A Preliminary Assessment of the Effects and Key Impacts of Global Climate Change on Water Infrastructure Systems in Alaska

By Andrea Sternberg

A degree project submitted in partial fulfillment of the
requirements for the degree of

Master of Public Administration

University of Washington
Daniel J. Evans School of Public Affairs

2007

Approved by:

Daniel Carlson, University of Washington

Preface

This report was undertaken by Andrea Sternberg in fulfillment of the degree project requirement for her Masters of Public Administration at the Daniel J. Evans School of Public Affairs, the University of Washington at the request of the Environmental Protection Agency (EPA) Region 10.

Acknowledgements

I would like to thank Dan Carlson, the Environmental Clinic Advisor and Chris Castner, my EPA Region 10 contact for their assistance and guidance. Their patience, encouragement, and enthusiasm proved invaluable.

I would also like to thank the people who I contacted in Alaska for their time and insights into their communities water system operations, maintenance and construction.

Lastly – Malia, Wendy, Tim, and Becky – your friendship, kind words of support and the occasional trip to the pub made all the difference.

Table of Contents

List of Figures and Tables

Figures

Tables

Executive Summary

Sponsored by the Environmental Protection Agency (EPA) Region 10, this report offers a preliminary assessment of the effects and key impacts of global climate change on water infrastructure operations, maintenance and construction in Alaska in the next 20 to 50 years. According to a preliminary report to the Alaska Legislature dated March 1, 2007 by the Alaska Climate Impact Assessment Commission, "current science and climatology indicate that Alaska is a bellwether for climate change in the United States".

The challenge for many decision makers is to translate climate change predictions from scientific numbers and trends to their impact on policies and structures. Thus, this report is designed to function as a health check-up, to ensure policy-makers are indeed aware of risk factors and the potential impacts of climate change to water infrastructure systems in Alaska. Through a literature review, case studies of publicly owned treatment works (POTWs) and semi-structured interviews of water system managers and planners, the effects and key challenges posed by climate change to Alaska's water infrastructure system were identified.

Climate change has very specific and pronounced impacts for Alaska, many which have already begun to be noticed. Such effects include:

- Permafrost thawing
- Melting sea ice
- Seal level rise
- Receding glaciers
- Shortened snow season
- Changing precipitation levels and frequency

These climate impacts are anticipated to have varying and potentially devastating effects on Alaska's water infrastructure universe. In Alaska, a wide diversity in system and services of water supply and disposal facilities exists, depending upon water source, treatment, distribution and disposal method used. Key findings include:

- Infrastructure systems in Alaska are designed to function in weather extremes;
- The capacity of a community plays an important role in their ability to receive and react to information and weather extremes;
- Uncertainties involved with climate change make it difficult for many communities to plan accordingly;
- There is a need to downscale global and even regional forecasts;
- Climate change impacts will vary geographically in Alaska, however, thawing permafrost, lack of snow cover and increases in erosion (from storms on unfrozen seas and river run-off) are the biggest challenges;
- How climate change impacts industry and community livelihood is an important indirect concern to water infrastructure operations;
- Climate change impact projections are not widely used in water infrastructure planning decisions as most water managers/planners are often more concerned about how to respond to the crises of today.

A risk matrix was created to make more explicit the key risk factors of water infrastructure in selected Alaskan communities to climate change impacts. These risk factors for individual municipalities included:

- Presence of thawing permafrost;
- Community location;
- Water system source;
- Adaptive capacity;
- Type of infrastructure.

As the EPA begins to acknowledge the importance of climate change and plan for its implications on water infrastructure maintenance, operations and construction in Alaska, the report concludes with these recommendations:

- Support an integrated look at climate change;
- Form partnerships with other ongoing climate change efforts to keep abreast of new research results;
- Develop a system-wide data base summary of the water infrastructure systems in Alaska;
- Include potential impacts from climate change in land-use planning and infrastructure design;
- Build upon preliminary risk assessment, using risk factors to assess climate change water infrastructure vulnerability in other communities;
- Foster local knowledge and the monitoring of local conditions, as well as the downsizing of global and regional forecasting efforts;
- Encourage information exchange amongst local/state/federal agencies, researchers, planners, and water infrastructure managers/operators;
- Focus on climate changes that are likely to occur in the next 10-20 years.

Introduction

A. Project Overview

This report offers a preliminary assessment for the Environmental Protection Agency (EPA) Region 10 of the effects and key impacts of global climate change on water infrastructure operations, maintenance and construction in Alaska in the next 10 to 30 years.[1] It aims to provide EPA Region 10 with policy recommendations regarding possible considerations, policies and strategies to effectively plan for climate change's impacts. Included is a framework for EPA Region 10, as well as state and local decision-makers for assessing climate change vulnerabilities. It is designed to function as a health check up, to ensure policy-makers are indeed aware of risk factors and the potential impacts of climate change to water infrastructure systems in Alaska.

The challenge for many decision makers is translating climate change predictions from scientific numbers and trends to their impact on policies and actions. According to the 2007 Intergovernmental Panel on Climate Change (IPCC) policy recommendations, warming of the climate system is unequivocal (IPCC 2007). Climate change impacts, such as warmer temperatures, increased rainfall/flooding events, changes in annual precipitation, shorter snow seasons, thawing permafrost and rising sea levels are already being felt in Alaska and could significantly affect water resources and water infrastructure operations.[2]

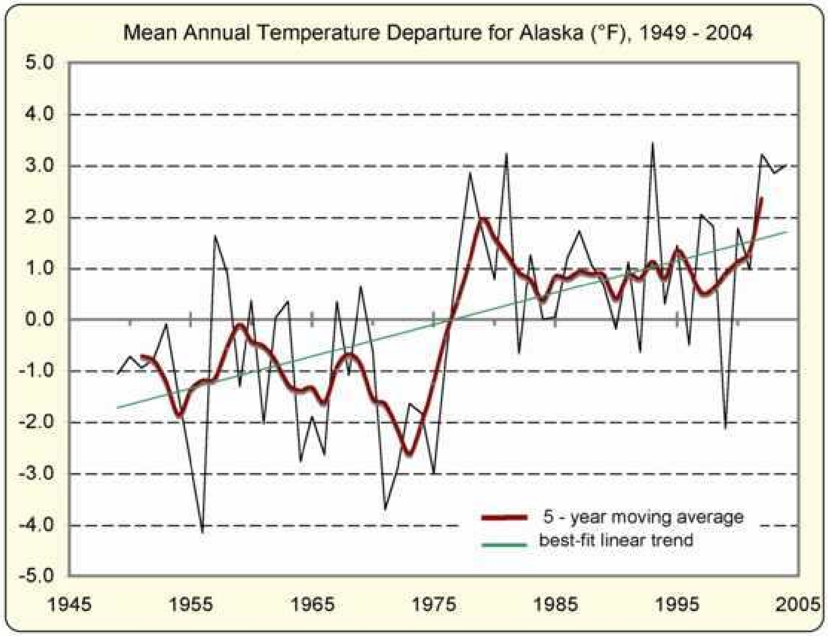


Figure 1: UAF, Geophysical Institute 2006

The effectiveness Alaska's water infrastructure will be determined under future climate conditions that differ significantly than those of the past century. In the past 100 years, average Artic temperatures have increased at almost twice the rate of global temperatures (IPCC, 2007). Alaska has seen its climate warm on average 4°F since the 1950s, while the interior of the state has experienced an average warming in the winter of 7°F (Parson, 2000). The figure below, from the University of Alaska-Fairbanks identifies the total change in mean annual temperature for individual towns and cities in Alaska. Identifying and including climate-related risk factors in planning schemes

---

[1] This report focuses on drinking water systems and waste water systems and does not address infrastructure related to projects for irrigation, flood control, power supply or recreation.

[2] This report will focus mainly on water infrastructure operations, addressing climate change impacts as they relate to water resources only as they are expected to affect infrastructure operations.

will help decision-makers prepare now for the effects of climate change and to guide resources to where they will have the most benefit.

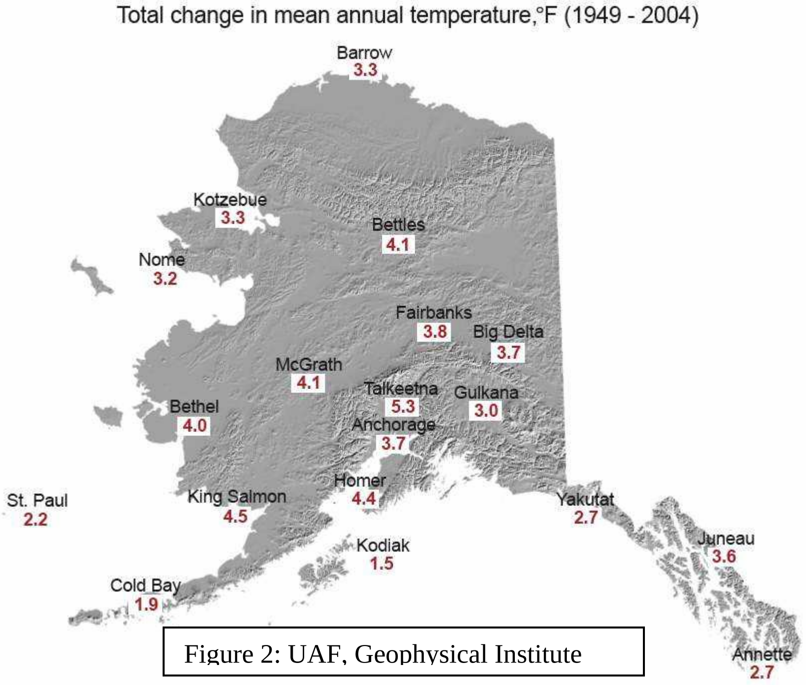


Figure 2: UAF, Geophysical Institute

Much of Alaska's infrastructure was designed in the 60s-70s before any realization of global change had occurred in the engineering psych (Goering, 2005). It is pertinent to look at the climate change impacts of wastewater and drinking water systems, because they typically have long lifetimes, significant capital costs, and design characteristics that are directly tied to location and hydroclimatological characteristics. There is a wide range of systems and services in water supply and disposal facilities. Furthermore, the potential results of climate change on water infrastructure systems in Alaska will vary depending on location, populations served, infrastructure type, water source and economic capacity of locality.

Although the effects of climate change involve a degree of uncertainty, the ability to predict climate change trends has improved significantly through a wider assortment of measurements, broader geographical coverage, and improvements in and quantity of data collection. “Downscaling” of global effects to the local level has also begun, leading to further confidence in regional-scale features and modeling.

In many ways, Alaska is the canary in the climate change coalmine. According to a preliminary report to the Alaskan Legislature dated March 1, 2007 by the Alaska Climate Impact Assessment Commission (ACIAC)[3] “current science and climatology indicate that Alaska is a bellwether for climate change in the United States” (Alaska ACIAC, 2007). Although the impacts and stresses of climate warming faced by Alaska may be more intense and more immediate, they are an indication of the types of climate related planning issues the rest of the lower 48 states may face in the future. Understanding these impacts and costs begins with an introduction to Alaska and identification of its water supply and disposal universe given in Chapter 3. Chapter 4 discusses the history of federal involvement in the regulation and funding of water infrastructure. Chapter 5 and 6 provide an overview to climate change and potential impacts on Alaskan water infrastructure, while Chapter 7 examines potential frameworks for addressing climate change risk management. Chapter 8 and 9 discuss the report’s findings, while Chapter 10 presents policy recommendations to EPA-Region 10 for action steps to address the effects of climate change on Alaska’s water infrastructure systems.

---

[3] The goals of this Commission are located in Appendix C.

II. Research Methods

Three main research methods were used to identify the risks and challenges posed by climate change to Alaska's water infrastructure system.

- Literature Review
- Case studies of Publicly Owned Treatment Works
- Semi-structured interviews of Water System Managers and Planners

A. Literature Review

The purpose of the literature review was to identify the most recent scientifically forecasted climate change trends and their consequences in Alaska. Additionally, the literature review was used to explore how other jurisdictions are using climate change projections to make planning decisions, as well as to investigate potential frameworks for climate change risk management.

B. Case Studies of Publicly Owned Treatment Works (POTW)

A summary of the drinking and waste water systems universe was established by collecting information from the Alaskan Community Database and other sources. "Case studies" were then selected and highlighted based on their potential to be impacted by climate change.

C. Semi-structured Interviews

The purpose of the semi-structured interviews was to gain insight in to[4]:

- Whether water managers use climate forecasts in actual infrastructure related decision-making?
- How could forecast information be tailored to water management/operations?
- What do water managers see as the biggest climate related threats to water infrastructure in Alaska?
- How much climate related change can their water infrastructure absorb?
- Are these impacts preventable, can the systems adapt, or will replacement be necessary?

Interview participants were either managers of or planners for water infrastructure systems. They were initially contacted via email. Although some chose to respond via email due to time constraints, the majority of interviews were conducted over the telephone. A complete list of those interviewed is located in Appendix A.

Localities were chosen for diversity based upon:

- Population served (the top ten largest municipalities were contacted)
- Location (coast, northern, and island communities)
- Water source (surface water type – lake or river and aquifer)
- Water treatment type (lagoon or treatment facility)

---

[4] A list of these questions is located in Appendix B.

The following 20 communities were contacted (15 completed interviews):

- Anchorage
- Barrow
- Bethel
- Dillingham
- Fairbanks
- Homer
- Juneau
- Ketchikan
- Kenai
- Kodiak
- Kotzebue
- Nome
- Palmer
- Petersburg
- Sitka
- Seward
- Togaik
- Unalaska
- Valdez
- Wasilla

Figure 3: National Geographic – Map of Alaska with major communities.

The literature review, POTW case studies, and the semi-structured interview responses were used to determine and evaluate the effects and key impacts of climate change on Alaska infrastructure operations, maintenance and construction in Alaska. These results led to the identification of high, medium and low risk (with regards to the effects of climate change) communities, as well as recommendations to EPA Region 10 for the effective development of policies and strategies to address the impact of climate change.

D. Research Limitations

There are several limitations to consider when interpreting the results of this research

- Lack of system wide water infrastructure database
- Lack of specific local information related to climate change
- Uncertainty involved with climate change
- Mitigation effects

Lack of System-wide Water Infrastructure Database

Although the state of Alaska's Department of Commerce and Economic Development has an online searchable Community Database, there is no central depository that compiles important water infrastructure information by location. Such system-wide data would be quite helpful to understanding the complete picture facing Alaska's water infrastructure system in the face of climate change.

Lack of Specific Local Information Related to Climate Change

Much climate modeling has been concerned with global trends. While pertinent, downscaling of these climate models to local regions is more useful to policy makers and planners. Many global models have outcomes that are too broad to be of use for local planning adaptation options (Jones, 2001). Due to particular characteristics of a given region (such as being in a bay/sound or affected by the Japanese current) and complex climatalogical interactions, climate change often results in different regional and location specific effects. For example, many global warming forecasts the coast of Alaska is expected to be wetter in the future, while inland is expected to be drier (Artic Climate Impact Assessment (ACIA), 2004). For some systems climate change could be a net benefit, while for others its impacts may have serious cost ramifications. Unfortunately, much of this "down-scaling" research and modeling has yet to be completed. Temperature and precipitation variability is larger at the regional level than the global level, making it more difficult to discern causal trends.

Uncertainty Involved with Climate Change

The effects of climate change inherently involve a degree of uncertainty. It is true that our ability to predict climate change trends has improved significantly through a wider assortment of measurements, broader geographical coverage, and improvements in and quantity of data collection, however many uncertainties still abound. Although it is generally agreed upon today that climate change is occurring, scientists are still in disagreement over the magnitude and timing of change that should be expected. Additionally, it remains unclear to what extent feedback loops (such as the ice-albedo feedback) will be of importance in perpetuating the climate warming cycle. For example, in the 1980s the Artic changed from being a carbon sink (due mainly to the presence of permafrost) to a carbon source due to regional warming (Hengeveld, 2002). Future warming is expected to enhance this cycle, but what impact the increased releases of carbon will have is yet to be clearly understood.

