# Challenges to community water security in Bristol Bay, Alaska

*A Report on Climate Change, Vulnerability, and Community Capacity*


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## *A Report on Climate Change, Vulnerability, and Community Capacity*

## *WERC-HD Occasional Report No. 02*

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## *About the Human Dimensions Laboratory*

*Faculty and students at the Human Dimensions Lab study coastal and environmental issues such as water and food security, marine resource policy and governance, environmental quality, and the engineered environment through a social and cultural frame.*

## *About Sustainable Futures North*

*The Sustainable Futures North (SFN) project is concerned with developing a more sophisticated understanding of the interactions among environmental security, natural resource development, and climate change in the North American Arctic and Subarctic regions. With principle study sites in Bristol Bay, Alaska, Kotzebue Sound, Alaska, and Baffin Island, Nunavut, SFN combines integrated assessments of community needs and challenges, ethnographic research, large-scale data synthesis, engineered systems analysis, and an education and outreach program intended to enhance community capacity for responding to change.*

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# Executive Summary

What impacts are climatic and environmental changes having on the water security of rural Alaskans? How are local managers and planners responding to these challenges? How can people in rural Alaska, a place that is often typified by the things it lacks—a statewide road system, affordable fuel and food, reliable year-long logistics, and other infrastructures that many people associate with industrialized nations—collaborate to achieve better outcomes in terms of environmental health and sustainability? These are the questions that this research set out to answer.

The newly-exposed bottom section of seawall illustrates rapid coastal erosion in Dillingham, AK.

What we found was that **context matters**, meaning in order to anticipate whether and how a community will be impacted by long term trends in warming or drying, for example, one needs to collect extensive background information on the community, its various freshwater resources, its built infrastructure, its human resources, etc. This is not necessarily a new observation, and other researchers have described how to best measure these various kinds of "capital", to determine the ways that communities are "vulnerable" and/or "resilient". However, what many of these studies fail to recognize is that communities in Alaska are not standing still, waiting to respond to some new environmental challenge. Rather, it takes many people working long hours every day to keep the lights on and the water flowing. These people, **the first responders to climate change in rural Alaska,** are busy solving problems, writing grants, training employees, and dealing with pesky researchers. In many cases they are working at or over their capacity, much like the various engineered systems that they keep running despite limited resources. To anticipate how communities will be affected, we need a better understanding of the challenges that these people face every day.

Our goal with this report is two-fold: to provide an accurate summary of the challenges facing water security in the Bristol Bay region, and to share what we learned from local workers about the context in which these challenges are experienced. We introduce language from two frameworks: "community capacity" and "cumulative effects". In a nutshell, the language in these frameworks collectively provide an effective way to characterize environmental challenges from the perspective of the first responder.

We intend that the findings and recommendations offered herein will improve understanding of policymakers, researchers, and other professionals with a bearing on rural issues, so that these first responders can find the support they need in pursuing a healthy and sustainable environment for their community.

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## 1. Introduction

This report explores the issue of water security in rural Alaska, focusing on the details of the Bristol Bay region (Figure 1). **Water security is an environmental management and human health concern that has received increased attention from academic, governmental and non-governmental sectors over the past decade**. It is an issue of growing concern across Alaska, and it is also a "nexus" issue, in that captures the confluence of multiple social, political, ecological, and climatic issues simultaneously. Water security therefore provides an ideal lens through which to evaluate the effects of social and environmental changes on Alaska's communities; water systems link hydrology with human communities through engineered systems and through local social and cultural practices and norms. In rural Alaska, water systems also exemplify many of the nuanced aspects of life in the north, including highly seasonal populations and lifestyles, livelihoods tightly coupled to the land, and hydrological systems in flux.

*Water security means having reliable access to affordable and safe water and sanitation services. In Alaska, this must also include the many ways that people rely on rivers and other bodies of water for transportation and subsistence activities.*

However, in contrast to many areas of the world where climate change and high demand challenge local communities with water shortages and changes in hydrological cycles, the problem in Alaska relates more to a lack of infrastructure than it does to insufficient water supplies. This is not to imply that climate change is not affecting hydrology in Alaska, but rather that the more immediate problem remains one of infrastructure, distribution, accessibility and water quality. Indeed, many rural Alaska homes do not enjoy "modern" piped water systems, or have in place the most basic sanitation infrastructure that one expects to find in most rural communities in the continental US and Canada. In many of the smallest villages, which can be home to as few as 20 people during the winter, sanitation consists primarily of outhouses and/or 'honey buckets'—five-gallon buckets topped with a toilet seat and lined with a trash bag that is disposed of outside the home.

A great deal of literature is already available that examines the sociocultural and health dimensions of the limited water infrastructure in rural Alaska, addressing such issues as skin, gastrointestinal, and respiratory infections (see the Bibliography for some representative citations). In many ways, water *insecurity* in rural Alaska is a manufactured problem, a nearly ubiquitous companion of the transition by Alaska Native peoples to living in fixed communities. Rural Alaskans want access to safe, clean water and state, federal, and non-profit agencies work hard to try to support community water security. Nevertheless, stark, and in many cases systematic challenges remain to developing water security across the state. The goal of this report is to explore these challenges.

Water security and insecurity are admittedly complex terms with shifting definitions, definitions that vary depending on the place, scale, or societal level of focus. For the purposes of this report, water security is defined generally, as when people have reliable access to affordable and safe water and sanitation services. By comparison, water *insecurity* can describe a variety of circumstances, including whether people are coping with some degree of water shortage or drought. It can also describe scenarios where people have consistent access to sufficient safe water, but the sources themselves are vulnerable to disruption. This is arguably the case for much of Alaska. Water security in Alaska also must take into account the many ways that rural people rely on rivers and other bodies of water for transportation and subsistence activities.

Thus, **water security as defined here also implies a degree of control over the quality and reliability of water resources, regardless of how that water is being used.** There is an important cultural dimension with respect to how control and self-sufficiency are defined. As such there are practical limits to generalizable and comparative measurable indicators of water security/insecurity and will be discussed in more detail in the methods section.

*In contrast to many areas of the world where climate change and high demand challenge local communities with water shortages and changes in hydrological cycles, the problem in Alaska relates more to a lack of infrastructure than it does to insufficient water supplies.*

Though universal measures and definitions for water security are rare, it is easy to recognize when people are not water secure, and most assessments of social and ecological challenges in the North identify water insecurity as a problem facing much of Alaska. For example, water resources figure prominently in Alaska Native Tribal Health Consortium (ANTHC)'s Center for Climate and Health climate change health impact assessments for eight communities across rural Alaska. Similarly, a recent study commissioned by the State of Alaska found that 25 rural communities are likely to face near-term impacts on their water and wastewater infrastructure from climate change, with another 44 communities also identified as potentially at risk.

To understand the full scale and scope of these challenges, however, it is important to understand the broader social, cultural, and economic circumstances in rural Alaska. Rural communities are undergoing a dramatic social and economic restructuring in the state, or ''dying'' in the words of some Alaska Natives, as many residents move out of the 'bush' and into Alaska's urban centers for jobs and access to less expensive food, fuel and healthcare. Basic resources cost more in rural Alaska (Figure 1); generally speaking, food and fuel prices are related, but for the most remote and rural communities in the state these costs are exacerbated. As a result communities can be especially vulnerable to the vagaries of the global geopolitics and economics. http://laborstats.alaska.gov/col/col.pdf

Food insecurity is also on the rise across Alaska. The statewide rate of food insecurity in Alaskan households in 2010 was 14.5% according to the US Department of Agriculture's "Household Food Insecurity in the United States" report, a report that has been released biennially since 2001. This rate is less than a national average reported by the same study (roughly 16%), but a "meal gap" model created by the non-profit organization Feeding America (www.feedingamerica.org) shows that rates of food insecurity in many rural and predominately-Alaska Native communities may be as high as 30%. What's more, these same models suggest that the highest values of food insecurity are likely among children in these regions.

These socioeconomic challenges, coupled with uncertain water security, result in an “axis of vulnerability”—a mutually reinforcing pattern of social, economic, and ecological problems.

