Infrastructure**

  - **River corridors.** Many of Alaska's villages and much of its infrastructure is located within river corridors. Climate change is altering the hydrology and sediment yield of the streams in the region. As the streams adjust to these changes, they are susceptible to dramatic transformations in morphology that include increased bank and bed erosion, channel avulsions, and flooding that threatens communities, roads, bridges, pipeline crossings and habitat. Improved capabilities are needed to predict, quantify, avoid and mitigate these impacts.
  - **Effects on contaminant processes and pathways.** Climate change alters the physical and hydrologic characteristics of the upper soil horizon. This, in turn, affects the chemical processes and pathways associated with contaminants such as PCBs, heavy metals, and petroleum products. Research is needed to quantify the impact of climate change on contaminant vectors and risks, and to assess different adaptation strategies for remediation.
  - **Ecological resources.** The effects of climate change on ecological resources are many and widespread. For example, increased water temperatures and altered timing of runoff as well as reductions in the availability, connectivity or extent of important freshwater habitats, in combination with altered nutrient conditions in the northeast Pacific, could jeopardize ecologically and economically important salmon populations. Little is known about the combined and cumulative effects of these stressors, and successful management of future salmon stocks is

contingent upon our understanding of the interrelations within these ecosystems.

- **Quantifying sediment load associated with spring snow melt and glacial run-off**. The amount of maintenance dredging required each year at navigation projects is linked to the quantity of sediment carried by streams and rivers during spring snow melt and during summer as glaciers melt. Presently it is impossible to predict (and budget for) the amount of dredging expected each year because the relationship between run-off and sediment load in glacial rivers is unknown. With increasing rates of melting of glaciers as climate warms, the contribution from glacial sources will continue to increase. Substantial cost savings could be realized if reliable dredging quantity estimates could be forecast based on analyses of the relationship between glacial runoff and sediment yield at active glaciers and on observed winter snowfall and measurements of spring run-off.
- **Quantifying sediment load derived from mud flats.** Alaska estuaries are characterized by extensive mud flats that contribute fine-grained sediment to the tidal flow. Some of the suspended sediment is deposited in maintained navigation channels. In addition to the usual re-suspension mechanisms, an unknown amount of sediment is mobilized by freeze/thaw cycles and direct effects of ice melting and breakup. In addition as climate warms, sea level is rising and current research suggests this is increasing erosion by tidal currents, thereby increasing rates of sediment input to marine environment. Research is needed to quantify both the influence of ice and freeze/thaw on the seasonal amount of fine sediment mobilization and on the effects of sea level rise on erosion and expansion of tidal flats.
- **Outburst flooding and other impacts of increased melt of glaciers and icefields as climate warms.** Glaciers and icefields across Alaska are thinning and receding as the climate continues to warm. This increase in melt results in increased discharge of water and sediment to rivers, with potential downstream impacts including increased bank erosion and bed scour that in turn will lead to loss of land and structures, including bridge piers, pipeline crossings and other structures within the floodplain. Further, retreat of glacial margins from end moraines commonly exposes overdeepened basins behind them that then fill with meltwater, forming a lake. The end moraines that now dam these new lakes may be ice-cored, highly unstable and subject to erosion and scour by streams flowing out of the lake. Both the ice core and sediment instability may result in catastrophic outburst floods, with severe downstream consequences for towns and villages. Because these lakes have formed since these remote regions were last mapped in the 1950's to 1970's, their existence is often unknown. Investigations are needed to identify moraine-dammed lakes, assess the potential for the catastrophic failure of the morainal dams and determine the consequences of flooding to downstream infrastructure and human life. Methods to monitor glacial lakes with potential for flood generation must also be identified and systems for remote, near real-time warning systems implemented where clear danger of outbursts are identified.

- **<u>Environmental Quality</u>**

- **Site Characterization and Assessment.** A sustainable military with a reduced environmental footprint requires improved effectiveness of site characterization and assessment of energetics, chemical, and biological contaminants, particularly in complex environments such as Alaska. This is especially true when there is a highly heterogeneous distribution of contaminants with unknown size distributions that may experience significant impacts from freeze-thaw and snow processes in the form of transport and changes in state. We need to develop methods, procedures and protocols to assess and characterize human impacts on military and public lands impacted by snow and freezing and thawing.
- **Remediation Processes.** Knowledge is limited in regions such as Alaska that are dominated by seasonal ground state dynamics, and where ecosystems are already stressed by other factors. Dynamic conditions in surface soil (e.g., temperature, moisture, carbon) that have seasonal, diurnal, and episodic changes that impact surface and near surface contaminant transport, biomimitic sensors, and nanosensors. We need to develop and match plant-microbial-soil driven processes to address remediation in, and sustainable use of, ranges and public lands in regions dominated by seasonal ground state dynamics.