Although many research centers have been studying climate change effects for a number of years, prior to the establishment of the Alaska Climate Impact Assessment Commission in 2006, the State of Alaska had only one public employee working on the impacts of climate change in Alaska (LR 49, 2007).

Furthermore, there is the risk of abrupt climate change. While climate scenarios typically assume gradual change, the earth's climate is not a linear system. Non-linear or abrupt changes would have an even more profound impact on Alaska than current linear models suggest. Different developmental pathways impact the magnitude and timing of predicted climate change.

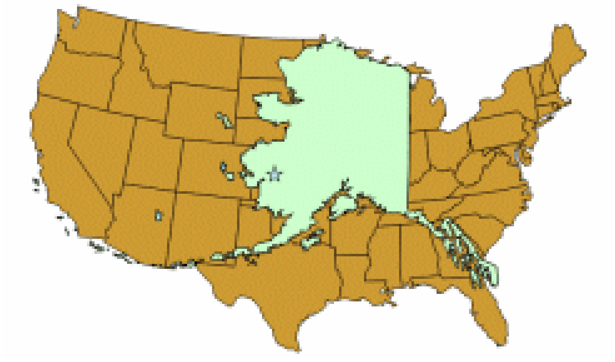
Mitigation Effects

Although some mitigation and adaptation actions are occurring now, estimates show that because of past emissions some degree of warming is unavoidable. Although many options for mitigation and adaptation are currently available (ranging from the technological, to the behavioral, managerial, to policy), it remains to be seen if they are politically, institutionally, and economically viable. According to the IPCC, there are barriers, limits and costs that remain to adaptation/mitigation strategies that are not fully understood due to specific geographical and climate risk factors (IPCC, 2007).

III. Alaska Overview

The state of Alaska covers 586,412 square miles, which is equal to 1/3 of the continental United States. It is a vast land and for the most part sparsely populated. Extreme distances, often road-less, harsh climate extremes, and the broad expanses of permafrost limit where people are able to live, making economic development at times difficult and expensive (ISER, 2006).

Figure 4: Size Comparison – Alaska and the Continental United States



Alaska is currently 48th in population size, with just under 627,000 inhabitants and is growing at about 1% per year. More than 40% of Alaska's residents reside in Anchorage. When the surrounding boroughs of Mat-Su and Kenai Peninsula are included, this percentage rises to 61%. About 10% of Alaska's population lives in small remote communities around the state, mostly along coastlines or on rivers.

Life in remote Alaskan communities has improved in the past 30 years ago, with the construction of new housing, local health clinics, and public infrastructure (water and sewer systems) in most communities. Between 1975 and 2003, the federal and state government built public sanitation systems in roughly 90 remote communities (ISER, 2006). However, in 2004 approximately one in six Native and rural households in Alaska lacked access to basic drinking water and wastewater facilities (Alaska Native Village Water Infrastructure Assessment, 2006). These low service regions include the Kotzebue area, the Norton Sound area and the Yukon-Kuskokwim Delta.

The 16 regional governments in Alaska are called boroughs, which have similar jurisdictional responsibilities as counties. Almost half of the state, however, has no organized borough government. In these non-organized areas, the state government has jurisdictional governance to provide basic services. Additionally, many small communities both in and not included in boroughs lack city governments. 12% of Alaska's land is under tribal governance.

IV. History of Federal Involvement in Water Infrastructure

A. Regulation and Funding

The federal government has a long history of regulating and funding wastewater and drinking water systems. The EPA has played and continues to play the most significant role, however the U.S. Department of Agriculture and the Alaskan Native Village Fund (administered by the EPA) have also funded water and wastewater loan and grant programs (in rural and Native communities).[5]

The Water Pollution Control Act of 1948 was the first legislation to create a role for the federal government in water quality control, however, the primary responsibility of creating and enforcing standards remained with the states. The Act was amended throughout the 50's and 60s, increasing federal assistance to municipal treatment agencies. The Federal Water Pollution Control Act Amendments of 1972 (which are more popularly known as the Clean Water Act (CWA)) strengthened the federal role in clean water, establishing national standards for a number of pollutants. To assist municipalities in creating wastewater treatment plants that were capable of meeting these new standards, the CWA established a system to provide federal financial assistance, first in the form of construction grants, which were modified several times and later replaced by the State Water Pollution Control Revolving Fund (SRF) in 1987. Through FY 2005, $75.6 billion in CWA assistance, including $23.7 billion in SRF capitalization grants has been appropriated (CRS, 2005).

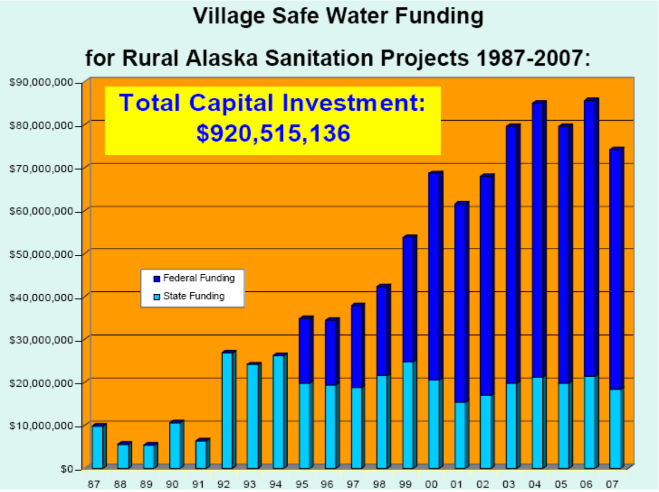
Public drinking water was first regulated under the federal Safe Drinking Water Act (SDWA) of 1974. This law gave the EPA significant discretionary authority to regulate drinking water contaminants and gave states the lead role in implementation and enforcement. Compared to the years of federal funding support for municipal wastewater treatment facilities, Congress only recently established a program when it enacted the 1996 SWDA Amendments, which helps finance drinking water systems. From FY 1997-2005, Congress appropriated approximately $7.7 billion for this program (CRS, 2005).

The U.S. Department of Agriculture (USDA) also plays an important role in rural communities (limited to communities of 10,000 in population or less) through its water and wastewater loan and grant programs. The purpose of these programs is to provide basic amenities, alleviate health hazards, and promote the orderly growth of the nation's rural areas by meeting the need for new and improved rural water and waste disposal facilities. The Rural Development Act of 1972 legislatively authorized these programs. More recently, the USDA has increased their coordination with state authorities in the funding of these grants. In FY 2005, Congress appropriated $598 million for this program (CRS, 2005).

In FY 1995, the EPA created the Alaskan Native Villager Fund through congressional funding, which makes grants to the State of Alaska to assist rural and Native villages in: (1) the development and construction of public water systems and wastewater systems to improve the health and sanitation conditions in the villages; and (2) training, technical assistance, and educational programs relating to the operation and maintenance of sanitation

---

[5] For a more detailed discussion of federal involvement in water infrastructure please see the CRS Report for Congress on Water Infrastructure Needs and Investment: Review and Analysis of Key Issues (Updated May 5, 2005).



services in rural Native villages. The graph below (Figure 5) presented to the Department of Environmental Conservation in January 2007 by ACIA (from their annual report) shows funding for the program. Through FY 2005, $324 million has been allocated to projects. The EPA, the State of Alaska, and United States Department of Agriculture entered into a three-party MOU in FY2006 on the implementation of the ANV program including establishing program goals. Program funding level was $34 million in FY06 and is expected to be $34 million in FY 07, and $16 million in FY 08 respectively (Alaska Native Village Water Infrastructure Assessment, 2006).

B. EPA's Four Pillars of Sustainable Infrastructure

In 2003, the EPA began their Sustainable Infrastructure Initiative, which identifies best practices in how the federal government views, values, manages, and invests in the nation's water infrastructure. How these pillars will be applied to EPA's climate change initiatives remains to be seen. As stated, the four pillars are:

- *Better Management*: Adoption of better management practices offers the ability to reduce costs and direct system investments using a risk-based approach. The EPA encourages the sharing of best practices across the industry.
- *Full-Cost Pricing*: Pricing that recovers the costs of building, operating, and maintaining a system is absolutely essential to achieving sustainability. Drinking water and wastewater utilities must be able to price water to reflect the full costs of treatment and delivery.
- *Efficient Water Use*: EPA is focused on developing a program that takes a broad approach by setting water efficiency levels for products, in conjunction with manufacturers, utilities and other stakeholders; building partnerships with manufacturers, distributors, utilities and others to promote water efficient products; and promoting an ethic of water efficiency through promotional activities.
- *Watershed Approaches to Protection*: Using a watershed approach to address impaired waters is needed. State and local governments should strive to look beyond their traditional geographic boundaries to create interstate and inter-local partnerships based on watershed boundaries.

V. Climate Change Overview

A. Background

Although there is evidence that Earth does have natural climate variation cycle, there is now scientific consensus that climate-warming trends are (IPCC, 2007):

- Unequivocally occurring;

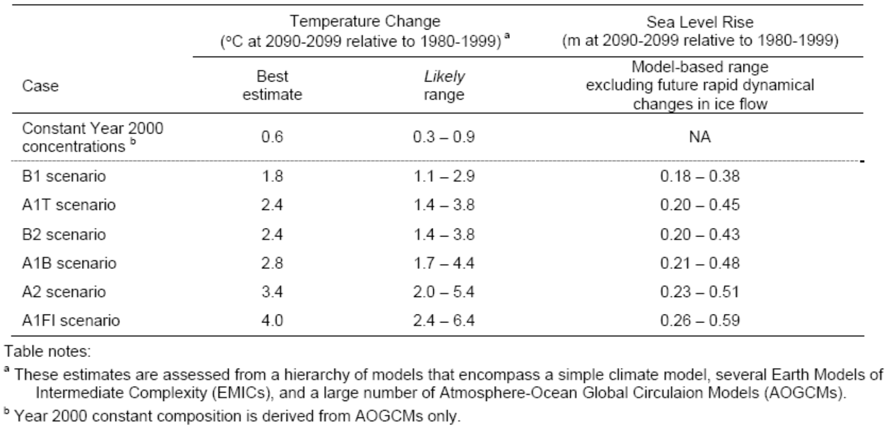
- Due to anthropogenic causes, most notably greenhouse (heat trapping) gas emissions;
- And unavoidable for centuries to come.

Greenhouse gasses, such as carbon dioxide and methane, absorb and radiate heat back down to warm the lower atmosphere and surface of the earth. The burning of fossil fuels, such as coal, oil and natural gas, as well as the clearing of land[6] have led to increased atmospheric concentrations of carbon dioxide and methane (by 31% and 149% respectively above pre-industrial levels) and warmer global average temperatures (by about 0.6^0 C) (ACIA, 2004).

According to the IPCC, anthropogenic warming of about 0.2°C per decade will continue for the next two decades. This is due to the time lag associated with climate processes, which is caused by excess carbon dioxide remaining in the atmosphere for centuries and various feedback cycles.[7] If greenhouse gas concentrations were stabilized at current levels 2000 levels, the IPCC would still expect further warming of about 0.1°C per decade. Thus, in 2004 the Artic Climate Impact Assessment concluded, *altering the warming trend will be a long-term process, and the world will face some degree of climate change and its impacts for centuries.*

The best estimates of warming projections are similar for each emission scenario studied by the IPCC until 2030 and are very likely to be at least twice as large as changes in the 20th century.[8] However, the model predictions diverge for the end of the 21st century and are shown in below Figure 7. These models do not include any climate-carbon cycle feedback or the full effects of changes in ice sheet flow, because the knowledge on their effects is too limited to assess their likelihood or provide a best upper bound estimate (IPCC, 2007).

Figure 6: IPPC 2007 Summary for Policy makers



Case	Temperature Change (°C at 2090-2099 relative to 1980-1999) [a]		Sea Level Rise (m at 2090-2099 relative to 1980-1999)
	Best estimate	*Likely* range	Model-based range excluding future rapid dynamical changes in ice flow
Constant Year 2000 concentrations [b]	0.6	0.3 – 0.9	NA
B1 scenario	1.8	1.1 – 2.9	0.18 – 0.38
A1T scenario	2.4	1.4 – 3.8	0.20 – 0.45
B2 scenario	2.4	1.4 – 3.8	0.20 – 0.43
A1B scenario	2.8	1.7 – 4.4	0.21 – 0.48
A2 scenario	3.4	2.0 – 5.4	0.23 – 0.51
A1FI scenario	4.0	2.4 – 6.4	0.26 – 0.59

Table notes:

[a] These estimates are assessed from a hierarchy of models that encompass a simple climate model, several Earth Models of Intermediate Complexity (EMICs), and a large number of Atmosphere-Ocean Global Circulaion Models (AOGCMs).

[b] Year 2000 constant composition is derived from AOGCMs only.

---

[6] Thus decreasing potential carbon sinks.

[7] One example of an important feedback process is ice-albedo feedback. The increased CO_2 in the atmosphere warms the Earth's surface and leads to melting of ice near the poles. As the ice melts, land or open water takes its place. Both land and open water are on average less reflective than ice, and thus absorb more solar radiation. This causes more warming, which in turn causes more melting, perpetuating the cycle.

[8] These emission scenarios refer to those looked at in the IPCC Special Report on Emission Scenarios (2000). These scenarios can be found in Appendix C of this report.

In an article by Rahmstorf et al. (2007) recent climate observations were compared to projections as summarized in the 2001 assessment report of the IPCC (the 2001 scenarios are fairly similar to those in the 2007 report – located in Appendix C). Their results show that carbon dioxide concentration followed the projections almost exactly, while the global mean surface temperature increase (land and ocean combined) was in the upper part of the range predicted and the observed sea level has been rising faster than the rise projected by the models. They conclude that IPCC projections, have not exaggerated, but rather underestimated the impacts of global climate change.

B. Key Impacts of Climate Change in Alaska

Climate change has very specific and pronounced impacts for the Artic, many which have already begun to be noticed. The average artic temperature has increased at nearly twice the global rate or 4°F since the 1950s (7°F in the interior winter), which has led to:

- Permafrost thawing
- Melting of sea ice
- Sea level rise
- Receding glaciers
- Shortened snow season
- Changing precipitation levels and frequency

The Lawrence Livermore National Lab in conjunction with NOAA and ISER projected the following temperature changes for Anchorage, Barrow, Bethel, Fairbanks, Juneau and Nome in 2030 and 2080:

Table 1: Predicted Temperature Change in Alaska (2030 and 2080)

Predicted Temperature Change in Alaska (2030 and 2080)			
Alaska Climate Region	**Average Annual Temperature (1980-99)**	**NOAA GFDL Projection (2030)**	**NOAA GFDL Projection (2080)**
Anchorage	36.7F	38.8F	42.1F
Barrow	10.8F	14.5F	19.5F
Bethel	30.2F	33.8F	37.2F
Fairbanks	28.0F	30.6F	34.1F
Juneau	42.1F	43.8F	47.1F
Nome	27.3F	30.9F	34.9F

Thus, the impacts already seen from global climate change in Alaska are only expected to intensify.