## Climate Change Impacts

*Food and water security, combined with dramatic climatic and environmental change, and increasing costs of food and fuel, create an “axis of vulnerability” for rural Alaskans*

The impacts of a warming climate on Alaska have been pronounced and are projected to continue. Even communities with new and/or well-functioning water security infrastructure are experiencing or should expect to experience multiple challenges to the integrity and O&M of their water and wastewater systems. Alaska ‘s annual and seasonal warming trends have clear and measurable effects on hydrological variables including: winter frost depth, period of snow cover, form of precipitation (i.e., rain vs. snow), distribution, movement and quality of near-shore sea ice, permafrost condition, and growing season length.

Given the wide diversity of community water and wastewater systems found across the state coupled with the geographic size and variety of biogeographic regions, water security in Alaska requires a place-based approach with each community bearing its own suite of challenges. That said, shared environmental challenges do exist and are relevant for many communities. One example is permafrost, which is a key part of the cryosphere comprising nearly a quarter of the Northern Hemisphere. Permafrost is soil frozen for at least two consecutive years and typically forms where the mean annual air temperature is less than the freezing point of water. The extent of permafrost varies with temperature, vegetation and snow cover. When 90-100% of a large area is underlain by permafrost, that permafrost is termed continuous. Areas that are covered in 50-90% permafrost are called discontinuous, and this occurs in areas where mean annual air temperature is only slightly below 0 °C. In discontinuous zones, permafrost is often restricted to sheltered, low lying or north facing areas. Permafrost, especially in the discontinuous zones, is vulnerable to thaw to thaw as the climate warms (Figure 4).

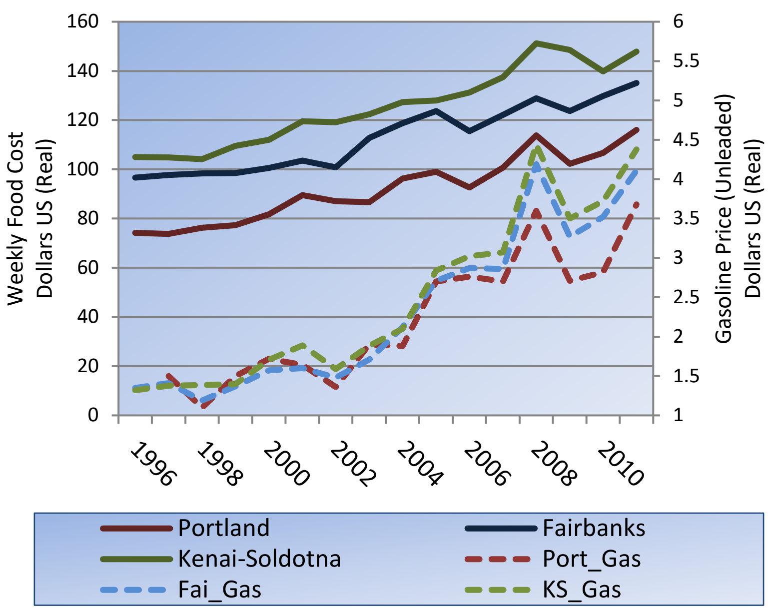



**Figure 1.** Weekly food costs for a family of four and gasoline prices for Fairbanks, AK, Kenai-Soldotna, AK, and Portland, OR. Data are from the UAF Cooperative Extension Service.

When ice rich permafrost thaws, ice melts away and the

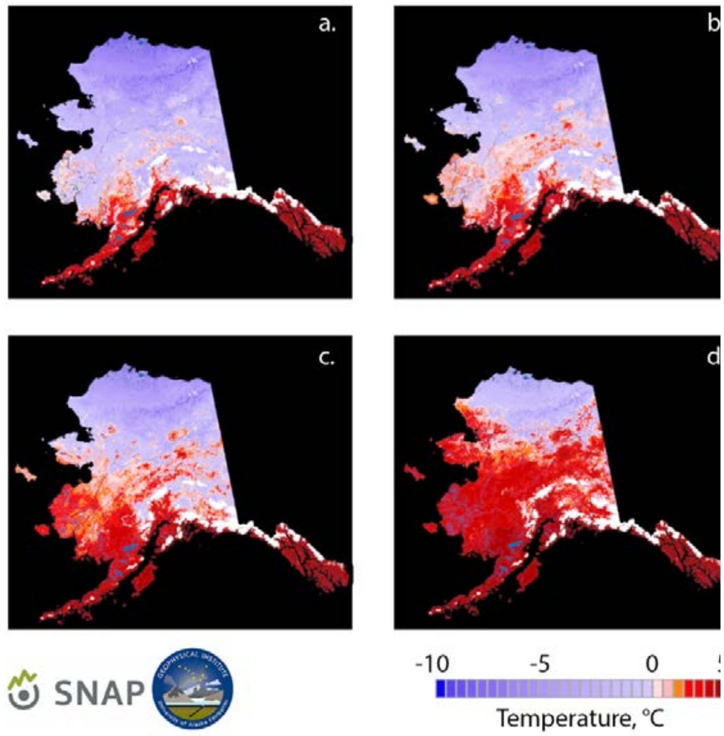



**Figure 2.** Permafrost in Alaska, represented by mean annual soil temperature projections at 1m depth for a)2010-2019, b) 2030-2039, c) 2050-2059, and d) 2090-2099. Images courtesy of the Scenarios Network for Alaska and Arctic Planning (SNAP), and the Permafrost Laboratory, Geophysical Institute, University of Alaska Fairbanks.

surrounding soil can settle significantly resulting in depressions in the landscape. This can significantly impact local hydrology as well as negatively impact infrastructure on the thawing ground. Thawing permafrost can disrupt water services in communities that draw from rivers as a primary source of fresh water, in part because thawing permafrost can increase bank erosion and water turbidity (when water is muddy), and in some cases increase nutrient concentrations. Increased turbidity, for example, can overwhelm water treatment systems and cause short-term "boil water" notices for some communities. Permafrost thaw is also a concern because water and wastewater infrastructure are often located above ground in these communities. As the network of piping and other components such as lagoons are often adjacent to rivers and other bodies of water they are subject to bank erosion (Figure 5). As thawing and settling occurs unevenly it can cause stress and damage to the fittings that connect homes and other components of water and wastewater systems. In the village of Kiana in northwest Alaska, for example, more than a dozen water main breaks were reported over the last 10 years as a result of permafrost thaw. Permafrost thaw also can threaten sewage lagoons and the sewage mains and lift-stations that move wastewater to these facilities.

## Responding to Change

Alaskans are aware of water security challenges and are actively searching for innovative and effective solutions. Unfortunately, however, academic research on issues like climate change and water and food security often focuses on problems, using terms such as "vulnerability" to describe the current state of affairs. While well intentioned and not necessarily inaccurate, when academics, planners, and policymakers overuse this deficit-oriented language, it can cast too much of a negative light on local peoples, possibly undermining their agency and reducing them to victims. Indeed, finding ways to make rural Alaska more "resilient" and enabling rural peoples to "adapt" to ongoing environmental challenges has become the *de facto* policy posture at both state and federal levels. In our experience, however, rural Alaskans are already resilient in multiple dimensions, and are already responding to environmental challenges every day.

**Figure 3.** Permafrost thaw in concert with river bank erosion compromises a sewage lagoon. Photo by Dan Schubert.

While rural Alaska is impressively staffed in terms of people with skill and innovative ideas, there are still multiple barriers that have challenged or stalled the development of water security. Funding, social policies and infrastructure are major issues for rural communities. Rural Alaskan communities operate relatively unique water and wastewater systems that were built with one-time capital improvement grants from state or federal agencies. Since the early 1980s the State of Alaska and the Federal Government have made significant investments in water and wastewater infrastructure in many rural Alaskan communities, but these investments have for the most part been for initial construction and development, and not for maintenance or facility sustainability. Due to limited availability of funds for ongoing operation and maintenance (O&M), these facilities are regularly in various states of repair and are often kept in operation well past their planned end-of-life.

Ultimately, no two communities in rural Alaska face identical challenges to managing water security, nor do they have equal access to the same resources needed to solve the problems. Some communities must contend with changing hydrological cycles while others are impacted by storms. Differential funding is also a challenge as some communities are eligible for funding and engineering support from the State or organizations such as ANTHC, while neighboring communities are not. Lack of eligibility can range from ethnic demographics to previous funding of water/wastewater infrastructure, regardless of its age or state of repair. Additionally, many rural environmental professionals addressing short-term needs in favor of long-term planning, and are stuck in a cycle of mitigation and crisis management. Others still are unable even to address short-term needs because in the long-term their community has been deemed unviable by State or Federal decision makers. A goal of this work is to identify best practices for planning and management that account for unique local needs and circumstances but remain relevant across the state.