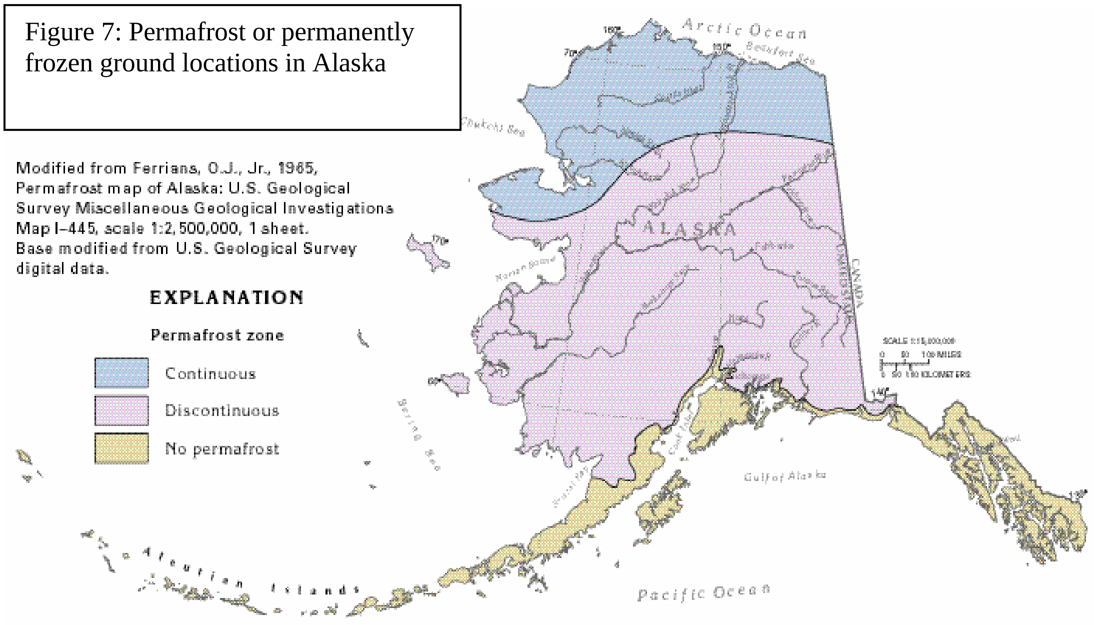
1. Thawing Permafrost

Permafrost is the technical term used to describe permanently frozen ground. It underlies 85% of Alaska and any infrastructure built on it requires specialized building techniques and precautions. Typically, only the top 30-100 cm of soils, the "active layer" thaw every summer (NOAA). The extent of permafrost is often controlled by climate conditions, but terrain also matters as local variation in soils, vegetation, slope, snow cover and surface water impact variations in permafrost thickness and continuity (Siefert 2007). Permafrost occurring in discontinuous patches is called, appropriately, discontinuous permafrost. Most of the discontinuous permafrost in Alaska is located in the interior of the state, in a band running across the state.

According to the 2007 IPCC Report, temperatures at the top of the permafrost layer have generally increased since the 1980s in the artic. Although continuous permafrost temperatures on the North Slope of Alaska have warmed 4-7F in the past century, no significant loss of permafrost is expected in the 21st century as temperatures at the upper surface remain around 23F (US National Assessment). However, warming temperatures in these northern areas will increase the depth of the seasonal active layer.

Changes in Alaska's climate have already begun to impact the extent and depth of discontinuous permafrost layers located in southern parts of the state. Where there is high ice content (about 50% of the discontinuous permafrost in Alaska), thawing is often more intense and can induce severe, uneven sinking of the surface called thermokarst. Furthermore, the presence of saline water lowers the melting point of permafrost, accentuating climatic pressures. According to ACIA (2004), as much as the top 30 feet of discontinuous permafrost is projected to thaw in the next 100 years.

Figure 7: Permafrost or permanently frozen ground locations in Alaska



Modified from Ferrians, O.J., Jr., 1965, Permafrost map of Alaska: U.S. Geological Survey Miscellaneous Geological Investigations Map I-445, scale 1:2,500,000, 1 sheet. Base modified from U.S. Geological Survey digital data.

As permafrost thaws, it loses its mechanical strength – especially in ice-laden soils. For example, a permafrost temperature change from -4 to -1^{0} C results in a decreased load capacity of 70% (Cole, undated). In locations such as Fairbanks, where soil temperatures are near 32 F, small changes in warming could be quite costly. Thawing of discontinuous permafrost will cause ground subsidence, erosion and landslides, disrupting and destroying built structures. According to Vladimer Romanovsky, Associate Professor of Geophysics at the University of Alaska-Fairbanks, "[melting permafrost]…will trigger changes in ecosystems and infrastructure because the stability of these systems in the north relies on the stability of ice that, so far, holds these systems together.

Figure 8: Thermokarst depression on the edge of the Geophysical Institute (UAF parking lot). Surface disturbance related to the construction of the parking lot triggered permafrost degradation.

In losing permafrost, we are losing the stability of the system" (NOAA website, 2007). Although thawing is likely to result in more stable soils, the transitional period of decades (or longer) is expected to be quite devastating to built infrastructure, as can be seen in Figure 8.

Thawing permafrost is also expected to have significant effects on the hydrology of the artic. The presence of permafrost significantly limits the amount of water penetration into the soil (recharge) and subsurface storage. A loss of permafrost could result in "dry thermokarst", which is characterized by improved subsurface water drainage leading to drier soils overall and increased penetration of the water table by contaminants. Osterkamp, Vierek, Shur, Jorgenson, Racine, Doyle, and Boone (2000) found that permafrost melting can also lead to "wet thermokarst", which is characterized by ground surface subsistence and pounding leading to the ground becoming over-saturated (resulting in the replacement of boreal forest with wetlands). Because the loss of permafrost results in soils no longer being cohesively frozen, increased erosion potential and increased amount of sediment run-off are also to be expected.

2. Melting Sea Ice

Artic sea ice has grown thinner and declined in area over the past few decades. Although sea ice extent and thickness does vary seasonally (up to 50%) and year-to-year, shrinking trends have already been noted in recent decades. For example, studies have shown a loss rate of sea ice around 2.8% per decade in the 1980s and a 4.5% rate in the 1990s (ACIA, 2005).

Sea ice is expected to shrink in both the Artic and Antarctic under all of the climate scenarios studied by the IPCC. According to some projections, Artic late-summer sea ice disappears almost entirely by the latter part of the 21st century (IPCC, 2007). Furthermore, processes related to ice flow (not currently captured in models studied by the IPCC) suggest an increased vulnerability of ice sheets to warming, increasing future sea level rise. Understanding of these processes is still limited and a lack of consensus as to their extent exists.

3. Sea Level Rise

Melting sea ice not only allows for larger storm surges, leading to coastal inundation and erosion, but it also leads to sea level rises. The picture below is of the Village of Shishmaref suffering the effects of erosion due to sea surges and sea level rise. The IPCC stated with *high confidence* that the observed rate of sea level rise increased from the 19th to the 20th century, with the aggregate rise estimated to be .17 [.12-.22] M. Current estimates measure sea level rising from 3.1 mm per year (IPCC, 2007) to 3.3 mm a year Rahmstorf et al. (2007). However, in 2006, studies by Bette Otto-Bliesner (National Center for Atmospheric

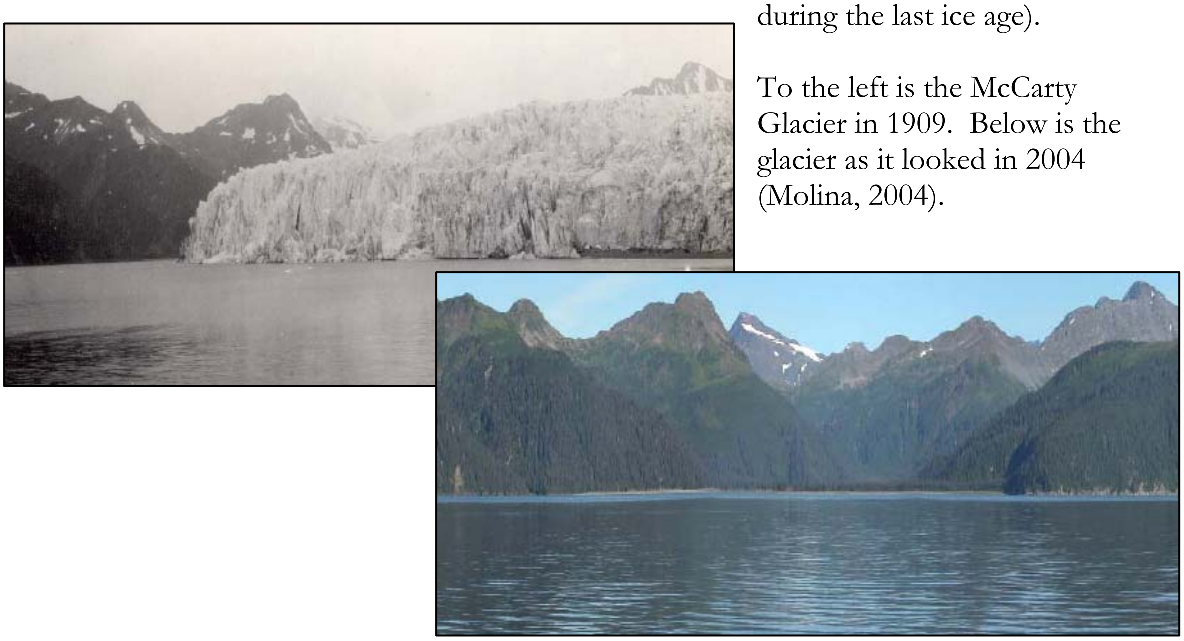
Figure 9: Village of Shishmaref. Photos from Nome Nugget Newspaper

Research) and Jonathan Overpeck (University of Arizona) predicted that Arctic summers by 2100 may be as warm as they were nearly 130,000 years ago, when sea levels eventually rose up to 20 feet (6 meters) higher than today. According to Rahmstorf et al., the rate of sea level rise in the past 20 years is 25% faster than the rate or rise in any 20-year period in the preceding 115 years.

4. Receding Glaciers

According to recent studies, Alaska's glaciers are receding at twice the rate previously thought (Science, 2002). This has implications for aquifer recharge and isostatic rebound (which refers to the rise of land masses that were depressed by the huge weight of ice sheets during the last ice age).

To the left is the McCarty Glacier in 1909. Below is the glacier as it looked in 2004 (Molina, 2004).



The two pictures above show the Muir Glacier in 1976 (to the left) and in 2003 (to the right) (Molina, 2004).

5. Shortened Snow Season – changes in seasonality

In recent decades, climate change has impacted the snow season in a number of ways. First, warmer temperatures have decreased the amount of time snow covers the ground (i.e.: early spring melt, late fall freeze). Higher frequencies of northerly airflows during the winter have also tended to diminish snowfall over northern Alaska. Furthermore, during spring, intrusions of warm moist air from the North Pacific have become more common, which tend to accelerate the melting of snow on the North Slope of Alaska. A shortened snow season and low snow levels can lead to diminished aquifer recharge as well as for deeper freezing of the soil (lack of snow insulation).

6. Precipitation Levels and Frequency

Additionally, although more difficult to predict, the frequency of precipitation and intense rainfall events have increased and these trends are expected to continued. The average precipitation in Alaska increased by 30% between 1968 and 1990 and according to the ACIA 2005 Report; precipitation is expected to increase another 20-25% in the north and northwest, with some decreases along the south coast. However, increased evaporation from warming will more than offset the increase in precipitation leading to generally drier soils throughout most of the state.

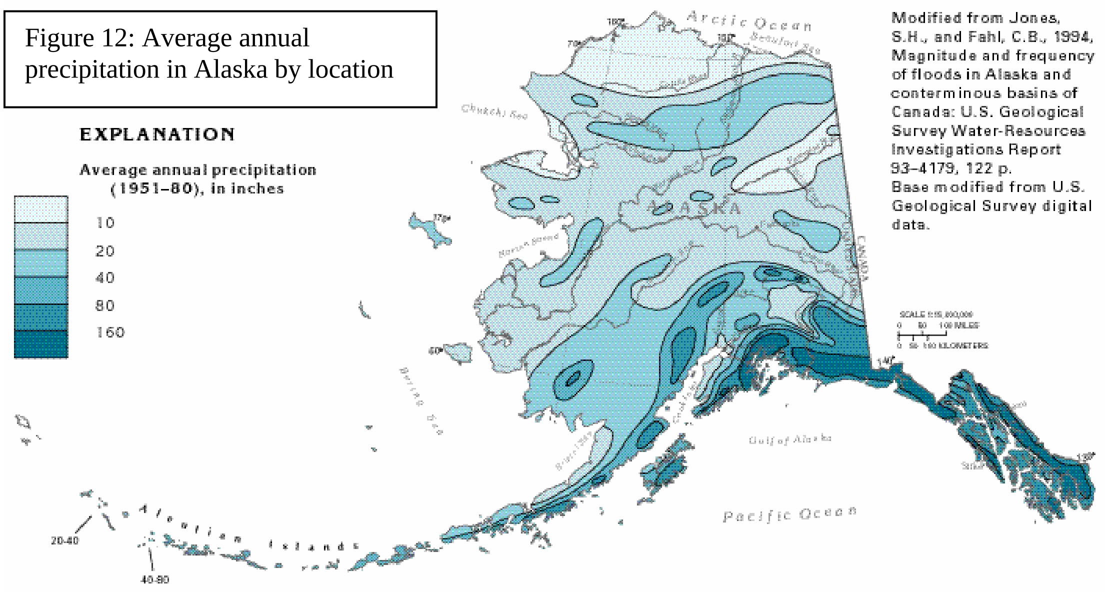


Figure 12: Average annual precipitation in Alaska by location

Modified from Jones, S.H., and Fahl, C.B., 1994, Magnitude and frequency of floods in Alaska and conterminous basins of Canada: U.S. Geological Survey Water-Resources Investigations Report 93-4179, 122 p.
Base modified from U.S. Geological Survey digital data.

VI. Potential Impacts on Alaskan Water Infrastructure System

A. Overview

The climate impacts described above are anticipated to have varying and potentially devastating consequences on Alaska's water supply and disposal universe (although in some areas the effects could be potentially beneficial or neutral over time). In Alaska, there are a wide range of systems and services in water supply and disposal facilities. For example, some Alaskans who live in remote villages still carry water and wastes to and from their residences. Most of the population in Alaska however, relies on piped services to deliver water and dispose of wastewater. These systems however, vary depending on water source, treatment, distribution, and disposal method.

1. Water sources

Water sources in the artic include surface water sources such as lakes and streams, groundwater, and manmade structures that capture snow and rain. They are pertinent to an overall infrastructure's functioning, as the quality and properties of a source ultimately dictate the types of treatment and distribution needed. Warner, Berner and Curtis (2005) listed climate change impacts to these sources:

- Limited recharge of groundwater supplies due to changes in precipitation and higher evaporation rates;
- Reduction in available surface water as a consequence of less precipitation, melting permafrost and intense rainfall events (more water lost to run-off than previously);
- Contamination of water sources from sea level rise and storm surges[9];
- Damage to water impoundment, intake structures, as well as facilities located adjacent to highly erodable lands (such as those near streams or coasts) due to structural damage from melting of permafrost, storm surges, and intense precipitation events.

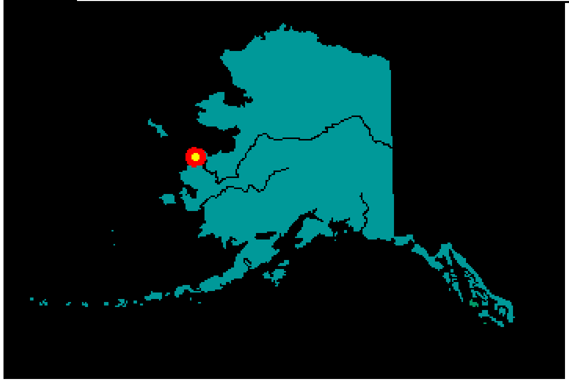


Figure 13: Location of Nunam Iqu, Alaska

Case Example: Nunam Iqu, Alaska

The 35 families who live in Nunam Iqu rely on a nearby river for water that they then store during the winter in a 200,000-gallon tank. In December 2004, a storm surge contaminated that river and it destroyed a tank fitting, which drained the village's stored water. Without a clean water source, the state Division of Homeland Security and Emergency Services began flying 500 gallons of water each day to Nunam Iqu. When the river cleared later in the month, residents were able to begin storing water again and officials called off the water airlift. This incident, however, highlights the concern that such events may become more frequent with increased sea level rise and storm surges resulting from global warming.