*Rural Alaskans are resilient in multiple dimensions, and are already responding to environmental challenges every day. … However, many rural environmental professionals find themselves having to address short-term needs in favor of long-term planning, and are stuck in a cycle of mitigation and crisis management.*

## Impetus, Aims, Scope

This study was designed to dig deeper into the social aspects of water security challenges in rural Alaska and more specifically into the day-to-day context of water resources managers in the Bristol Bay region. Need for the study emerged from multiple ongoing conversations with people of the region, but was underscored by a nearly averted crisis in the community of Naknek, Alaska in September of 2007. A wastewater lift station in the community failed, releasing untreated wastewater onto the beach adjacent to the Naknek River. The sewage main line that runs along the river and lift station and were damaged from bank erosion. Public works employees were able to respond to the event in time and limit the extent of environmental contamination. However, in interviews local managers expressed a profound sense of relief that the event did not occur during the height of the salmon fishing season. During this time wastewater system would have been running at 150% capacity, due to the seasonal increase in population from fishermen, cannery workers, etc. Likewise, a coordinated response by community workers would have been reduced, as many employees would have been fishing and been out of contact. Finally, the prospect of releasing untreated wastewater into a river full of highly valued salmon destined for human consumption raises health and safety issues and such a failure would have had devastating long-term effects on the reputation of the fishery.

This "near miss" alerted us to several related key points that are missing from ongoing discussions of climate change and community impacts:

- *Timing matters, in terms of natural hazards, infrastructure failures, and other stresses, in terms of both the extent of impacts that will be experienced and people's ability to respond in a timely and effective manner*
- *Human resources matter, and can limit how communities respond regardless of what other resources and capacities communities have to draw on.*
- *If one wants to understand the "place based" nature of how challenges like climate change interact with other social, environmental, and economic circumstances, the day to day experiences of local "first responders" is the first place to look*

The frameworks we provide in this report attempt to account for these key points simultaneously.

It should be noted that this research was developed following demonstrated community interest and need. Exploratory interviews were held with representatives from multiple community stakeholder groups in the region, including:

- Bristol Bay Native Association http://www.bbna.com
- Bristol Bay Borough http://www.bristolbayboroughak.us/
- City of Dillingham http://www.dillinghamak.us/

Likewise, we received much important guidance in the design of this project from regional partners, including:

- Bristol Bay Area Health Corporation http://www.bbahc.org/
- The Center for Climate and Health at the Alaska Native Tribal Health Consortium http://www.anthc.org/chs/ces/climate/
- Faculty of the UAF Bristol Bay Campus http://www.uaf.edu/bbc/

## 2. Key Observations

Through the research we recount below, we learned of a variety of concerns among local residents related to issues of water and food security, climate change, and community health. Specifically, five key observations emerge when considering the results of this research. We summarize these here, and address them in more detail in the sections that follow.

### Observation 1: regional coordination in rural Alaska is lacking

An initial goal of this research was to assess the capacity for managing water security at a regional scale (i.e, Bristol Bay), including the extent to which communities coordinate regionally to address water and wastewater challenges. Our assumption was that regional collaboration and coordination is happening among water resource managers in the region; perhaps surprisingly, however, given both the geographic proximity of many communities and the shared challenges that they experience, we found little evidence of regional coordination on water/wastewater management challenges in Bristol Bay. We did find several examples of social capital, in the form of regional agencies and networks such as Bristol Bay Native's Association and the Bristol Bay Area Health Corporation, but workers in individual communities did not report relying on their counterparts from neighboring communities for expertise, manpower, or supplies.

Barriers to regional coordination, which we discuss in more detail below, include highly specialized water and wastewater treatment infrastructure, differential access among communities to funding/revenue, and high turnover in personnel in many communities.

### Observation 2: timing and seasonality matters

The cumulative effects framework employed in our analysis (See Section 3.2.2) is designed to draw attention to both spatial and temporal dimensions of environmental challenges. In this research we encountered several instances of the latter, the temporal dimension, in how communities are impacted by equipment failure or weather events, and whether or not they are have the capacity to respond effectively. Coastal processes such as erosion provide one example: erosion is most intense during spring and summer; shipping of equipment and supplies is reduced during winter when ports are closed due to seasonal sea ice and human resources are scant during subsistence hunting and fishing seasons.

### Observation 3: combining the community capacity and cumulative effects framework proved more productive and engaging than a vulnerability approach

We found communities responded positively to the language of community capacity and cumulative effects. Specifically, the language was effective in reaching a shared understanding in discussions of these multi-faceted water security challenges. Encouragingly, we also found that the language of these frameworks served as a positive starting point for developing new ideas, one oriented around capabilities and opportunities to improve those capabilities. Several community partners noted that they appreciated this language over the deficit-oriented language of vulnerability.

**Figure 4.** A septic system pump truck deposits anaerobic waste into the City of Dillingham's aerobic sewage lagoon. The wastewater outflow from this lagoon repeatedly fails to meet water quality standards.

### Observation 4: Built capital is extensive, but not always engineered to meet the needs and O&M constraints of rural Alaska

All of the communities we visited have existing engineered water and wastewater systems, which sets them apart in some respect from communities that still lack such systems entirely. However, many of these systems are operating past their planned end-of-life and/or are being used in a manner for which they were not designed. An example of the latter is in Dillingham, where pumping trucks deposit septic (anaerobic) waste on a regular basis into the community's aerated (aerobic) lagoon. A lack of standardization in equipment makes maintenance difficult, and in one community a brand new system is in a state of disrepair because local people do not have the expertise to maintain the new technology.

### Observation 5: Human capital is essential, but turnover is a problem

The communities that had the most robust water and wastewater management systems were the ones, such as in Togiak, where the people managing those systems had long tenure, with the experience necessary to write and manage successful grant applications and train new personnel. By contrast, in communities where the offices such as city manager and water plant manager experience frequent turnover, the atmosphere was more along the lines of constant crisis mitigation. This should not be misunderstood as a critique of these dedicated and skilled workers, but an observation that tenure in these jobs matters in terms of building capacity for planning for change and mitigating surprises.

## 3. Study Area and Methods

The sociocultural, economic, and geographic details of rural Alaska and the Bristol Bay region in particular are unique in a number of respects from rural areas in the contiguous US. Geographically, the Bristol Bay region is located in Southwest Alaska and includes the Nushugak, Kvichak, and Naknek watersheds. The area is roughly the size of the state of New Hampshire, and the watersheds are renowned for supporting the largest sockeye salmon fisheries the world. Yet, despite the large-scale economic activities in the region related to fisheries and tourism, infrastructure and development are limited; there are few roads, and travel between communities is limited to air and water routes in the summer and snomachines in the winter. The climatic is maritime, though the subarctic climate of the Interior also can affect the coast. Dillingham is the largest community in the region (population ~2,800) and serves as the primary regional hub for provisioning (food, fuel, supplies) and healthcare services to the region's 34 villages.

Major regional economic activity in Bristol Bay is centred on fishing, to the order of 80% of local revenues. Numerous large canneries operate in the region during summers, driving a spike in local population both from fishers and cannery workers. Fishing harvest is focused on salmon, most of which is sold commercially, although significant subsistence catch is taken by individuals who fish from boats or simply place set-nets along the shore of rivers. There is also minor tourist activity that includes adventure tours, air taxis, hunting, and sport fishing that accounts for a small proportion of catch and a small proportion of economic support. Federal transfer income is also a noteworthy source of income.


**Figure 5.** Dumpsters in the community of Togiak, AK.

This study defines Bristol Bay to include communities in multiple watersheds and administrative municipalities adjacent to the Bay proper. These communities include: Dillingham, the regional hub located at the mouth of the Nushugak River; Naknek, which is across the bay on the Alaska Peninsula; Togiak, a coastal village to the west of Dillingham; Perryville and Chignik Bay, also on the Alaska Peninsula; and Kokhanok, an up-river community on the southern shore of Lake Iliamna. Appendix II shows current trends in demography for the communities in this study; trends for the region match those for Alaska in general, population is steady or growing in rural regional hubs like Dillingham, while populations in the smaller rural communities is declining due to outmigration. Appendix III provides historical and projected climate information for temperature and precipitation.

There are several environmental change-related concerns facing communities in the region. Coastal erosion in communities on both the south and north shores of the Bay is a commonly identified climate-related stress with significant ramifications for community infrastructure and security. The frequency and intensity of marine storms are also increasing, and these bring both heavy waves and water level surges that can worsen coastal erosion. Land cover changes are also expected; including the expansion of shrubs in the tundra and a northward and westward drift of the arctic tree line. Continuation of these trends could increase the water loss due to evapotranspiration, which suggests overall drier seasonal and annual means for Alaska in the future.

Our selection of Bristol Bay as a strategic case study region is thanks primarily to interest in these issues among our various local collaborators (see list above). It is important to note that Bristol Bay communities are not among the ones identified by the State of Alaska report mentioned earlier as having imperiled water resources. This is in part perhaps because the region largely lacks the vulnerable discontinuous permafrost, one of the primary issues challenging water security elsewhere in the state. That is not to say that climate impacts are not happening, of course, and the case of Naknek described above is just one of many anecdotes that have been related to us by local residents.

Another concern for water security during research for this report is a proposed copper and gold mine to be located at the headwaters of the Kvichak River, which supports important salmon fisheries. The proposed mine is a contentious social and political issue spurring debate over the merits and dangers of the proposed mining and mine technologies. As such, we see communities in this region as providing an important sociocultural "base line" for understanding the realities of rural community environmental management, whether in the context of climate change or industrial resource development.

## Background on Water and Wastewater Management in Alaska

*The Village Safe Water (VSW) program, an initiative administered by the Alaska Department of Environmental Conservation (AKDEC), provides financial and technical assistance to small Alaskan communities for the implementation of water, sewerage and solid waste capital projects*

In the smallest Alaska communities, which can range from 20 to a few hundred people, fresh water is often gathered from lakes, rivers and streams or rainfall in summer or from lake or river ice in winter and stored for later use. Honey bucket waste is often dumped in landfills or unmonitored lagoons, as only the largest communities have central, managed and monitored sewage lagoons. For the larger rural communities with more robust water and wastewater infrastructure there is greater diversity in design and function, with some communities relying on groundwater wells, others relying primarily on water pumped from rivers and streams, and still others relying on water drawn from tundra lakes. In our experience, each community operates relatively unique systems that were built with one-time capital improvement grants. Due to limited availability of funds for operation and maintenance (O&M) and trained personnel, however, these are regularly in various states of repair and are often in operation long past their planned end-of-life.

Since the early 1980s the State of Alaska and the United States Government have made significant investments in water and wastewater infrastructure in many rural Alaskan communities, but these investments have for the most part been for initial construction and development, and not for maintenance or facility sustainability. The earliest federal efforts to develop infrastructure and to modify hygienic practices in rural Alaska were conducted by the Indian Health Service in the 1960s and 1970s, efforts that were dramatically expanded via state involvement with the passage by the Alaska Legislature of the Alaska Village Safe Water Act (VSWA) in 1972. The VSWA established the Village Safe Water (VSW) program, an initiative administered by the Alaska Department of Environmental Conservation (ADEC) to provide financial and technical assistance to small Alaskan communities for the implementation of water, sewage and solid waste capital projects. In order to receive VSW support, applicant communities must first demonstrate that proposed projects will address critical community health needs, and demonstrate that the community has the carrying capacity to properly manage and maintain the proposed facilities. By statute, only small communities with a population less than 600, and unincorporated areas are eligible for VSW support. The VSW has arguably yielded broad improvements for many of the 214 communities that are eligible for its support. These are communities where the average per capita income ranges between 30 and 40% lower than the state-wide average. In rare circumstances, larger communities may apply in order to provide service to a small isolated settlement within its boundaries, but by-and-large this is an assistance program that targets the smaller remote rural settlements across the state.

Another active source of support for rural community water systems and security is the Alaska Native Tribal Health Consortium (ANTHC), a not-for-profit tribal health organization managed by Alaska Native tribal governments and their regional health organizations. ANTHC was established in 1997 to administer health services for Alaska Natives state-wide, and among its many divisions the organization operates a Division of Environmental Health and Engineering (DEHE) program that oversees the development of safe water and wastewater disposal facilities, and provides technical assistance with the construction, maintenance and renovation of health care facilities. DEHE also assists and trains operators and managers of water and sewer systems, and provides environmental health monitoring support services such as environmental sampling and assessment. ANTHC draws from a variety of state and federal funding sources to provide this support, including the VSW program, Indian Health Service, Environmental Protection Agency, and the Denali Commission, though many of these sources can come with limitations regarding projects allowed and whether or not non-Native residents can be served. In 2012, nearly $300 million in capital improvement projects were in process for 69 communities in Alaska, with about $34 million or 11.6% of that budgeted for 2012 alone.

ANTHC also operates a Centre for Climate and Health (CCH), which among other projects has completed five community health assessment reports that focus on climate change-driven impacts, including effects on water and wastewater systems. The review and community profiles that follow draw heavily on the data provided in these reports.

A final well-established funding source is the Indian Environmental General Assistance Program (IGAP), which provides grants to federally-recognized tribes and tribal consortia for planning, developing, and establishing environmental protection programs in tribal lands, as well as for developing and implementing solid and hazardous waste programs. EPA's Region 10, which includes rural Alaska, awarded nearly US $25 million in IGAP funds to 231 Tribes and Tribal Consortia in 2008. In recent years, and in response to pressure from local community and tribal groups, the implementation of the IGAP program has expanded beyond solid waste management projects to include capacity-building activities as eligible for funding. This program evolution addresses the shifting needs of rural communities, which now include responding to such challenges as climatic change and economic development, and the protection of subsistence resources. Changing focus to increase communities' capacity to respond to change is important and our experiences cautiously suggest that activities using such funds continue to be dominated either by solid waste management (e.g., new landfill construction, hazardous waste backhaul programs) or by a perceived need to generate baseline water quality data on sources likely be impacted by climate change, mining, or other economic development.

*Community capacity represents the cumulative abilities of people in a community to manage their day-to-day lives and responsibilities while also coping with external stresses and disturbances as a result of social, economic and environmental changes. It offers a more positive and arguably more accurate perspective than does the vulnerability-oriented language found in most scholarly research on the impacts of climate change. It* *offers a more positive and arguably more accurate perspective than does the vulnerability-oriented language found in most scholarly research on the impacts of climate change.*

## Analytical Framework: Community Capacity and Cumulative Effects

We link two concepts in this report that we find instrumental for understanding the water security challenges in rural Alaska. These are: community capacity, which speaks to the resources from which people can draw to solve problems; and, cumulative effects, which provides language for understanding how the impacts of multiple challenges and stressors interact or accumulate over time or in particular locations.

### Community Capacity

The concept and language of community capacity, also sometimes called community capital, has been used for decades to guide development policy around the globe. This term identifies the capabilities and resources a community has to manage its on-going needs and challenges, and to innovate and adapt when necessary. We prefer this approach as a counterpoint to the more pejorative term of "vulnerability" that dominates discussions of environmental problems in Alaska (see Box 1). We find in our work with city planners, managers, water systems operators, and other rural community leaders, that they appreciate this **positive language of agency and ability** over the more negative and passive tone that often accompanies vulnerability frameworks.

As we define it here, community capacity represents the cumulative abilities of people in a community to manage their day-to-day lives and responsibilities while also coping with external stresses and disturbances as a result of social, economic and environmental changes.

Two different, but related lenses can be taken for evaluating this capacity: the focus can be on a community's **carrying capacity** or **adaptive capacity**. Put simply, the former includes the resources and abilities necessary for people to maintain the status quo—to perform regular O&M, for example, and also to manage the impacts of external stresses that result from social, economic or environmental changes. By comparison, adaptive capacity describes the resources that people need to fundamentally change their existing practices and technologies in order to improve the condition of their lives and communities. We recognize that we are making a distinction here that most other published literature on capacity does not; the concepts of adaptive capacity and adaptation are applied quite loosely in the literature on climate change for example. As we describe below, however, the distinction is quite important when understanding how people in these communities experience and respond to new challenges.