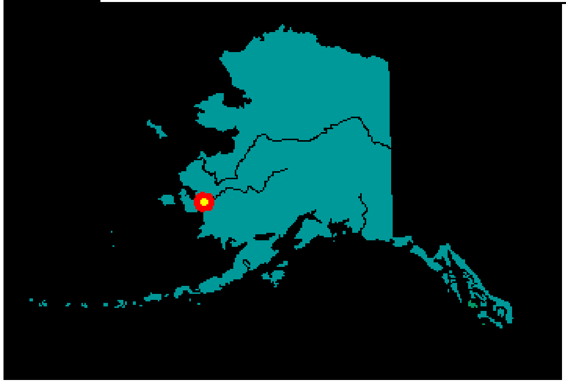


Figure 14: Location of Bethel, Alaska

Case Example: Bethel, Alaska

Permafrost acts as a barrier that traps water near the surface in many areas; when it melts, the water above it may drain away. The City of Bethel's Public Works Director, Wayne Ogle, voiced concern regarding the 450ft wells that supply Bethel with water. "Permafrost is a protective layer, when that begins to melt, you may have more of an opportunity for

---

[9] Many of Alaska's small, remote communities utilize brackish groundwater or in coastal areas, depend on lakes and rivers susceptible to saltwater intrusion, as their drinking water source.

contaminates to get into the substrata and contaminate the water source" (personal communication, May 2007).

Dan White of the University of Alaska-Fairbanks' Water and Environmental Research Center is troubled by what the absence of permafrost could mean for precipitation amounts. White is currently leading a four-year study on the water supplies of Seward Peninsula villages and how a changing climate might affect those water sources. White believes that in the warmest-case scenario of Alaska's future, permafrost wetlands could turn into an arid landscape - areas of Alaska's North Slope receive less precipitation than Tucson, Arizona. According to White, "The whole reason water's abundant in the Arctic is permafrost. If the permafrost melts, it likely won't be a wetland" (Rozell, 2005).

Case Example: Petersburg, Alaska

Petersburg is located on Mitkov Island and is built at sea level. According to Karl Hagerman, the Public Works Director for the City of Petersburg, rising sea levels could pose a problem for their community, "maintaining the integrity of our potable water system as well as our sanitary sewer system would be the largest problem for Petersburg if severe climate changes were forecast over the next 50 years" (personal communication, May 2007).

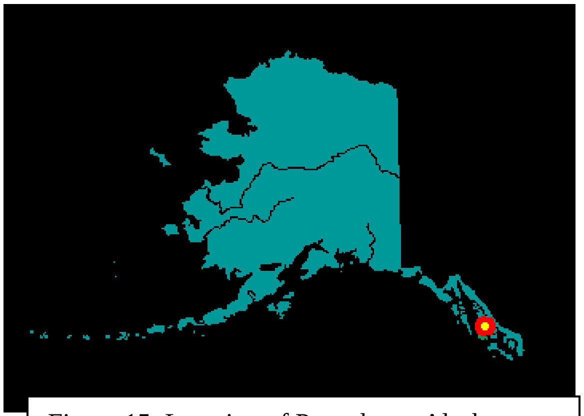


Figure 15: Location of Petersburg, Alaska

The community is fairly small (~ 3300 population) and the economy is based largely on commercial fishing and timber harvests. Mr. Haggerman believes that small rises in sea level over a long period of time would allow for an adequate lead time on planning and the funding of projects to improve or upgrade Petersburg's water distribution system, however, sudden and large shifts in sea level would be difficult to handle or adapt to, and could raise their local sea water table, allowing for cross connection problems and contamination (personal communication, May 2007).

2. Water Treatment Systems

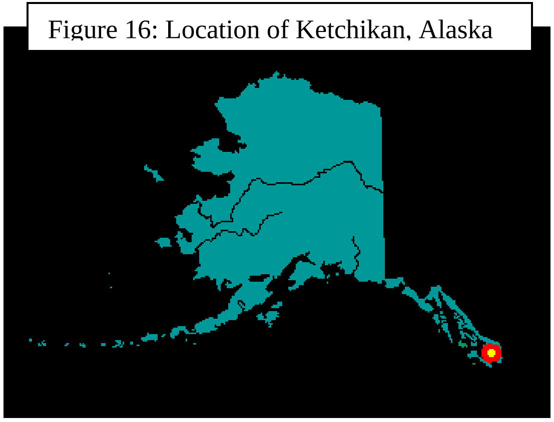
Water treatment systems are designed to make water safe for drinking. Depending on the source, climate change could result in increased or new contaminates and pathogens, which in turn may overwhelm the treatment process or reduce treatment capacity. Such climate change impacts on treatment include (Warner et al., 2005; ACIA, 2005).

- Saline intrusion (through sea level rise or storm surges) into groundwater and surface water may make a source undrinkable or could require a more specialized, complicated, and costly process to treat the contamination.
- Warmer weather may facilitate the increased incidence of northward migration of animals with disease (such as beavers), which in turn may increase the treatment level to produce safe drinking water.

- Increased rainfall and more frequent intense precipitation events may lead to increased turbidity[10], pathogens and organics. These additional loads to a system could result in a system's treatment capacity being exceeded.
- Warmer weather may also result in increased algae blooms in surface water sources, leading to clogged systems and formation of dangerous byproducts.

Case Example: Ketchikan, Alaska

Figure 16: Location of Ketchikan, Alaska



Water in Ketchikan comes from the drainage area surrounding Ketchikan Lakes and Granite Creek. These draining basins feed into Fawn Lake, where another series of tunnels takes the water to the Bear Valley Reservoir, where it is mixed with chlorine and stored, spending additional time before it's piped to homes within the city's boundaries. Ketchikan's municipal water system remains unfiltered and by the city's estimates has saved the community much of the cost of constructing a water filtration plant with an estimated cost of over $20 million as well as the annual operating costs for chemicals, electricity, and labor. Since 1995, Ketchikan has remained in compliance with all the governing criteria of the EPA's Surface Water Treatment Rules.

The Bear Valley Reservoir serves a population of 8,000 and is Ketchikan's only water source. Because it remains unfiltered, Ketchikan faces some unique planning challenges. Ketchikan is required by the EPA to monitor its turbidity and contaminate load. Although Ketchikan has never exceeded the maximum allowable turbidity levels, there is concern that increased periods of heavy rain could compromise water quality. Organic chemical contaminants (including synthetic and volatile organics) can also increase with heavy storm water run-offs and may impair water quality. Furthermore, microbial contaminates, such as viruses and bacteria, from increased/different wildlife activity (such as the presence of beavers) due to warmer temperatures may increase.

Case Example: Homer, Alaska

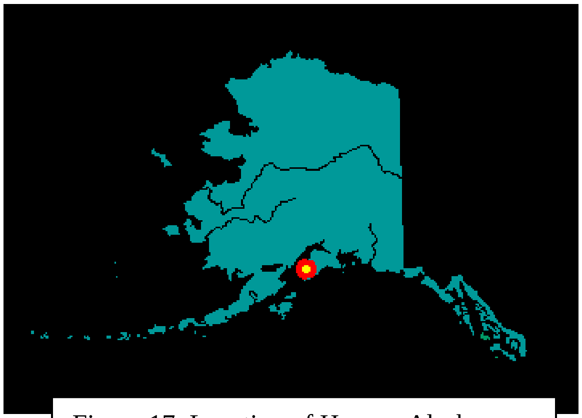


Figure 17: Location of Homer, Alaska

Homer is located on the north shore of Kachemak Bay on the southwestern edge of the Kenai Peninsula. The city has one surface water source for their drinking water called the Bridge Creek Reservoir. Water is pumped from the reservoir, filtered at the water treatment plant to remove silt (turbidity) and color. The PH (acidity) of the water is adjusted to reduce corrosion and chlorine is added to inactivate any disease causing organisms. New regulations dealing with chlorination by-products and lower turbidity standards, however, have greatly reduced the

---

[10] Turbidity is a measure of the cloudiness of the water and it is tested as an indicator of microbiological quality. Heavy rainfall periods lead to increased turbidity.

amount of water Homer can produce in with their existing water treatment plant. Plans are currently being made for upgrading their process to a membrane/low-pressure system (life-time of 20 years), which will be the first municipal "large scale" plant of its kind in Alaska. According to Jim Hobbs, the Water Treatment Plant Operator in Homer, the city's largest concern with their water source is treatment, specifically increased organics, turbidity and changes brought about by sunnier days (causing larger algae blooms) (personal communication, May 2007). Although Homer does not deal with the effects of melting permafrost, which he considers to be a larger area of concern, warmer weather, increased turbidity and organics did play into their decision for what type of water treatment plant to build. As the membrane technology has become more conventional in the past few years, the prices for the technology have come down drastically. Additionally, under the new system Mr. Hobbs expects reduced engineering and maintenance costs for the city (personal communication, May 2007).

3. Water distribution

Water distribution in Alaska varies from self-haul to community-haul to piped facilities. While self-haul relies on minimal infrastructure, both community-haul and piped facilities require significant infrastructure investments. In Alaska, community-haul requires passable roads and boardwalks for distribution. Additionally, most piped utilities rest on supports above ground or, if the soil is thaw-stable, the pipes are buried below the ground. These piped facilities must continuously circulate water in order to protect from freeze failure. Climate impacts facing distribution systems include (Warner et al., 2005; ACIA, 2004).

- Infrastructure systems may be prone to structure damage from melting permafrost (loss of foundation support) and grade changes in gravity mains.
- Infrastructure may be prone to structural damage from increased thawing/freezing cycles associated with more erratic weather patterns.
- Increased precipitation and storm surges can lead to flooding and erosion, which damages roads, boardwalks, pipelines and water storage facilities, especially if these waters include ice.
- Infrastructure in coastal communities may become more vulnerable to erosion from storm surges due to lack of normal sea ice and rising sea levels.

Case Example: Barrow Alaska

Barrow has been dealing with coastal erosion and storm surges for many years, although their intensity has increased in recent years. The vulnerability of the utilidor - a heavily insulated utility corridor built in 1984 at a cost about $270 million (it provides water, sewage, and other utility services to Barrow

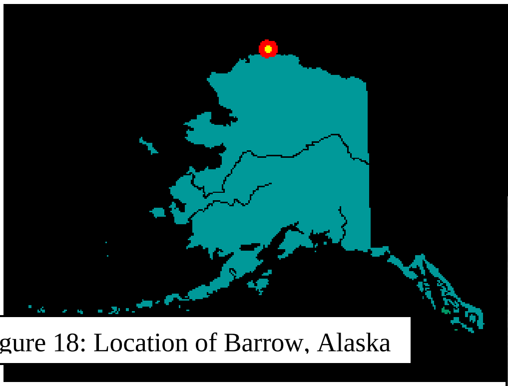


Figure 18: Location of Barrow, Alaska

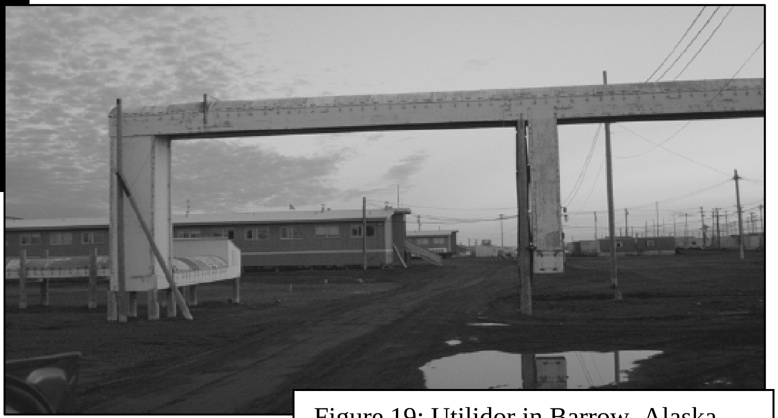


Figure 19: Utilidor in Barrow, Alaska

residents) - to coastal erosion and flooding is a major concern for the city of Barrow. The utilidor was built during a period that saw relatively few severe storms, thus the pumping stations and access manholes near the coastline were not designed with erosion and flooding in mind.

Additionally, Barrow is located in a region that has seen increased levels of permafrost thawing. This warming has reduced the load bearing capacity of their soils. The depths at which piling must now be set in Barrow have increased by several feet over twenty years, creating concern that the utilidor may be at risk for structural failure (ACIA, 2005).

Case Example: Togiak, Alaska

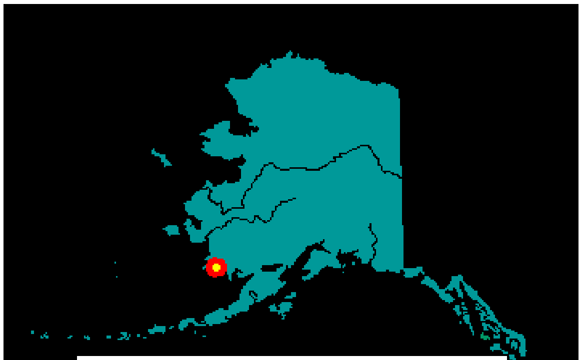


Figure 20: Togiak, Alaska

The village of Togiak is at the head of Togiak Bay and has a population of about 780 people. Located in a climatic transition zone, Togiak experiences average summer temperatures ranging from 37 to 66 F, while average winter temperatures range from 4 to 30 F. In 1985, the village built a mile long and 5-7 ft high sea wall. According to Darryl Thompson, Public Works Director for Togiak, towns along the western coast have recently begun to deal with more erosion activities from fall storm surges as the normal protective sea ice freezes are coming later and later in the year. At one point, an analysis was done that showed it would cost around $100 million dollars to move a town "to safety" (personal communication, May 2007). Togiak's seawall protects the coastline in front of the village from the effects of erosion, although severe storms (which in Mr. Thompson's opinion are occurring more frequently) have been able to breach this wall every few years with some negative consequences for the sewage system.

Togiak's water system was built in 1970 with state of the art (at that time) PVC piping. The system is now suffering from broken or corroded pipes, valves and service connections. Although the system's age is a primary cause for these failures, lack of snow cover combined with cold temperatures led to an increased number of pipes freezing and breaking this year. According to Mr. Thompson the village plans to spend $6 million dollars over between now and 2011 on high-density polyethylene (HDPE) pipes that will be more resistant to colder temperatures and less brittle (personal communication, May 2007).

4. Wastewater disposal systems

Wastewater disposal systems will also face challenges. In Alaska, these systems are comprised of individual sites, septic tanks, community lagoons, holding tanks, and piped facilities. Changes in the artic climate could impact wastewater systems much as they may impact drinking water systems (Warner et al., 2005). For example, systems will be susceptible to floodwaters spreading waste, erosion intercepting the lagoon, and melting permafrost breaking built dikes. Additionally, septic tank/drainfelds and outfalls will also be prone to riverbank or shoreline erosion, heavy precipitation events, and rising sea levels.

Case Example: Barrow, Alaska

The picture to the right is of Barrow's South Salt Lagoon (dark green in color) and Middle Salt Lagoon (larger, tan color lagoon). Wastewater flows to pumping stations located throughout the village, where it is then pumped through the utilidor. As this effluent combines with snowmelt run off, the level in the South Salt Lagoon comes close to full capacity in the spring. In order to prevent overflow, water is pumped from the South Salt to the Middle Salt Lagoon, to reduce effluents through additional storage time and dilution before eventual discharge into the ocean. The Lower Salt Lagoon and Middle Salt Lagoon are approximately at the 8-foot contour [above sea level] and approximately 500 feet from the ocean.

Although erosion and flooding from big storms have *not* caused any significant problems for the as of yet, Ben Frantz, General Manager of the member-owned Barrow Utilities and Electric Cooperative (which operates this sewage treatment lagoon), a storm surge was able to breach the lower lagoon a few years ago, compromising the spill-way between the two lagoons (personal communication, April 2007).