Community capacity is generally understood to have five dimensions: natural, human, built, social, and financial. Natural capital describes the environmental resources upon which people can rely, such as sources of fresh water. Human capital represents the ability of people to perform management tasks and respond to problems, and can be measured by experience, expertise, and education. Built capital represents the existing infrastructure with which people have to work when managing the environment, whether water treatment facilities, seawalls, and airports and seaports. Social capital includes organizations for regional collaboration and strategic plans for development and disaster mitigation. Finally, financial capital represents the finances available, and can include local revenues as well as grants and federal transfers, to manage existing systems and respond to change.

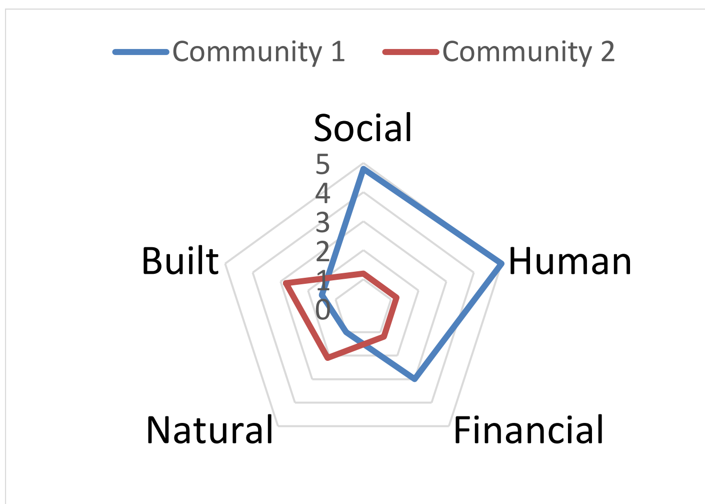



**Figure 6.** A stylized representation of community capacity used to compare communities on a normalized scale of 0-5, where 5 indicates robust resources and 0 represents a lack of resources.

It has become popular among academic and agency researchers to seek out quantitative indicators of community capacity and to use these in the creation of complex "indices" for measuring and comparing community capacity or vulnerability

(Figure 6). This is an approach that we take here (Table 2) but we are careful to recognize the limits of such indices.Specifically, such indices provide rough details that can inform more rigorous qualitative research (Box 1).

### Cumulative Effects

In this research we couple the concept of community capacity with a "cumulative effects" framework originally developed in the United States by the White House Council on Environmental Quality (CEQ), in conjunction with the National Environmental Policy (NEPA) act of 1970. By comparison to other conceptual frameworks for assessing environmental stressors, such as vulnerability, the cumulative effects approach is explicitly more holistic, attending to how problems and surprises interact with one another and how their impacts accumulate, additively or synergistically, over time. The approach focuses not just on the short-term but also the long-term impacts, and accounts not just for proximate or immediate causes but anticipates the accumulation of stressors toward the potential for thresholds and 'tipping points', beyond which an entirely new suite of negative impacts may appear.

Radon gas exposure provides an example of the nuances that the cumulative effects approach captures. A single short-term exposure to a background concentration of radon gas will not cause increased incidents of lung cancer. But, long-term exposure to higher concentrations of the gas significantly increases risks for lung cancer. Interestingly, radon exposure also has an important temporal/seasonal dimension. When tested for radon the same house will generally have a higher concentration in winter compared with summer. During cold months people keep their windows and doors closed trapping the gas within the house. In warm weather people open their windows, thus ventilating the radon gas and keeping it at a low concentration.

In addition to details about the stressors themselves, such as magnitude and duration, the CEQ framework emphasizes three attributes:

1. Temporal crowding, which occurs when the interval between perturbations is less than the time required for an environmental system to recover from each perturbation. The rate of temporal crowding may be continuous, periodic, or irregular and occur over short or long time frames.

2. Spatial crowding, which is analogous to temporal crowding but where spatial proximity between perturbations is smaller than the distance required to mitigate or disperse the effects of each perturbation. Spatial accumulation may be characterised by scale (local, regional, global), density (clustered, scattered) and configuration (point, linear, areal).

3. Synergistic effects, which assumes that stressors do not merely accumulate in an additive way, but that complex interactions among environmental stresses and other local circumstances, whether economic, demographic, or cultural, can create complex and unanticipated outcomes.

| | Description | Indicators |
|---|---|---|
| Natural Capital | Refers to land and the many natural resources it contains, including ecological systems and processes, biological species, mineral deposits, etc. | • Water balance (P-PET)<br>• Winter precipitation<br>• Managed land not in development (future use) |
| Built Capital (Infrastructure) | Encompasses the entire infrastructure (e.g. buildings, roads, public transit, sewage, water), as well as technology (e.g. machines, tools). | • Water/wastewater facilities<br>• Solid Waste facilities<br>• Transportation<br>• roads, airports |
| Financial Capital | Financial resources available to the community to manage the sector of interest (i.e., water). This can include flows as well as stocks. | • Operating budgets<br>• Federal transfers<br>• Grant funding (existing and opportunities) |
| Human Capital | Includes both the physical labor (health, ability) and know-how (skills, knowledge) | • Number of employees in sector (trained, part time, full time)<br>• Training in climate change impacts and adaptation |
| Social Capital | Includes social factors such as interpersonal connections, institutional partnerships and collaborations. Social capital also includes information, including scientific information and community preparedness. | • Partnerships between communities and regional or state agencies or non-profits.<br>• Political will (interest in, and consensus regarding, a specific issue)<br>• Presence of community plans for disaster mitigation or climate adaptation |

**Table 1. Five dimensions of community capacity, with examples**

## Seasonal Stress: Combining Community Capacity and Cumulative Effects

The concept of community capacity, as described above, represents the total capabilities of a community to manage ongoing community operations as well as some unexpected stress or disturbance (e.g., equipment failure, storm, etc.). One way to understand these stresses and how they interact is by the capacity that is expended or "locked up" when a community water manager is busy fixing a broken sewage lift station, for example, he or she is not free to work on proposals to fund the installation of new equipment.

*A monthly, or seasonal time frame, is especially poignant for planning and for understanding the cumulative effects of environmental challenges.*

The case of the Naknek sewage pump failure provides an informative example. The people of Naknek were fortunate; the cumulative effect of the various circumstances could have been disastrous by comparison had the failure happened during the fishing season, and while a failure could very well occur at any time, it is not unreasonable to expect that failures are more likely when the system is under higher operating load as it is during salmon fishing season (June to September) when a community population can increase 2 to 3 fold. Coastal erosion, another process that played a role, is also intensified in Bristol Bay during spring and fall storm events.

In fact, a great many aspects of life in rural Alaska have strongly seasonal characteristics. Shipping of supplies, equipment can only happen for many communities during the ice-free season, for example. Municipal offices are often understaffed during subsistence hunting and fishing seasons. In winter, extreme conditions make it difficult or impossible to work outdoors on failed infrastructure. Seasonal affective disorder (SAD) related to the limited sunlight during winter at high latitudes can also impact human resources. As such we sought to test with this work a hypothesis that a monthly or seasonal time frame is most relevant for planning and for understanding the cumulative effects of environmental challenges.

## Box 1. Vulnerability, Capacity, and Resilience: Beyond the Jargon

**People talk a lot about rural Alaska being "vulnerable" to climate change, but what exactly does that mean?** There are multiple definitions and frameworks for understanding the concept of vulnerability. In general, vulnerability describes how a person, community, or some other system will respond to some external harm. It involves three major concepts: exposure to harm, sensitivity to that harm once exposed, and ability to recover and respond. Vulnerability also has a number of related concepts: **resilience**, for example, which many people define as the ability of some person or community to recover from harm, is frequently discussed as the third component of vulnerability. **Adaptability,** or the ability of a person or community to change their practices in order to reduce future vulnerability, is another concept that is frequently mentioned in this same vein.

**Because vulnerability is not directly measured,** like rainfall amount or river height it must be measured indirectly from other variables. Researchers from many different disciplines have attempted to identify indicators of vulnerability, things that *are* measurable that can give clues to whether communities are vulnerable. High unemployment is one example. Relative abundance or lack of the five kinds of capital described in Table 2 is another example.