Barrow is currently in an advanced planning stage for a new Barrow Sewage Treatment and Disposal System to replace the current sewage lagoon system. Currently the facility itself is expected to cost about $18 million. With tie-in to the Barrow Utility System, a road, power lines, etc., the total is expected to be about $28 million. Additionally, increased operational costs are expected with the new wastewater treatment plant.

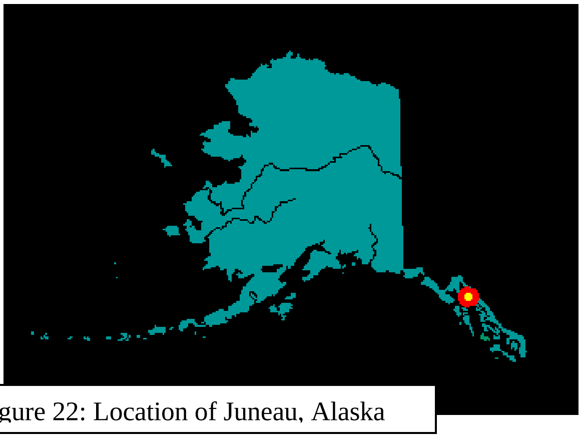


Figure 22: Location of Juneau, Alaska

Case Example: Juneau, Alaska

Juneau is a coastal, low-lying community, receiving over 92 inches of annual precipitation. These two factors have significant implications for the three city/borough-operated wastewater plants, which are all gravity flow and located very close to sea level. According to Liam Carnaham, Public Works Director at the City/Borough of Juneau, a significant or abrupt rise in sea level could mean loss of function to the system, although the sea level rise would have to be nearly 5-7 feet before things became "dicey" (personal communication, April 2007).

Additionally, Juneau currently has a combined wastewater system (combination of domestic sewage and storm water), which receives treatment before it is released into the Gastineau Channel. When there are extremes in flow, usually caused by heavy rains, the city/borough finds it necessary to divert the water into Gastineau Channel without treatment in order to relieve the system. This results in a combined sewer overflow (CSO). Although the city/borough are working on separating these systems, Mr. Carnahan believes that an increase in bigger/extended storms would result in an intensity of rainfall that would pose significant problems for the city's system, leading to an increase in CSO occurrence (personal communication, April 2007).

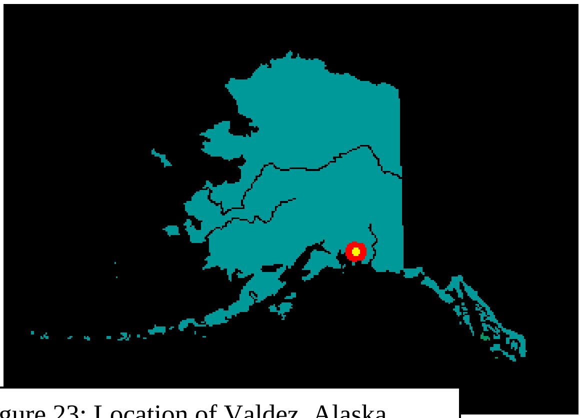
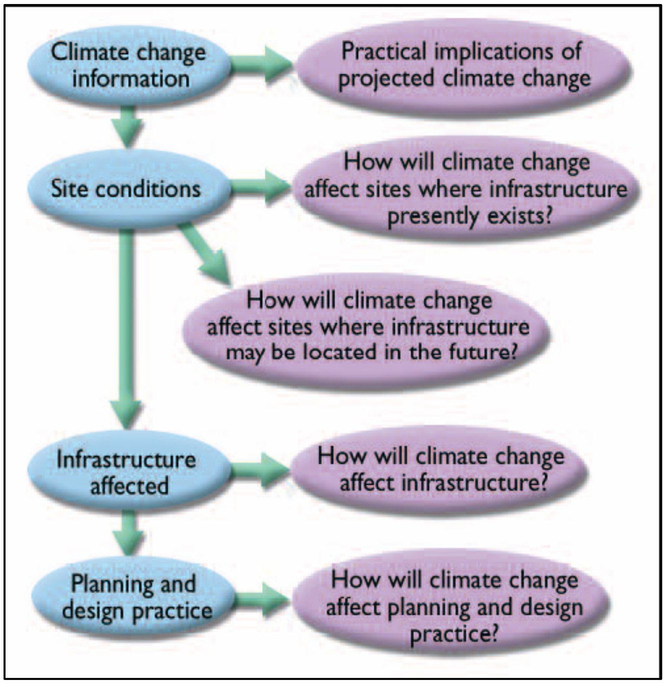


Figure 23: Location of Valdez, Alaska

Case Example: Valdez, Alaska

Valdez receives over 280 inches of snow annually. With annual precipitation around 63 inches and annual temperatures ranging from 21 to 31 F in January and 46 to 61 F in July, Valdez is a city of weather extremes. Their current wastewater disposal system is a series of three lagoons with aeration. This wastewater system actually discharges into a man-made creek/ditch that has been designated andronomous fish terrain. Because of this, their wastewater faces much stricter parameters. Although Valdez receives a lot of rain and snow, it typically falls in steady, predictably slow patterns. Last year, however, the town received 6.5 inches of rain in 24 hours, which resulted in the third sewage lagoon coming within an inch of spillover. If extreme rainfall events become more likely in the future, their outcomes could have important consequences on such sewage treatment systems.

VII. Climate Change Risk Management Framework



Risk is a combination of two factors:

- The probability that an adverse event will occur;
- The consequences of the adverse event.

Climate change risk analysis tries to quantify uncertainties related to modeled climate outcomes. Risk management is the process of attempting to reduce the consequences of adverse events identified by risk analysis. Thus, if uncertainties surrounding the effects and impacts of climate change can be assessed, their consequences can also be managed.

With regards to climate change impacts, these criteria are often referred to as thresholds – the point where a stimulus leads to a significant response (Parry, Carter, and Hulme, 1996). Jones and Pittock (2000) argue that impact thresholds should be defined *as any degree of change that can link the onset of a given critical biophysical or socio-economic impact to a particular climate state or states.*

As suggested by Parry (1996), Jones (2001) and modified for water infrastructure systems in Alaska, the following steps in an environmental risk assessment/management framework are:

1. Identify the **key climatic variables** affecting the infrastructure systems being assessed.
2. **Create scenarios** or project ranges for these key climatic variables.
3. Carry out a **sensitivity analysis** to assess the relationship between climate change and impacts.
4. Identify the **impact thresholds** with input from stakeholders.
5. Carry out **risk analysis.**
6. Evaluate risk and identify feedbacks that are likely to result in **autonomous adaptations** (adaptations that occur spontaneously).
7. Consult with stakeholders, analyze **proposed adaptation/mitigation responses** and recommend options.

Many other centers, consortiums, localities, states and nations are currently determining climate change impacts for their region, as well as drafting and implementing strategies for climate change adaptation. Examples of such reports include:

- Center for Integrated Regional Assessment, Pennsylvania State University (CIRA): *Vulnerability of Coastal Communities to Sea-level Rise: a case study of Cape May County, New Jersey, USA*
- State of Washington: Impacts of Climate Change on Washington's Economy, a Preliminary Assessment of Risks and Opportunities
- Finland: *Finland's National Strategy for Adaptation to Climate Change* (this is done by sector, assessing climate change impacts, adaptor capacity, vulnerability, and opportunity)
- Canada: *The Canada Country Study: Climate Impacts and Adaptation*
- Norway: *Norwegian Artic Climate Impact Assessment*

VIII. Findings: Perception of Risk

More recent work on risk assessment/management acknowledges that the functions of analysis and management cannot be separated, and that those who treat the risk must be involved in the formation and analysis stages of assessment, mainly through the formalized involvement of stakeholders (Jones, 2001). Two main questions concerning the results of risk analysis with respect to climate change are:

- Is the level of risk sufficient to warrant treatment?
- What forms of adaptation/mitigation are acceptable to stakeholders?

Thus, the purpose of the semi-structured interviews was to gain insight regarding:

- The use of climate forecasts in infrastructure related decision-making;
- The biggest perceived climate related threats to water infrastructure in Alaska;
- The amount of climate related change current water infrastructures can absorb;
- The adaptive capacity of systems (will impacts be preventable, can the systems adapt, or will replacement be necessary?)

The 15 interviewed participants were either managers of or planners for a city or borough water infrastructure system.[11] Expanded on below, the main themes that emerged from the interviewed participants were the following:

- Alaska is a land of extreme weather and engineering practices in Alaska are highly evolved meet these harsh and volatile conditions;
- Capacity of communities plays an important role in their ability to receive and react to information and weather extremes;
- There are large uncertainties involved with climate change (is it simply weather or a climate related event)
- There is a need to downscale global climate trends to the regional/local level;
- Climate change impacts will vary geographically, however, thawing permafrost, lack of snow cover and the increases in erosion (from storms on unfrozen seas) are the biggest direct challenges;
- How climate change will impact industry in Alaska (such as the timber/fishing industries) is an important indirect concern on water infrastructure operations;
- Climate change impact projections are often not used in planning decisions as most water managers/planners are often more concerned about how to respond to the crises of today.

Alaska is a land of extreme weather. Many water infrastructure systems have been designed to handle the extreme weather conditions in Alaska. From variable amounts of rainfall to tidal fluctuations and artic temperatures, such systems have a high degree of adaptability to extreme weather events. For example, according to Mr. J.R. Pearson, Utilities Analyst and Compliance Coordinator for the city of Unalaksa, the city is capable of handling extremes in weather, including extreme winds and extremely heavy rains – "even the electrical distribution system is all underground - at least half the hurricanes that hit Florida would be called a "blow" in Unalaska and would be considered somewhat normal"(personal communication, April 2007). The communities of Valdez, Petersburg, Ketchikan and Kodiak, Alaska, receive so much rain (upwards of 115 inches) annually that their systems

---

[11] It is important to note that there are advantages and disadvantages for stakeholder-defined perceptions of risk. These interviews definitely contain value judgments, do not always represent consensus, and represent only a fraction of Alaska's water system managers/planners. However, these stakeholders have the closest frame of reference and expertise. They are dealing with the constant pressures of Alaska's ever changing, harsh environment on a daily basis.

have to be capable of accommodating erratic and extreme weather. In the words of Mr. John Kleinegger, Water Division Manager in Ketchikan, “With the amount of rain we already have, a few feet more would be no problem. Less rain would be welcome to everyone who lives here" (personal communication, May 2007). According to Mr. Karl Hagerman, Public Works Director at the city of Petersburg, their systems could most likely sustain a rise in sea level of 2-3 feet before they started having problems with their water and wastewater systems (persona communication, May 2007).[12] In communities where semi-permanent permafrost is present (such as Anchorage) they have built flexible infrastructure systems that use artic engineering practices and can adequately withstand freeze-thaw cycles.

The **capacity** of a community plays an important role in their ability to receive and react to information and weather extremes. In Alaska, small, rural, and remote communities face much different realities than larger cities. Although Juneau, Fairbanks, and Anchorage are relatively large communities, the fourth largest city is Sitka, with a population of 8,000 people. Many coastal and remote towns have populations ranging from 100-1000 inhabitants. When, for example, Newtok, a town of 315 residents decided they needed to abandon their village for higher ground, costs of the move due to remoteness, climate and topography were estimated at $130 million, nearly $413,000 per person (Yardley, 2007).

Additionally, the public works director in smaller towns is often in charge of the entire water and sewer system (and often oversees other city responsibilities) – a “jack of all trades”. Frequently the rates they charge to customers are not enough to cover system costs, so smaller towns engage in other contracting activities such as plumbing, heating services, and pump servicing to balance the budget.

According to Mr. Thompson in Togiak, they need highly trained personal to maintain and repair their infrastructure systems (personal communication, May 2007). Although the city of Togiak makes a point to pay a “livable” wage and thus does not have much turnover, in communities where they have a hard time paying such wages they often have a difficult time keeping workers interested in their employment opportunities. Because there is such a high cost of living in remote areas (fuel and electricity), the lure of the city and higher paying wages often deprives smaller communities of valuable talent.

Furthermore, Mr. Hagerman summarized the attitude of many small system operators when he commented that, “it is hard for small rural Alaskan communities to jump on board with large global planning scenarios as most people that live here just don't buy into the fact that these issues will impact them. As is the case with most every global concern, large urban areas are the center for concern and changing attitudes while the small rural areas often take years to understand the impacts of a changing climate” (personal communication, May 2007).

---

[12] Mr. Hagerman, however, found it hard to gage due to the extreme tides that they experience in Petersburg. During their largest tidal fluctuations, they see a difference from low tide to high tide of over 24 feet of water (-4.0 low tide to 20.0 high tide). If the city were to start seeing high tides over 23.0 feet (from mean low water levels) from rising sea levels, Mr. Hagerman said it would “definitely cause problems for our infrastructure”.

Uncertainties involved with climate change (is it simply weather or a climate related event) make it difficult for many communities to plan. Although many communities mentioned that weather seemed warmer, wetter, drier, or stormier – depending on their location, it was difficult for many to translate these events to policy or programmatic responses. For example, Juneau has experienced an increase in avalanches (which has affected the turbidity of their water supply) and their production in their "Last Chance" aquifer has been less in recent years. Mr. Carnahan, Public Works Director in Juneau, thought that these outcomes might be tied related to climate change related factors, "we know the symptoms, but we're not really sure of the cause" (personal communication, April 2007). Mr. Frantz of Barrow agreed, "it's hard to correlate climate change with the system" (personal communication, April 2007). Others who were interviewed expressed concern that "you just can't predict" what the weather will do so it's hard to plan. Many felt that climate change was more abstract than other pressing, daily issues.

There is a need to downscale global and even regional forecasts. Because Alaska is so large and varied geographically there is a need to downscale climate forecasts to particular regions for greater effectiveness. Some costal communities deal with unique currents (Pineapple express and the Japanese coastal current) and their locations (due to mountain ranges and bays) have a tendency to create their own weather systems. In order to more effectively match scientific trends with their impact on policies and planning, downscaling of global climate trends needs to occur.

Climate change impacts will vary geographically, however, thawing permafrost, lack of snow cover and the increases in erosion (from storms on unfrozen seas) are the biggest direct challenges currently facing water infrastructure/sources in Alaska. Other, less cited concerns involve sea level rise and extreme rainfall events.

Problems from thawing permafrost are found mostly in the northern third of Alaska. Unusual freeze-thaw cycles brought about by lack of snow cover (insulation) and oddly timed cold snaps have been difficult in communities with infrastructure systems that have not designed for such extremes, either because such technology pre-dated their installation or because the area does not traditionally receive such severe and volatile weather patterns (southern third of Alaska). Coastal erosion, brought about by later and less ice extensive ice freezes and the resultant more powerful late-season storms, is typically found on the more unprotected western and northern coasts.

Although some communities cited sea level rise as a concern, the degree to which the sea would have to rise in many communities is quite high. Additionally, because most extreme rainfall events have occurred where rainfall has a history of being excessive, they have typically led to only one-time CSO events in comparison to system destroying events of thawing permafrost and coastal erosion.

How climate change will impact community livelihood (such as the Alaskan timber and fishing industries) is an important indirect concern on water infrastructure operations. The town of Unalaksa exemplifies these concerns. According to Mr. Pierson, "the city's main concern would be anything that would affect the fishing industry, since a collapse in fishing could bankrupt the entire community." Mr. Pierson was also concerned about their large timber industry, "Certainly if we get 2-3 weeks without any rain in the summer months, the ground cover becomes very dry and the forest fire danger increases rapidly. With this much rain we seldom have forest fires of any size but if the climate became much dryer, forest fires would be a real concern (like they are presently in the Interior areas of Alaska)" (personal communication, April 2007).

In Togiak, the problems relate to economic sustainability and subsistence living. The high costs of living in a remote location, combined with low paying fisheries are causing many people to leave the city for greener pastures. With a 50% dropout rate in their local high school, many children are not getting the vocational skills they need to readily find employment. Additionally, the native culture of subsistence hunting and fishing is becoming more difficult to reconcile as with changing ice and tundra conditions.

Furthermore, other challenges to the livelihood of a community that are more easily understood, thus become easier to quantify and address. In Juneau, there is the ever-present talk of moving the capitol to Anchorage, with such a move resulting in the loss of a substantial amount of ratepayers. Thus, in Juneau's 10-year strategic plan, the "risk" of the capitol moving was addressed while the effects from climate change were not taken into consideration.

Climate change impact projections are often not used in planning decisions
According to Jones (2001), two inter-related difficulties facing the communication of risk under climate change are:

1. The large uncertainties that accompany climate change projections and the other major drivers of change that will manifest over long time scales.
2. Risks that unfold over long time scales are often discounted in favor of commercial, political and event-based risks that may manifest over the short term.

Although some managers saw climate change as an immediate topic of concern, many others did not feel at risk from climate change due to many of the reasons listed above such as:

- The large uncertainties involved;
- The necessity to react to immediate concerns - "You have to design with what you're dealing with now";
- Their geographic location - not in an area with thawing permafrost;
- The high degree of capacity and adaptability of their current water infrastructure systems. If climate change does occur, it will happen slowly and steadily enough that systems will be able to adapt to or mitigate the outcomes of climate change.

An example of this is mindset is found in the City of Petersburg, which performed a lengthy study of watershed flows (rainfall and creek flows) at their most recent raw water reservoir site before initiating a project to impound the water. According to Mr. Haggerman, "We have theoretically set up our water supply so that even in long dry spells, our water supply will be adequate at all times of the year". Because their system is capable of handling such extremes, Mr. Haggerman believes that the forecasting of wet or dry weather (due to climate change) would not change any operational considerations or have an impact on future installations of infrastructure in Petersburg (personal communication, May, 2007).

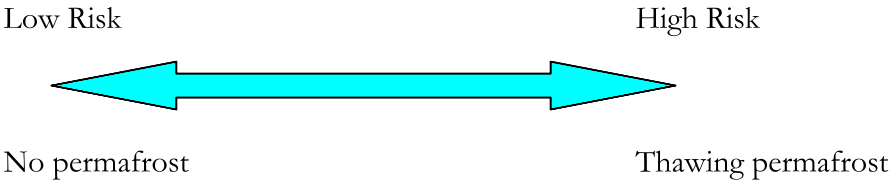
Those cities/boroughs who used climate change forecasts in their strategic planning processes tended to be larger, in geographic locations with risk factors (presence of discontinuous permafrost, coastal location), were in some cases already facing difficulties from climate change related events, and their current water infrastructure system displayed a low degree of adaptability.

IX. Discussion and Analysis: Risk Matrix and Exposure Ratings

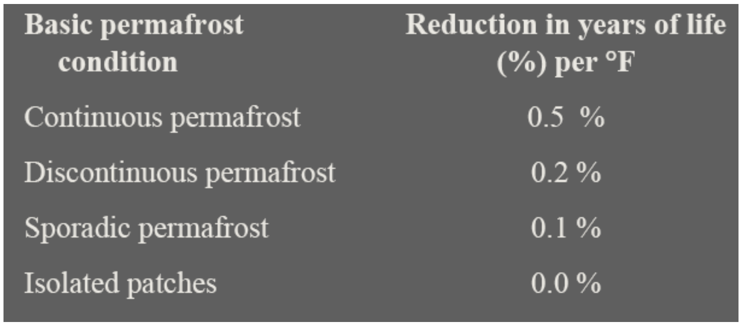
A matrix was created to make more explicit and correlate exposure risk factors of water system infrastructure in selected communities to climate change. Each box was scored and given an exposure rating (low, medium, and high) to determine the severity and likelihood of climate change risk. The risk factors included were:

A. Risk Factors

- **Presence of thawing permafrost**. Communities where different freeze-thaw cycles are expected in the discontinuous permafrost and where permafrost was expected to begin thaw are at a higher risk than communities where permafrost is not present.



Economists and policy analysts at the Institute of Social and Economic Research (ISER) at the University Alaska-Fairbanks have been trying to estimate the risk to public infrastructure from rapid Artic climate change. The table below shows the results of their analysis regarding the useful life reduction of infrastructure due to thawing permafrost. The greatest reduction in infrastructure life span is found in continuous permafrost, as many structures built on continuous permafrost were not done so with thawing in mind. Areas that are mostly thawed or contained no permafrost face the least reduction in life span (Engineers Perspective, 2007).

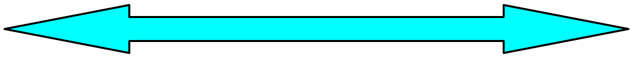


Basic permafrost condition	Reduction in years of life (%) per °F
Continuous permafrost	0.5 %
Discontinuous permafrost	0.2 %
Sporadic permafrost	0.1 %
Isolated patches	0.0 %

- **Community location**: Communities who are more remote and near the coast are more vulnerable to the effects of climate change. For example, Coastal community infrastructure is facing increasing exposure to storms and other implications due to the melting of sea ice and rising sea levels. The thawing of permafrost also threatens to further weaken coastal lands. Water contamination due to more frequent and severe saline intrusion from storm surges (seawater entering water bodies used as sources) and rising sea levels (saline water entering coastal river intake and intrusion into groundwater systems) is predicted to increase.

  Additionally, in northern Alaska, rough terrain and great distances isolate rural communities from the major population centers in the south. Their harsh environment and limited economic resources hamper water infrastructure such as piped distribution and collection. Their systems are highly dependent on sanitation roads and boardwalks, which are threatened by buckling and thawing permafrost.

Low Risk High Risk



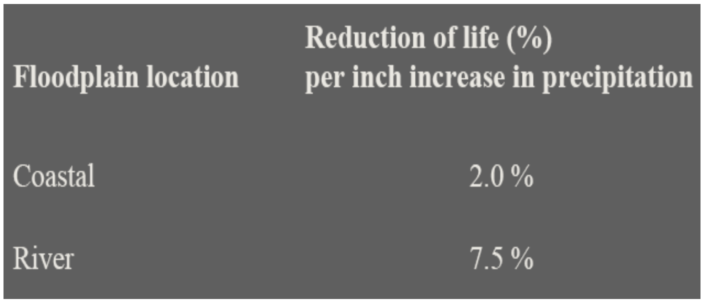
Inland
Southern

Coastal/near River Floodplain
Remote/Northern

In the graph to the right, the ISER group calculated the useful life reduction due to coastal exposure. As can be noted, an exposed coastal location leads to the highest reduction in life capacity per degree F, while a protected coastal location leads to a 1% reduction of life span (Engineers Perspective, 2007).

Coastal Location	Reduction of life (%) per °F
Exposed	7.5 %
Protected	1.0 %
Interior	0.0 %

In another table the ISER group calculated the useful life reduction to due to flooding from coastal and river locations (Engineers Perspective, 2007).



Floodplain location	Reduction of life (%) per inch increase in precipitation
Coastal	2.0 %
River	7.5 %

- **Water system source.** Surface water sources tend to be more vulnerable to increased incidences of turbidity, organic matter, disease and saline intrusion than ground water sources. Some ground water sources, however, may be impacted due to isostatic rebound or thawing permafrost. Additionally, communities with multiple sources for their water are at less risk communities with only one water source.

Low Risk	High Risk
Ground	Surface
Frozen/Non-frozen conditions	Freeze/Thaw cycles
Multiple sources	One source
Filtration System	No filtration/chlorination

- **Adaptive capacity**: Adaptive capacity refers to the ability of the system to adjust to climate change (including climate variability), to take advantages of opportunities, or to cope with the consequences. Community size and economic resources available to the community are a part of this category.[13] Typically, larger towns have greater adaptive capacity due to more staff and money, and larger infrastructure operations.

Low Risk	High Risk
Large community size	Small community size
Large budget	Small budget
Large staff	Small staff

- **Type of infrastructure**: There are many different types of water infrastructure systems in Alaska. Lagoons tend to be more susceptible to climate change impacts than secondary treatment facilities. Presence of a filtration system is another layer of protection for facilities that may face increased turbidity and presence of pathogens/organics.[14] Furthermore, PVC plastic piping is more likely to shatter in freeze/thaw cycles or colder temperatures than high-density polyethylene (HDPE) piping.

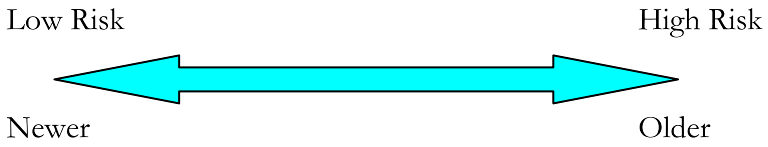
Low Risk	High Risk
Secondary Treatment	Lagoons
Filtration System	No treatment
HDPE piping	PVC piping

---

[13] Several of Alaska's water sources contain naturally occurring arsenic. EPA's new arsenic rule will put ~75 mostly small and rural water systems out of compliance (White, 2003).

[14] Many surface water (and some groundwater) sources used by small communities in Alaska contain high concentrations of organic matter often called "tundra tea" (White, 2003). According to White (2003), EPA's Stage 1 Disinfectant and Disinfection Byproducts Final Rule (D/DBPR) and Stage 2 D/DBPR will make it more difficult for many of Alaska's smallest communities to comply using existing technology.

- **Age of infrastructure**: Most infrastructure investments have a lifetime of 20-30 years. New infrastructure has been built with more up-to-date, climate versatile technology.



B. Risk Matrix

The discussed risk factors are a good starting point for evaluating the potential for effects and key impacts of climate change on a communities water infrastructure system. The following table identifies high, medium and low risk communities based upon these factors. The communities are listed in alphabetical order. Red indicates an overall high risk to the effects of climate change, yellow is medium, and green is a low risk.

Table 2: Water System Infrastructure Risk Assessment Matrix for Selected Communities in Alaska.

Water System Infrastructure Risk Assessment Matrix for Selected Communities in Alaska

	Risk Factors					
Community	**Presence of thawing permafrost**	**Community Location**	**Water System Source**	**Adaptive Capacity**	**Type of Intrastructure**	**Age of Infrastructure**
Anchorage	Low Risk	Low Risk	Low Risk (three sources - surface and ground water)	Low Risk (largest municapality in Alaska)	Low risk	Medium (some infrastructure is older)
Barrow	High Risk	High Risk (remote, northern coast)	Medium Risk (one surface water source, constructing second source)	Medium Risk (medium size town; research station nearby)	High Risk (sewage lagoons, utilidor)	High Risk (older infrastructure)
Bethel	High Risk	Medium Risk (located near river, which has shifted course, forcing parts of town to move)	Medium Risk (ground water, but risk of contamination with permafrost thawing)	Medium Risk (medium size town)	Medium (water/sewer pipes located above ground)	Medium Risk
Dillingham	Low Risk	High Risk (remote, western coast, at confluence of two rivers)	Low Risk (ground water)	Medium Risk (small town in remote location, however, largest town in area)	Medium (sewage lagoons or private haul)	Medium Risk (more infrastructure is needed to the northeast, additional water supply)
Fairbanks	Low Risk (already in active zone)	Medium Risk (interior is expected to have increased climatic extremes)	Low Risk (abundant water supplilied by deep wells)	Low Risk (large city - privately owned water and sewer systems)	Medium (sewage lagoon)	Medium Risk (infrastructure is older - prone to failure in extremes)
Homer	Low Risk	Medium Risk	High Risk (one surface water source, turbidity and algae issues)	Medium Risk	Medium	High Risk (older outdated technology, but building new system)
Juneau	Low Risk	Medium Risk	Low-Medium Risk (current abundance of surface and ground water, but have noticed some decline)	Low risk	Medium Risk (currently has a combined wastewater system, gravity discharge)	Medium Risk
Ketchikan	Low Risk	Medium Risk (coastal)	Medium (surface source)	Low Risk (medium-large city	Low Risk (designed for extreme weather)	Low Risk
Kenai	Low Risk	Medium Risk (coastal)	Low-Medium (ground water, no treatement, some saline intrusion, 25% of population on individual wells)	Medium Risk	Low-Medium (sewage recieves secondary treatment)	Low-Medium (growth in area)
Kodiak	Low Risk	High Risk (remote, coastal community)	Low-Medium (two surface water sources)	Low (medium sized town, current excess capacity)	Low risk	Low Risk
Kotzebue	High Risk	High Risk (remote, coastal community)	Medium (surface source)	High Risk (smaller town)	Mediuim Risk (sewage lagoon, piping on ground)	High Risk (aging 30 year old lagoon facility)
Nome	High Risk	High Risk (remote, coastal community)	Low-Medium (ground water)	High Risk (smaller town)	Medium Risk	High Risk (older infrastructure - burried utilidor from the 1960s needs replacement)

Community	Presence of thawing permafrost	Community Location	Water System Source	Adaptive Capacity	Type of Intrastructure	Age of Infrastructure
Palmer	Low Risk	Low Risk	Low Risk (three deep ground water sources)	Low-Medium Risk	Low Risk	Low Risk (recently upgraded)
Petersburg	Low Risk	High Risk (coastal, low-lying community)	Medium (surface source)	Medium (smaller, but top commercial fishing and timber port)	Medium Risk (sewage lagoon)	Low-Medium (although much of the system has been recently upgraded, 22% of pipes still need to be replaced)
Sitka	Low Risk	Medium Risk (coastal)	Low-Medium (two surface sources)	Low-Medium	Med-High Risk (CSO events, sewage lagoons)	Medium-High Risk (aging)
Seward	Low Risk	Medium Risk (coastal)	Low (ground sources)	Medium (growing small town)	Med-High Risk (CSO events, sewage lagoons)	Medium
Togaik	Low Risk	High Risk (remote, coastal community)	Low (ground sources)	High Risk (smaller town)	High Risk (outdated technology, storm surges)	High Risk (system is 25-30 years old and suffers from broken pipes)
Unalaska	Low Risk	High Risk (remote, coastal community)	Low-Medium (two surface water sources)	Medium Risk	Low risk (designed for extreme weather)	Medium Risk
Valdez	Low Risk	Medium Risk (coastal)	Low-Medium (four ground water sources, but currently not treated)	Medium Risk (Medium sized town, but important port)	Medium Risk (large capacity, secondary lagoon that discharges into andronomous habitat)	Medium-High Risk (they may need to replace current copper pipes with artic (HDPE))
Wasilla	Low Risk	Low Risk	Low (three ground sources, most use indiviudal wells)	Low-Medium	Low Risk	Medium (high population growth rate)

Although many communities have a high risk for at least one of the risk factors, there were five communities either due to some extreme circumstance (i.e. aging pipes) or a combination of factors were classified as “high risk”. These communities included:

- Barrow
- Bethel
- Kotzebue
- Nome
- Togiak

X. Policy Findings – Recommendations for EPA Region 10

As the EPA begins to acknowledge the importance of climate change and plan for its implications, the following recommendations will enable EPA in the short term to more effectively develop policies and strategies for climate change's impacts on water infrastructure operations, maintenance, and construction in Alaska.

EPA Region 10 should:

- **Take an integrated look at climate change;**
- **Form partnerships with other ongoing climate change efforts to keep abreast of new research results;**
- **Develop a system-wide data base summary of the water infrastructure systems in Alaska;**
- **Include potential impacts from climate change in land-use planning and infrastructure design;**
- **Build upon preliminary risk assessment, using risk factors to assess climate change water infrastructure vulnerability in other communities;**
- **Support local knowledge and the monitoring of local conditions, as well as the downsizing of global and regional forecasting efforts;**
- **Encourage information exchange amongst local/state/federal agencies, researchers, planners, and water infrastructure managers/operators;**
- **Focus on climate changes that are likely to occur in the next 10-20 years.**

Integrated look at climate change

Climate change effects may lead to significant ecological, financial, and health impacts across a wide sector of industries. Thus, responses to its effects necessitate integrated thinking. Although it is important to understand the implications of climate change on water infrastructure, such effects may be irrelevant in comparison to communities who rely on the timber or fishing industries for their economic survival.