Today, there are many different indices available for "measuring" vulnerability, adaptability, and resilience in this way. Too often, however, they over-estimate the level of detail they can provide, or make inaccurate assumptions about people and their abilities. For example, many indices use household income, and the number of people per capita with college degrees to determine response to environmental challenges. Anyone from rural Alaska can speak to how reductive only using these measures can be... Intuitively, however, we know that people are creative, that they experiment and innovate in different ways, and therefore we should expect that no two communities will mobilize resources in the same manner.

This wooden seawall in Togiak, Alaska, is an example of built capital that significantly reduces the community's vulnerability to storm surge. Other kinds of capital do not has such straightforward or esy-to-measure benefits in the context of environmental change.

## Methods

We report here on research that employed a mixture of qualitative research methods. At the core of this work are informal interviews and participant observation research performed over the last three years in 11 coastal communities in the Bristol Bay and Northwest Arctic regions of Alaska. This work involved interviews, focus-groups, and community tours taken by one or more of the study authors and led by city managers or planners. Key informants were most commonly identified with the aid of city officials or similar representatives from regional tribal governments or consortia. Interviews were semi-structured, with questions guided only in the most general terms by the same set of deductive codes described above.

Recognizing the limitations of indices noted in Box 1, we also developed a survey tool (Appendix I) in close collaboration with community partners for the purpose of assessing assets for community water resources management. We implemented the survey tool in the six communities in Bristol Bay noted earlier. Depending on the community member consulted or even the community itself, we used judgment to inform when and how data were collected. Simply put, we employed a 'listen first, question second' approach. The process was particularly useful when consulting with members of the communities who are not normally contacted by researchers (e.g. treatment plant operators). Where appropriate, the community inventory was used as a source of talking points for interviews.

*We employed a 'listen first, question second' approach*

We also strove to not redo or recreate work that has already been done, and many people in agencies and academia are working hard to improve water security for all Alaskans. As such, we also completed a literature review and document analysis of existing publications (such as those by ANTHC on the impacts of climate change on community health) focusing naturally on water resources. The data from this review provides much of the background we describe above. We do not cite these documents in-text, which is a convention in academia but not necessarily conducive to reports such as these; rather key literature is listed in the Select Bibliography. Note that not all of this literature is specific to Bristol Bay communities; nonetheless, they cumulatively provide a clear picture of the sorts of challenges being faced by rural communities across the state, and the needs that they have in order to respond effectively.

# 4. Results

## Ethnographic Research

Among the many city managers and water managers that we have interviewed, the most regularly discussed challenge concerns both regular and unexpected O&M on community water and wastewater infrastructure. Invariably, we find that informants are actively engaged in addressing one or multiple infrastructure issues at the time of our visits, whether a failed sewer pump or the relocation of a sewer main or some other issue. One city manager described "always being on his back foot", and another, who was new to his position, explained that day to day operations and upkeep kept him from "ever moving forward in his job".

A common category of O&M challenge raised by several key informants is human resources. Issues in this area range from minor challenges, including the need for additional training and certifications, to major ones, such as the inability to achieve employee retention. In one extreme case we have seen the offices of city manager and water plant manager be vacated and re-filled three times in the past three years for one community. In two other study communities at least one key position has been vacated over the same time period as well. In the few communities where employee tenure is not reported as an issue, employee redundancy is. Intervieweesdescribe such communities as being vulnerable to the loss of key individuals. In the aforementioned community with extremely high employee turnover the office of city manager had originally been held by one individual for 15 years; only since his retirement has the community struggled to keep the position filled.

**Figure 7.** Project team members Henry Penn and Bill Schnabel walk to the city manager's office in Togiak, AK

A related human resources challenge is training and expertise: because water systems vary so significantly from community to community, workers trained in one village likely lack the skills necessary to work elsewhere. In one example, a community's water plant operator explained to us that his employees had been repeatedly unable to pass a state-level certification despite many years on the job because the test included systems and scenarios to which they had no exposure.

Yet another commonly reported impact on human resources comes during subsistence fishing and hunting seasons. Many people in rural communities are allowed time off from their jobs in order to participate in these important activities. While this benefit is important to livelihood and food security, a challenge that it creates is that during this period community water and wastewater infrastructure can also be under more stress than it is at other times of the year. During fishing season the population in many villages can double or triple, pushing water and wastewater infrastructure well past designed limits while reducing the workforce available to address emergencies should they arise.

The design and engineering of water and wastewater systems is another commonly cited challenge relating to O&M. Multiple informants expressed frustration with the lack of standardized equipment, for example. In one community, where a wastewater pump was being repaired during our visit, the city manager explained that of the five pumps stations along the wastewater main in question, no two were alike. In a second community, some state-of-the-art systems in a recently built water treatment facility are being bypassed because local workers lack the expertise to fix them. In a third, a similar problem is being caused not by a lack of expertise, but by extremely high costs of freight for obtaining replacement parts.

The last common issue cited by key informants relates to funding, both for O&M and for new projects. With this issue, however, we find that some communities report excellent access to financial support while others struggle to find sources of revenue. One of the larger communities in the study has limited access to external funding and support, because of its size and its demographic composition—it is considered a "first class" city and is ethnically diverse, which precludes eligibility for VSW funding and also precludes any financial support that targets communities with smaller and predominately Alaska Native populations. In several communities applying for funding we observed the projects were relating not toward long-term planning or the implementation of new systems but for baseline studies and other environmental quality monitoring initiatives. With a goal to plan for the likely future impacts of climate change and natural resource extraction activities.

### Thoughts on "Adaptation"

> *Sure, we adapt. We always have. But what we're doing out here, it's not adaptation. We're reacting, coping with the changes that we're seeing. It takes every resource we have to keep things running as they are. I'm not thinking about what I need to do differently in the future. I'm thinking about how to keep the animal control building funded so we don't have to put down all those dogs. I'm thinking about how to keep my employees from quitting when they're sick of having to fix broken sewer pumps and getting people's shit all over them in the process.*
>
> -- Community Manager

Much of the contemporary discussion regarding climate change impacts in Alaska and elsewhere centers on the concepts of adaptation and adaptation planning, which generally are understood as involving anything that people must change or transform in their livelihoods to cope with a changing world. Despite the ubiquity of the concept in the academic literatures and agency/non-profit reports on climate change, we encountered a notable dislike of the term (at least, that is, a dislike for how it is currently being used), among the people we interviewed. Many residents often talk proudly of their "adaptability," but they are also concerned that this creates something of an excuse or an "out" for the people responsible for causing climate change in the first place.

Too, some of the people we interviewed simply don't think using the word adaptation to describe every little adjustment they make or new practice that they experiment with is accurate. As one rural water plant manager explained,

> *It used to be, in order to get funding, you just had to prove need. We don't have a water treatment facility, so we need one. Then you started needing a 'sustainability plan' to get funding. Then FEMA came and said we needed 'disaster mitigation plans' to get funding. Now everyone is telling us we need 'climate adaptation plans'. If we spent all our time on writing these plans nothing [else] would get done around here. Don't get me wrong, we want a better future, but we don't want to change neither. You can keep your change. We just want cleaner water.*

In more general terms, another interviewee explained,

> *Do things fail now more? Sure. Do I have to try new things to fix them? Yeah. It's like that that TV show MacGuyver, you know? Yeah that's me. … Are we adapting? Sure, if holding our community together is adapting.*

We highlight these quotes here as they reinforce a concern regarding overuse of the adaptation concept that is emerging in both academic and agency literatures. An excellent example is found in the ANTHC climate change health impact assessment for Kivalina. Kivalina is a community that, because of erosion and coastal processes, is planning for complete relocation to a new site. Relocation remains may years out, however, and the community presently faces multiple environmental health challenges, including some related to water and sanitation infrastructure. However, the ANTHC assessment reports that people in this community have been unable to secure funding to address these immediate needs because of the specter of relocation. In other words, their community has been written off, and the focus on their future adaptation has undermined their ability to address immediate problems.

## Community Capacity Inventories

### Dillingham

Dillingham (pop. 2400) is Bristol Bay's regional hub for provisioning (food, fuel, supplies) and for healthcare services to the region's 34 villages. It is located at the northern end of Nushagak Bay in northern Bristol Bay, at the confluence of the Wood and Nushagak Rivers. It lies 327 miles southwest of Anchorage and is a 6 hour flight from Seattle. The primary climatic influence is maritime; however, the arctic climate of the Interior also affects the Bristol Bay coast. Average summer temperatures range from 37 to 66 °F. Average winter temperatures range from 4 to 30 °F. Heavy fog is common in July and August, and winds of up to 60-70 mph may occur between December and March. The Nushagak River is ice-free from June through November.