Partnerships with ongoing efforts

There are many centers, commissions, and researchers looking at climate change impacts and their implications for Alaska.

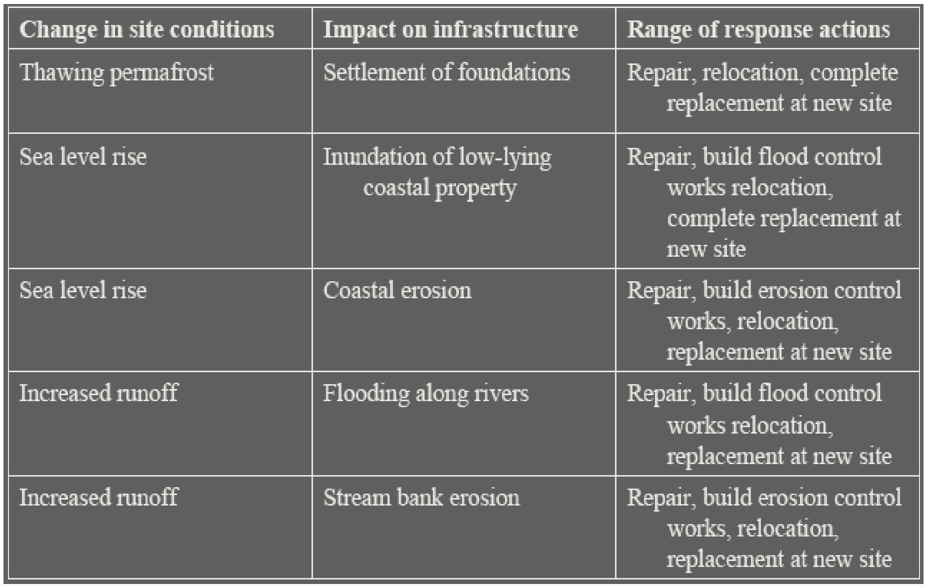
Such ongoing local efforts include (this list is not meant to be exhaustive). A more thorough description of their missions and strategies is located in Appendix D and E:

- Alaska Climate Impact Assessment Commission (ACIAC)
- Alaska Center for Climate Assessment and Policy (ACCAP)
- Artic Climate Impact Assessment (ACIA)
- Institute of Social and Economic Research Center (ISER) at the University of Alaska-Fairbanks
- International Arctic Research Center (IARC) at the University of Alaska-Fairbanks
- University of Alaska-Fairbanks (UAF) – Institute of Northern Engineering (INE)
- The Denali Commission

In addition to these regional groups, there are a number of other international assessments studying climate change impacts (on infrastructure) in the artic. Because climate change trends are expected to continue with slight enhancement, it is imperative that such research efforts, especially local groups, partner to meet information needs. Collaborative efforts will allow groups to use their strengths more efficiently to quickly build and enhance the current knowledge of climate change effects, impacts, and mitigation/adaptation strategies. Furthermore, as a major regulator and funding source for water infrastructure projects, the EPA should be at the table during discussions that seek to integrate science and policy for more informed decision-making.

Develop a system-wide data base summary of the water infrastructure systems in Alaska. As mentioned earlier, Alaska does not have a central depository that compiles important water infrastructure information by location. Although Alaksa does have an online searchable community database (the Department of Commerce and Economic Development: http://www.commerce.state.ak.us/dca/commdb/CF_COMDB.html) this information is not always complete and not available in summarzied form. A summary of the water infrastructure systems in Alaska should include such information as community location, type of water source, community population, anticipated increase/decrease in demand, age of infrastructure, water treatment system type, water distribution system used, and wastewater disposal system. Although ISER is currently complining an Alaksa infrastructure database, at this time it is unclear if such information listed above will be included in the database.

Include potential impacts from climate change in land-use planning and infrastructure design The graph to the right by the ISER group shows range of potential impacts on infrastructure and a range of responses to changes in site conditions from climate change (Engineer's Perspective, 2007).



Change in site conditions	Impact on infrastructure	Range of response actions
Thawing permafrost	Settlement of foundations	Repair, relocation, complete replacement at new site
Sea level rise	Inundation of low-lying coastal property	Repair, build flood control works relocation, complete replacement at new site
Sea level rise	Coastal erosion	Repair, build erosion control works, relocation, replacement at new site
Increased runoff	Flooding along rivers	Repair, build flood control works relocation, replacement at new site
Increased runoff	Stream bank erosion	Repair, build erosion control works, relocation, replacement at new site

Climate change is occurring at the local level, thus adaptation and planning must occur at the local level. EPA should encourage and support the use of climate change impacts in infrastructure planning decisions. EPA should also consider explicitly stating "ability to cope with climate change" in their four pillars of Sustainable Infrastructure Initiative.

Risk factors can be used to assess vulnerability and inform planning processes. The factors presented and discussed earlier were:

- Presence of thawing permafrost
- Community location
- Water system source
- Adaptive capacity
- Type of infrastructure
- Age of infrastructure

When encouraging the inclusion of climate change impacts for planning purposes, these risk factors provide an excellent starting point for a vulnerability analysis for the EPA and other stakeholders. Additionally, as Alley et al. (2005) recommends, it is critical that policy makers take into consideration abrupt climate change when discussing climate change implications for high-risk communities.

Support local knowledge and monitoring local conditions

It is critical to have local observations/information to validate/refine projections and forecasts, thus the EPA should support local efforts to identify these trends. According to the Study of Environmental Artic Change's (SEARCH) 2001 Science Plan, a largely untapped source of information relevant to the artic…is the base of "traditional knowledge" accumulated by long time residents of the artic, particularly the native communities (SEARCH, 2001). Mendelsohn (2006) suggests communities should start monitoring basic indicators for water and sanitation systems to help prepare for the affects of climate change. Such indicators include:

- Trends in the saline content of coastal fresh water source(s)
- Concentrations of types of contaminants in water source(s)
- Repair costs for sanitation infrastructure, boardwalks, and roads
- Movements of structures on permafrost
- Shoreline/river bank erosion rates
- Flood depth and occurrence frequency
- Loss of water containment in tundra ponds, lakes, reservoirs, and lagoons
- Trends in ice thickness, duration, and extent
- Trends in snowfall/rainfall
- Incidence of waterborne diseases

Additionally, it is critical for the EPA to have local stakeholder involvement and buy-in for any decisions made on infrastructure planning processes. Furthermore, although there is not much of a role for the EPA to provide, there are local capacity needs in the way of qualified workers and engineers - especially in rural communities. Alaska currently graduates half of the national average of engineers. According to Professor Orson Smith, Alaska needs to double the annual number of engineering degrees awarded in the state to meet current and projected demand (Smith, 2007).

Support downsizing of global and regional forecasting efforts

In order for improved decision-making regarding the potential impacts of climate change, more research of downsizing global and regional forecasts should be supported.

Information Exchange

The EPA could play a valuable role in education and outreach to the public on the impacts of existing scientific research. Additionally, the EPA could play an important role in making sure that information exchanges are occurring between public works directors/system operators/planners and scientists. Many public works directors/system operators and planners said that climate change was either not on their minds or very difficult to plan for. With increased information flow, more informed decisions could be made regarding the implications of climate change for water infrastructure management and construction in Alaska. Because many Alaskan communities may be forced to contend with similar implications from climate change, there is a unique opportunity for collaboration and partnership.

Furthermore, interaction with economists by both scientists and local managers/planners is critical to estimating costs associated with climate change impacts and adaptation. Without more information on what these costs and benefits are expected to be, water infrastructure planners and operators will continue to find it difficult to assess what climate change means for their communities.

Focus on climate changes that are likely to occur in the next 10-20 years. Due to climate change uncertainty, there is not much that can be done today to anticipate changes 50-100 years from now (Mendelsohn, 2006). Most water infrastructure systems, however, have lifetimes of 20-30 years in the harsh artic environment. As time passes and greater knowledge is collected about how models have predicted what changes have actually come to pass, communities will be in better positions to understand, anticipate, and plan for the impacts of climate change.

XI. Conclusion

"Cheshire Cat," Alice began, "Would you tell me, please, which way I ought to go from here?""That depends a good deal on where you want to get to," said the Cat.
-Lewis Carroll

There is now scientific consensus that climate related warming trends are unequivocally occurring and unavoidable for centuries to come. Although the impacts and stresses of climate warming faced by Alaska may be more intense and immediate, they are an indication of the types of climate related planning issues the rest of the lower 48 states may face in the future. It is pertinent to look at the climate change impacts of waste water and drinking water systems, because they typically have long lifetimes, significant capital costs, and design characteristics that are directly tied to location and hydoclimatological characteristics.

Identifying the impacts of climate change, their effects on water infrastructure, and creating climate-related risk factors in planning schemes will help decision-makers prepare now for the effects of climate change and guide resources to where they will have the most benefit. More effort will be needed to gather information, coordinate, educate, and "downscale" global climate models in order to facilitate planning for (and adapting/mitigating) the effects of climate change.

Michael Oppenheimer, climate scientist at Princeton University and lead author of a recent report by a United Nations panel on the impacts and vulnerability presented by climate change was quoted in the New York Times as saying, 'We haven't sat down as a society and said, "How are we going to adapt to this?"'. Although many options are available ranging from the technological, to the behavioral, managerial, to policy, it remains to be seen if they are politically, institutionally, and economically viable. What is for certain is that the "way we ought to go from here" will be determined under future climate conditions that differ significantly than those of the past century.

Appendix A: Table of water infrastructure managers/planners interviewed

Interview Participants				
Community	**Name**	**Title**	**Date**	**Method**
Anchorage	Alison Sterling	Planning Engineer, City of Anchorage	5.08.2007	Email
Barrow	Ben Frantz	General Manager of Public Works Department	4.24.2007	Phone Interview
Bethel	Wayne Ogle	Public Works Director	5.01.2007	Phone Interview
Fairbanks	Dave Dean	Utility Services of Alaska System Director	5.01.2007	Phone Interview
Homer	Jim Hobbs	Water Treatment Plan Operator	5.08.2007	Phone Interview
Juneau	Liam Carnahan	Juneau	4.24.2007	Phone Interview
Ketchikan	John Kleinegger	Water Division Manager	5.01.2007	Email
Kenai	Jack La Shot	Public Works Director	5.15.2007	Phone Interview
Kodiak	Mark Kozak	Public Works Department Director	5.01.2007	Phone Interview
Kotzebue	Jeff Hadley	Public Works Director	4.24.2007	Phone Interview
Petersburg	Karl Haggerman	Public Works Director	5.08.2007	Email
Sitka	Mark Buggins	Environmental Superintendent	5.14.2007	Email
Tugaik	Darryl Thompson	Public Works Director	5.15.2007	Phone Interview
Unalaska	J.R. Pierson	Utilities Analyst/Compliance Coordinator	4.24.2007	Email
Valdez	Larry Weaver	Public Works Director	5.15.2007	Phone Interview

Appendix B: Questions Asked to Water Managers/Planners

- Do you use climate forecasts in actual infrastructure related decision-making? If so, please explain how.
- What forecast information would be the most useful to you?
- How could forecast information be better tailored to water management and operations?
- Do you feel your infrastructure will be impacted by climate change?
- What do you see as the biggest climate related threats to your water infrastructure systems?
    - Thawing permafrost
    - Increased rainfall/flooding events
    - Melting of sea ice/glaciers
    - Rising sea level
    - Other (please describe)
    - None
- What types, severity of change do you feel capable of handling/adapting to?
- Are these impacts, preventable, can your system adapt, or will replacement be necessary?
- Are there any other additional comments you would like to add relating to climate change impacts on water infrastructure that I have not asked about?

Appendix C: From the IPCC 2007 Summary for Policymakers:

The Emission Scenarios of the IPCC Special Report on Emission Scenarios (SRES)

A1. The A1 storyline and scenario family describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid-introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system. The three A1 groups are distinguished by their technological emphasis: fossil intensive (A1F1), non-fossil energy sources (A1T), or a balance across all sources (A1B).

A2. The A2 storyline and scenario family describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing population. Economic development is primarily regionally orientated and per capita economic growth and technological change more fragmented and slower than other storylines.

B1: The B1 storyline and scenario family describes a convergent world with the same global population, that peaks in mid-century and declines thereafter, as in the A1 storyline, but with rapid change in economic structures toward a service and information economy, with reductions in material intensity and the introduction of clean and resource efficient technologies. The emphasis is on global solutions to economic, social and environmental sustainability, including improved equity, but without additional climate initiatives.

B2: The B2 storyline and scenario family describes a world in which the emphasis is on local solutions to economic, social, and environmental sustainability. It is a world with continuously increasing global population, at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. While the scenario is also oriented towards environmental protection and social equity, it focuses on local and regional levels.

****The SRES scenarios do not include additional climate initiatives, which means that no scenarios are included, that explicitly assume implementation of the United Nations Framework Convention on Climate Change or the emissions targets of the Kyoto Protocol.

Appendix D: Ongoing Efforts Studying Climate Change Impacts and Implications for Alaska[15]

Alaska Climate Impact Assessment Commission (ACIAC). The ACIAC was established by HCR 30 (Legislative Resolve 49) in 2006 and is charged with assessing the effects of climate change in the Artic, as would affect the citizens, resources, economy and assets of the Stat of Alaska. The commission will assess the effects of "warming trends on the citizens, natural resources, public health, economy, natural resource development, forest safety, fish and game utilization, transportation, communities and resource development infrastructures". The commission will "estimate the costs of adverse climate change to Alaska's citizens and state, recommending policy and regulatory changes, and identify and coordinate efforts of mutual concern with federal, state, and local entities. A preliminary report to the Alaskan Legislature was submitted on March 1, 2007 and a full report is expected on June 10, 2008.

Alaska Center for Climate Assessment and Policy (ACCAP). The ACCAP was established in 2006 core funding from the Climate Program Office of the National Oceanic and Atmospheric Administration (NOAA). ACCAP is one of a group of Regional Integrated Sciences and Assessments (RISA) programs nation-wide.[16] They currently focus on climate impacts to Alaska's transportation sector. Over time, they envision expanding the network to include wildfire, ecosystem services and other infrastructure issues. They aim to:

- Create research partnerships to meet information needs
- Integrate science and policy for more informed decision-making
- Promote continuing feedback between information users and scientists

Artic Climate Impact Assessment (ACIA) provides scientific research on the current effects of climate change in the artic. It is an international project of the Arctic Council and the International Arctic Science Committee (IASC), to evaluate and synthesize knowledge on climate variability, climate change, and increased ultraviolet radiation and their consequences. ACIA, however, does not address the economic effects of climate change.

Institute of Social and Economic Research Center (ISER) at the University of Alaska-Fairbanks is currently working on a probabilistic model to estimate the value of Alaska public infrastructure at risk to climate change. Publication of this research is currently pending.

International Arctic Research Center (IARC) at the University of Alaska-Fairbanks has as its primary mission to nurture, integrate and synthesize research being conducted internationally by individuals and groups in order to identify natural and man-made changes. The Center's emphasis is to provide an opportunity to share knowledge about science in the Arctic, with an emphasis on global change research.

University of Alaska-Fairbanks (UAF) – Institute of Northern Engineering (INE) members conduct research in electrical, environmental, mechanical, civil and transportation

---

[15] This list in not meant to be exhaustive, but illustrative of the many and varied efforts currently underway.

[16] A map of other RISA's is located in Appendix E.

engineering, as well as areas such as atmospheric studies, water resources and several areas of sub-arctic research.

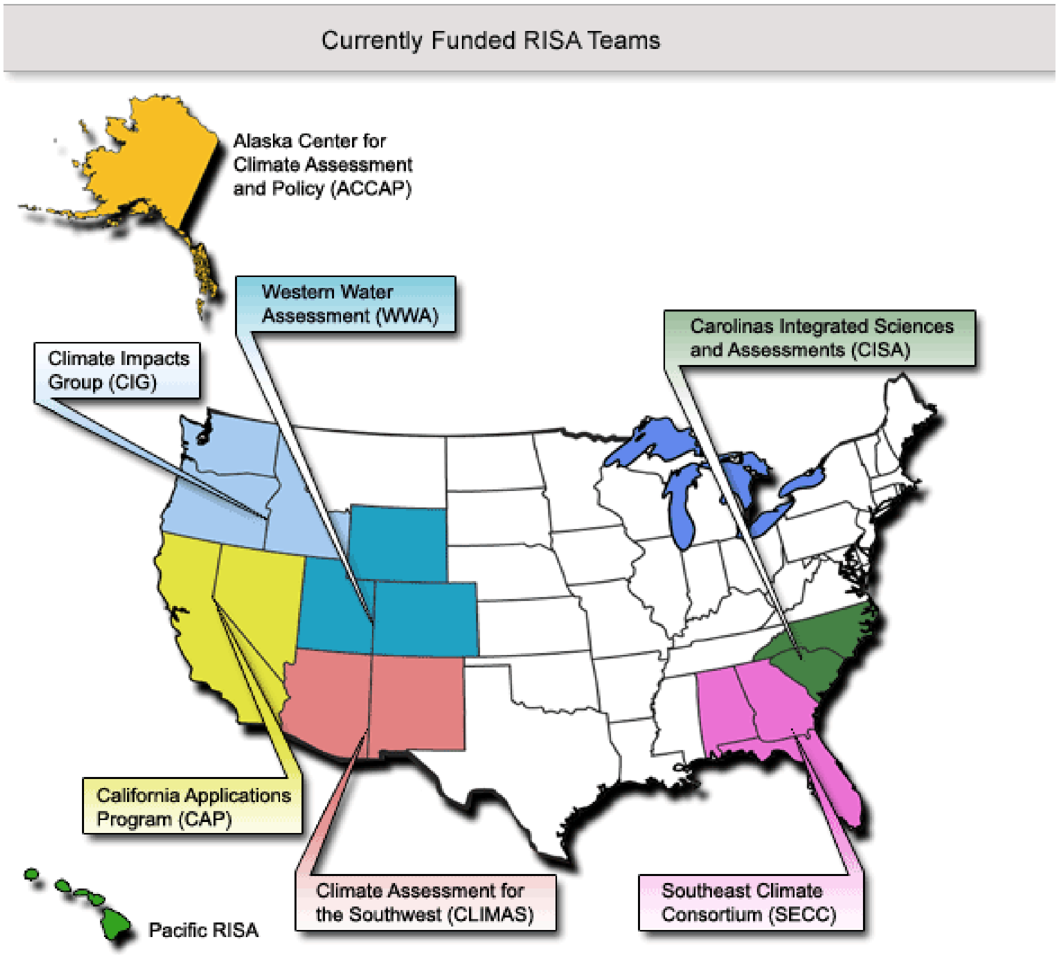
The Denali Commission was created by congress in 1998, as a federal-state partnership designed to provide critical utilities, infrastructure, and economic support throughout Alaska. Congress acknowledged saw the need for increased inter-agency cooperation and focus on Alaska's remote communities.

Appendix E: NOAA: Climate Program Office – Regional Integrated Sciences and Assessments

The Regional Integrated Sciences and Assessments (RISA) program supports research that addresses complex climate sensitive issues of concern to decision-makers and policy planners at a regional level. The RISA research team members are primarily based at universities though some of the team members are based at government research facilities, non-profit organizations or private sector entities. Traditionally the research has focused on the fisheries, water, wildfire, and agriculture sectors. The program also supports research into climate sensitive public health issues. Recently, coastal restoration has also become an important research focus for some of the teams.

The Alaska Center for Climate Assessment and Policy was founded in 2006 and currently focuses on transportation and water resources management.

.



Appendix F: References

ACIA. ACIA Scientific Report: Artic Climate Impact Assessment (2005). Cambridge University Press, New York. http://www.acia.uaf.edu/pages/scientific.html (Accessed online)

ACIA. ACIA Policy Document (2004). Issued at the Fourth Artic Council Ministerial Meeting. http://www.acia.uaf.edu/PDFs/ACIA_Policy_Document.pdf (Accessed online)

AK Climate Impact Assessment Commission, Preliminary Report to the Legislature, March 1, 2007. http://www.housemajority.org/coms/cli/commission_preliminary_report.pdf. Accessed online May 18, 2007.

Alaska Native Village Water Infrastructure Assessment (2006). http://www.whitehouse.gov/omb/expectmore/summary/10002272.2006.html (Accessed January 24, 2007).

Alaskan Office of Economic Development. Alaska Information. http://www.dced.state.ak.us/oed/student_info/learn/information.htm (Accessed online January 24, 2007)

Alaska Community Database – Department of Commerce, Alaska. http://www.commerce.state.ak.us/dca/commdb/CF_COMDB.html (Accessed online)

Alley, R.B., J. Marotzke, W. D. Nordhaus, J. T. Overpeck, D. M. Peteet, R. A. Pielke Jr., R. T. Pierrehumbert, P. B. Rhines, T. F. Stocker, L. D. Talley, J. M. Wallace, (2003, March) Abrupt Climate Change. *Science* 28:Vol. 299. no. 5615, pp. 2005 – 2010.

An Engineer's Perspective on Climate Change Impacts to Alaska Infrastructure. Presentation by Orson Smith to the ACIAC, February 2007. http://www.housemajority.org/coms/cli/uaa_orson_smith.pdf (accessed online)

Berner, Jim, Terry Callaghan, Shari Fox, Etc. "Arctic Climate Impact Assessment Highlights." (2004) http://amap.no/acia/Highlights.pdf. (Accessed May 8, 2007).

Cole H., V. Colonell, and D. Esch (undated). The Economic Impact and Consequences of Global Climate Change on Alaska's Infrastructure

CRS Report for Congress on Water Infrastructure Needs and Investment: Review and Analysis of Key Issues – RL 31116. Claudia Copeland and Mary Tenmann. (Updated May 5, 2005).

Department of Environmental Conservation. Presentation to Alaska Climate Impact

Assessment Commission. January 24, 2007. http://www.housemajority.org/coms/cli/DEC_Chapple_Juneau.pdf. (Accessed 5.18.2007)

EPA's 2003 Drinking Infrastructure and Needs Survey and Assessment (2005). www.epa.gov/safewater (accessed January 19, 2007)

EPA Sustainable Infrastructure for Water and Wastewater. http://www.epa.gov/waterinfrastructure/ (accessed online March 20, 2007)

Forest, C. et al (2002). Quantifying Uncertainties in Climate system Properties with the Use of Recent Climate Observations. *Science* 295,113.

Gamble, J.L., Furlow J., Snowver, A.K., Hamlet, A.F., Morehouse, B.J., Hartmann, H. and Paganot T., (2004). Assessing the Impact of Climate Variability and Change on Regional Water Resources: The Implications for Stakeholders, pp 341-368, *Water: Science, Policy and Management*, R. Lawford et al., editors, Water Resources Monograph No. 16, AGU Press

Hengeveld, H. (2002) *Review and Assessment of New Research Developments Relevant to the Science of Climate Change.* Climate Report. Environment Canada. Meteorological Service of Canada, Ontario. Winter 2002. 34pp.

Hinzman, Larry D. et al. (2005). Evidence and Implications of Recent Climate Change in Northern Alaska and Other Artic Regions. *Climatic Change* 72(3):251-298.

Intergovernmental Panel on Climate Change – IPCC (2001). Climate Change 2001: Impacts, Adaptation, and Vulnerability, Summary for Policymakers and Technical Summary of the Working Group II Report. http://www.IPCC.CH/ (accessed January 25, 2007)

Intergovernmental Panel on Climate Change – IPCC (2007). Climate Change 2007: The Physical Science Basis – Summary for Policy Makers. http://IPCC.CH/ (accessed February 7, 2007).

IPCC (2001). Climate Change 2001: North America. http://www.IPCC.CH/ (accessed January 24, 2007)

Institute of Social and Economic Research, University of Alaska Anchorage (2006). *Understanding Alaska: People, Economy and Resources. http://www.alaskaneconomy.uaa.alaska.edu (accessed January 24, 2007).*

Jones R.N. and Pittock, A.B. 2000. Managing uncertainty in climate change projections – issues for impact assessment. *Clim. Change* 45, 403-419.

Jones R.N. 2001. An Environmental Risk Assessment/Management Framework for Climate Change Impact Assessments. *Natural Hazards* 23:197-230.

Jones S.H. and Fahl, C.B. (1994). Magnitude and frequency of floods in Alaska and conterminous basins of Canada: U.S. Geological Survey Water Resources Investigations Report 93-4179, 122

Khrustalev LN, Pustovoit GP, Emel'yanova LV (1993) Reliability and durability of bases of engineering structures on permafrost soils under global climatic heating conditions. *Soil Mechanics and Foundation Engineering* 30(3): 92.

Larsen P.H., O.S. Goldsmith, O.P. Smith, and M.L. Wilson (2006). A Probabilistic Model to Estimate the Value of Alaska Public Infrastructure at Risk from Climate Change. Institute of Social and Economic Research, University of Alaska Anchorage. http://www.iser.uaa.alaska.edu/Publications/researchsumm/icicle.pdf (accessed January 24, 2007)

Bill Text of Legislative Resolve 49. http://www.housemajority.org/samuels/pdfs/hcr_030_2006.pdf. (Accessed online 5.18.2007)

Lettenmaier, D.P. (2004): The role of climate in water resources planning and management, pp 247-266 in *Water: Science, Policy and Management,*R. Lawford et al. editors, Water Resources Monograph no.16, AGU Press

McBeath, J. (2003). Institutional Responses to Climate Change: The case of Alaska Transportation System. *Mitigation and Adaptation Strategies for Global Change*, 8, 3-28.

Mendelsohn, Robert (2006). The Role of Marketing and Governments in Helping Society Adapt to a Changing Climate. *Climatic Change*. 78: pp 203-215.

Miller, Kathleen A. (1997). Climate Variability, Climate Change and Western Water – Report to the Western Water Policy Review Advisory Commission.

Molnia, Bruce F. U.S. Geographical Society. Documenting Changes in Alaskan Glaciers. http://www.housemajority.org/coms/cli/glacier_changes_molnia.pdf. (Accessed online 5.18.2007).

Morgan, M. G., M. Kandlikar, J. Risbey and H. Dowlatabadi (1999). "Why conventional tools for policy analysis are often inadequate for problems of global change." *Climatic Change* 41: 271-81.

Morison, J.H., K. Aagaard, and M. Steele (2000). Recent environmental changes in the Artic: A review, *Artic, 53*,4.

NOAA Artic Theme Page. http://www.artic.noaa.gov/essay_romanovsky.html. (Accessed online March 4, 2007).

Osterkamp, T.E., L. Vierek, Y. Shur, M.T. Jorgenson, C. Racine, A. Doyle, and R.D. Boone (2000): Observations of thermokarst and its impact on boreal forests in Alaska, U.S.A. *Artic, Antarctic and Alpine Research,* 32, 303-315

Osterkamp, T.E. and V.E. Romanovsky, (1999). Evidence for warming and thawing of discontinuous permafrost in Alaska, *Permafrost Periglac. 10*, 17-37.

Parry, M.L., Carter, T.R., and Hulme, M. (1996). *What is a dangerous climate change?* Global Environ. Change, 1-6.

Parson, E.A. et al. (2003). "Understanding Climatic Impacts, Vulnerabilities and adaptation in the United States: Building a Capacity for Assessment," *Climatic Change*, Vol 57, pp 9-42

Parson, E.A. (2000). Chapter 10: Potential Consequences of Climate Variability and Change for Alaska. National Assessment Synthesis Team: U.S. Global Change Research Program 2000. http://www.gcrio.org/NationalAssessment/overpdf/overview.html (accessed online)

Ramstorf, Stefan, Anny Cazenave, John A. church, James E. Hansen, Ralph F. Keeling, David E. Parker, Richard C.J. Somerville (2007). Recent Climate Observations Compared to Projections. *Science*. Vol. 316 (May 4), p 709.

Reilly, John et al. (2001). "Uncertainty and Climate Change Assessment. " *Science*, Vol. 293 (20 July), pp 430-433.

Richter-Menge, J., J. Overland, A. Proshutinsky, V. Romanovsky, L. Bengtsson, L. Brigham, M. Dyurgerov, J.C. Gascard, S. Gerland, R. Graversen, C. Haas, M. Karcher, P. Kuhry, J. Maslanik, H. Melling, W. Maslowski, J. Morison, D. Perovich, R. Przybylak, V. Rachold, I. Rigor, A. Shiklomanov, J. Stroeve, D. Walker, and J. Walsh. State of the Artic Report (2007): NOAA Special Report OAR PMEL, NOAA/OAR/PMEL, Seattle, WA, 36 pp (2006)

Rozell, Ned. Village water supplies in a warmer world. (2005, January 27). *Alaska Science Forum* http://www.gi.alaska.edu/ScienceForum/ASF17/1735.html (Accessed online March 25, 2007).

Seifert, Richard (2007). Permafrost: A Building Problem in Alaska. The University of Alaska Fairbanks Cooperative Extension Service. http://www.uaf.edu/ces/publications/freepubs/HCM-00754.pdf (Accessed online March 25, 2007)

Smith, Orson. (2007). Presentation to Joint Alaska Climate Impact Assessment Commission – An Engineers Perspective on Climate Change Impacts to Alaska Infrastructure. http://www.housemajority.org/coms/cli/uaa_orson_smith.pdf. Accessed online (May 19, 2007)

Smith, Orson, and Levasseur, George (2002). Presentation to the "Potential Impacts of Climate Change on Transportation: Workshop Summary and Proceedings. Impacts of Climate Change of Transportation Infrastructure in Alaska.

http://climate.volpe.dot.gov/workshop1002/index.html (Accessed online February 11, 2007).

Steinemann, Anne C., Using Climate Change for Drought Management. *Journal of Applied Meteorology and Climatology*. Volume 45, October 2006. 1353-1361.

Study of Environmental Arctic Change (SEARCH) Science Plan (2001). University of Washington. http://www.arcus.org/SEARCH/index.php (Accessed online May 27, 2007).

US National Assessment of the Potential Consequences of Climate Variability and Change *Education Resources* Regional Paper: Alaska. http://www.usgrcp.gov/usgrcp/nacc/education/alaska/ak-edu-3.html (Accessed online 3.24.07)

Ulmer, Fran. Presentation to the 2007 AFE Panel: Climate Change and the Economy: Challenges and Opportunities for Alaska Business Leaders. http://www.iser.uaa.alaska.edu/presentations/FransRoundTableFeb2007.pdf (Accessed online).

Washington Economic Steering Committee and the Climate Leadership Initiative/Institute for a Sustainable Environment, University of Oregon (2006). Impacts of Climate Change on Washington's Economy, A Preliminary Assessment of Risks and Opportunities. http://www.ecy.wa.gov/biblio/0701010.html (Accessed January 13, 2007)

White, D.M., D.S. Garland, J. Narr, C. Woolard (2003). Natural organic matter and DBP formation potential in Alaskan water supplies, *Water Research*, Vol 37/4 pp 393-947.

Warren, John A., Berner, James E., Curtis, Tine (2005). Climate Change and Human: Infrastructure Impacts to Small Remote Communities in the North. *International Journal of Circumpolar Health* 64:5 pp 487-497.

Yardley, William (2007) Victim of Climate Change, a Town seeks a Lifeline. *New York Times*. http://www,nytimes.com/2007/05/27/us/27newtok.html. (Accessed online 5.29.07)