**Figure 8.** The Dillingham wastewater outflow into the Nushagak River (left). Note the fishing net on the right. This beach is regularly used for salmon fishing, despite effluent repeatedly not meeting

**Community Planning & Resources**

- The community has developed and maintained a disaster response plan and source water protection plan.
- The community does not have a climate change adaptation plan. Without assistance it is unlikely that a plan will be created in the near future despite the City Planner acknowledging that climate change effects are being experienced in Dillingham (e.g., extreme weather events, changes in subsistence food harvests)
- Dillingham employs two full time joint water and wastewater operators. Both operators have 4 years' experience. One operative has all required certification, and there is a training plan in place to train the second operator to the same level.

**Drinking water system**

- The community operates a groundwater supply from 2 principle wells.
- The community has no official secondary source of potable water. There is land and funds available to explore options, but planning has only been preliminary.
- Raw water is treated through multiple filtration stages and chlorination.
- Approximately 80% of downtown Dillingham is supplied by piped water. This accounts for 1/3 of the total population. Remaining households and businesses are supplied by unregulated private wells.

**Sanitation System**

- The community operates two facultative wastewater lagoons to treat waste.
- Local septic pumping companies that service households not on piped sewer also discharge their waste into the lagoons (though they are not designed to receive anaerobic waste).
- Effluent is discharge into the bay.
- Existing system received extensive improvements in 2013-14 to improve the quality of effluent, which previously was not achieving Alaska Department of Environmental Conservation standards.
- Piped sanitation service is provided to approximately the same number of residents as piped water.
- Local operator reports that the wastewater system operates at 150% designed capacity during the summer, when the local population increases for fishing season.

**Summary**

- Dillingham's human and social capacity is high, possibly by virtue of being the regional hub and home location of groups such as the Bristol Bay Natives Association and Bristol Bay Area Health Corporation. The city and surrounding region are not incorporated into a borough, but Dillingham does levy taxes on the local salmon fishery to offset the costs of managing shared infrastructure such as the port.
- The sanitation system is being updated and wastewater effluent will now meet DEC minimum standards.
- Little is known about the hydrology surrounding Dillingham. It is known that the current drinking water supply wells are coming to the end of their service life, but an alternative supply has not yet been identified.
- There is also concern for the number of households currently operating private, unregulated wells and septic systems, for example with regards to cross-contamination.

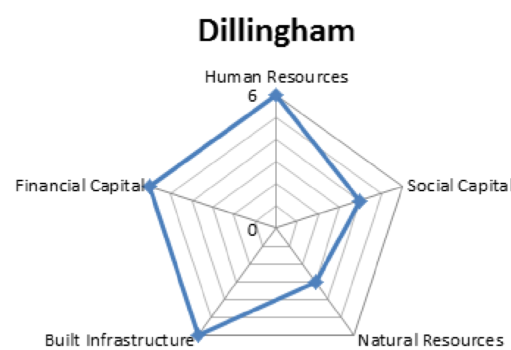



**Figure 9.** The rapid capacity inventory suggests that Dillingham is rich in all dimensions of community capacity for managing water resources

## Naknek

**Figure 10.** The Naknek wastewater lift pump on the beach of the Naknek River, protected by rip rap (left). This pump failed in 2006, spilling untreated effluent onto the beach. The Naknek River is an important salmon-bearing waterway.

The unincorporated village of Naknek (pop. 521) is in the Bristol Bay Borough, along with the communities of South Naknek and King Salmon. Naknek is located on the north bank of the Naknek River, at the northeastern end of Bristol Bay. It is 297 miles southwest of Anchorage. The climate is mainly maritime, characterized by cool, humid, and windy weather. Average summer temperatures range from 42 to 63 °F; average winter temperatures range from 29 to 44 °F. Fog is common during summer months. Aside from Dillingham, Naknek has the most prominent fishing industry presence of the communities visited.

**Community Planning & Resources**

- The community developed a disaster response plan in 1996.
- The community does not have a source water protection plan. There have never been any reports of wells running dry or changes in raw water quality.
- Naknek does not have a climate change adaptation plan, though community members reported numerous climate change related observations. The Naknek river did not freeze over sufficiently during winter 2012/2013 to allow transportation between Naknek and South Naknek. Coastal erosion is continuing at a rate of approximately 5-feet per year. The extreme heat of summer 2013 removed much of the moisture historically found in the tundra and severely reduced the availability of subsistence berries and increased the change of wildfires.
- Naknek employs one wastewater operator.

**Drinking water system**

- Naknek does not operate a centralized drinking water system. Each household and business operates its own groundwater well.
- Drinking water for households owned by HUD is required to be tested every six months.
- There is no official secondary source of water, nor are there plans to explore finding one.

**Sanitation System**

- All households and businesses discharge wastewater via a piped sanitation system operated by the Borough
- Wastewater is transported via lift stations along a forced main to two facultative lagoons, and effluent is discharged into the bay.
- The quality of the discharged effluent consistently meets minimum EPA standards.

- The wastewater line currently runs along an actively eroding beach. Plans exist to move to a new line further inland, but private landholdings have been an obstacle to finding a new route.
- The existing sanitation system does not have the capacity to meet the demand required by the influx of seasonal labor during fishing season. Operation of the system above capacity causes regularly failures in the system.

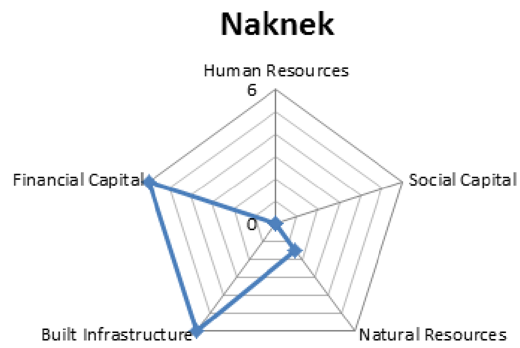



**Figure 11.** The inventory suggests that Naknek scores low in multiple dimensions of community capacity for managing water resources, though built and financial capital appear abundant.

**Summary**

- The single biggest challenge in the community is the exposed forced sewer pipeline which runs parallel to the beach front.
- Employee turnover has been high in Naknek. Nevertheless, much planning has been done around erosion, including an erosion survey and plans for relocation of the sewage main. However, a new port to service the fishing industry has been the community's primary priority in terms of capital projects.

## Togiak

**Figure 12.** Exterior of the Togiak water treatment facility, with offices on the first floor and equipment in the basement.

Togiak (pop. 890) is located in the Dillingham Census Area, at the head of Togiak Bay, and 67 miles west of Dillingham. It lies in Togiak National Wildlife Refuge and is the gateway to Walrus Island Game Sanctuary. Togiak is located in a climatic transition zone, with both maritime and arctic climate influences. Average summer temperatures range from 37 to 66 °F; winter temperatures average 4 to 30 °F. Precipitation averages 20 to 26 inches annually. Fog and high winds are prevalent during the winter. The bay is ice-free from June through mid-November.

Togiak was visited prior to the development of the Community Water Resource Inventory (Appendix I) As such, the data presented here was captured through un-structured conversations with community leaders and operators, and is in some instances less detailed than the information collected for subsuqent communities where the assessment was employed.

**Community Planning & Resources**

- The community employs two full-time water and wastewater operators. Both operators have all the state required certifications, and regular paid training is provided by the community.
- Togiak operates a Federal water and wastewater sustainability plan to receive funding to maintain the drinking water and sanitation infrastructure. The plan requires the community to maintain 80% utility collection rates and submit quarterly financial statements to ensure the continuation of the funding.

**Drinking water system**

- All households and businesses are supplied by piped water from a groundwater source.
- Groundwater received filtration and chlorination. Groundwater contains notably high concentrations of iron.
- There is no official secondary source of potable water nor any plans to explore finding one.

**Sanitation System**

- All households and businesses discharge wastewater via a piped sanitation system.
- The sanitation system is 40-years old, and the oldest of the communities visited.
- Wastewater is held in a lagoon that does not discharge.  Notably, summer rain events often cause overflow from the lagoon into the surrounding area.

- Community leaders expressed concern about wastewater pipes freezing and busting during the winter. Many of the main lines are over 12-feet below the surface and very labor intensive to fix or replace.

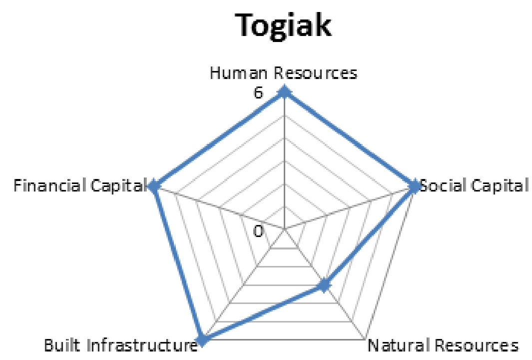



**Figure 13.** The inventory suggests that Togiak scores high in all dimensions of community capacity for managing water resources, save the natural capital category.

**Summary**

- Togiak possesses significant social and human capital, primarily through the local office of community manager, which has been held by the same individual for over two decades. The office is active in employee training, grant writing, and in finding innovative ways to make staff positions sustainable. The community is thought of in high regard by agencies working in the area.
- Addtionally, Togiak was the only community to report a long term relationship with nearby communities for sharing knowledge and O&M skills.

## Chignik Bay

Chignik Bay (pop. 92) is located on Anchorage Bay, on the south shore of the Alaska Peninsula. Administratively it is part of the Lake and Peninsula Borough. It lies 450 miles southwest of Anchorage. Chignik has a maritime climate characterized by cool summers and warm, rainy winters. Cloud cover and heavy winds are prevalent during winter months. Summer temperatures range from 39 to 60 °F. Winter temperatures average 20 °F. Two other small villages are nearby; Chignik Lagoon (pop. 78) is 8 miles to the east, and Chignik Lake (pop. 76) is 13 miles west.

**Figure 14.** The sourcewater dam at Chignik Bay.

**Community Planning & Resources**

- The community developed a disaster response plan in 2013.
- Chignik Bay does not have a climate change adaptation plan or a source water protection plan.
- The community employs one full time water and wastewater operator who has 3 years' experience and holds all State-required certifications. The community also employs one part-time/on-call operator.

**Drinking water system**

- All households and businesses are supplied by piped water from a reservoir 5 miles north of the community. The reservoir is a dammed rainfall and snowmelt catchment lake.
- Raw water receives slow sand filtration and chlorination.
- A secondary source of potable water can be supplied from city owned ground water well in the case of emergency.
- In 2011 Chignik Bay was given ownership of all drinking water infrastructure by Trident fisheries. The community is now responsible for maintaining the infrastructure at a cost that far exceeds the revenue of the utility.
- The treatment system operates continually. The storage tank is maintained at 95% capacity and surplus treated water is discharged into the bay at the end of the distribution system. This significantly increases the operating cost for the community.

**Sanitation System**

- With the exception of two, all households receive a piped sanitation service.
- Chignik Bay operates a series of newly built (last 5 years) underground holding tanks for wastewater storage. The liquid portion of waste is periodically discharged into the bay.

**Summary**

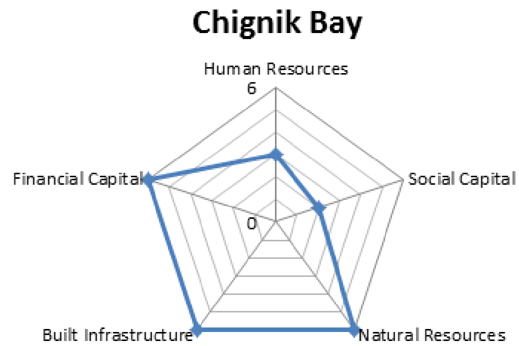



**Figure 15.** The inventory suggests that Chignik Bay scores high for financial, built, and natural capacity for managing water resources, but low for social capital and human resources.

- Chignik Bay has been active with the US EPA's Indian General Assistance Program (IGAP) since its inception.
- The community lost its school in 2013 due to an insufficient number of resident school-age children (a problem being experienced in multiple small communities in Alaska). Many families are considering relocation.
- There is no communication or collaboration on water management between Chignik Bay and the nearby communities of Chignik Lake and Chignik Lagoon.
- People in the community report a strong relationship with Trident fisheries. Trident orders fuel for both it's operations and for the community. The community purchases fuel from Trident at a cheaper rate due to the volume of fuel ordered. This is an important aspect of social capital that is not captured by the rapid index employed here (and an important illustration of the inherent shortcomings of vulnerability indices in general).

## Perryville

Perryville (pop. 120) is an unincorporated community in the Lake and Peninsula Borough. Perryville is located on the south coast of the Alaska Peninsula, 500 miles southwest of Anchorage. Perryville's maritime climate is characterized by cool summers, warm winters, and rainy weather. Average summer temperatures range from 39 to 60 °F; winter temperatures average 21 to 50 °F. Low clouds, rain squalls, fog, and snow showers frequently limit visibility.

**Figure 16.** Perryville’s source water infiltration gallery.

**Community Planning & Resources**

- Perryville does not have an official disaster response plan. There is a Tsunami emergency plan, and the community is working on a source water protection plan.
- Perryville does not have a climate change adaptation plan.
- The community employs one full-time (3-years’ experience) and one part-time water and wastewater operator. Neither operator has any certifications. Training was conducted by the previous operator.

**Drinking water system**

- Raw water is collected from an infiltration gallery approximately 2 miles northeast of Perryville. The source is influenced by a lake in the mountains around the community.
- Drinking water is treated by multi-stage filtration and chlorination.
- With the exception of two, all households have access to a piped water supply.
- The community expects that private wells could be employed as a secondary source of potable water in an emergency, although there is currently no infrastructure to distribute well water throughout the community. There is also a small creek that runs through Perryville which community members occasionally collect water from.

**Sanitation System**

- There is no wastewater system in Perryville. Household wastewater is collected via septic truck and dumped without treatment in a land fill-style pit approximately 2 miles from the community.

**Summary**

- Interviewees suggested to us that the community values its independence and is happy with the status quo of water and wastewater management. They have very little contact with, or desire to be contacted by state or Federal agencies for funding or other resources.
- A volcano approximately 22-miles from Perryville poses a significant threat to both water security and the community as a whole. There has been little planning for a large scale eruption beyond simply evacuating the community via boat.

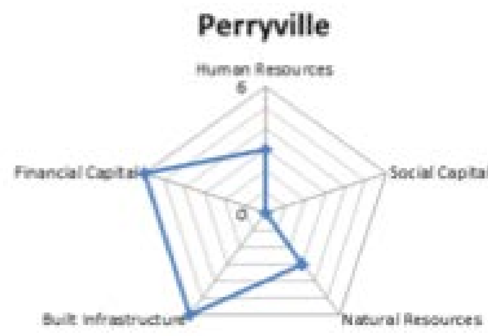



**Figure 17.** The inventory reflects Perryville's general policy of not seeking outside assistance for community works.

## Kokhanok

Kokhanok (pop. 174) is an unincorporated community in the Lake and Peninsula Borough. Kokhanok is located on the south shore of Iliamna Lake, 22 miles south of Iliamna and 88 miles northeast of King Salmon. Kokhanok lies in a transitional climatic zone, from maritime to continental influences. Average summer temperatures range from 40 to 64 °F; winter temperatures average 3 to 30 °F. The record high is 84 °F and the record low -47 °F. Wind storms and ice fog are common during winter.

**Figure 18.** Kokhanok water plant

**Community Planning & Resources**

- Kokhanok has developed and maintained a disaster response plan.
- The community does not currently have a source water protection plan or a climate change adaptation plan.
- Community members reported that ice across Lake Illiamna has been thinner and forming later in recent years. One community death due to falling through the ice has been attributed to warmer, wetter winters. A change in caribou migrations was also reported. Many community members now travel to neighboring communities to subsistence hunt.
- The community employs one full time operator who has over 12-years' experience and is fully certified.

**Drinking water system**

- Raw water is pumped directly from Lake Iliamna, treated by multiple filtrations and chlorination and distributed to 35 of the 45 households.
- The remaining households have private wells.
- There is no official secondary source of potable water. The operator suggested that in an emergency the community could access water from private wells, but it is not known how long this strategy would support community needs.
- Water usage is relatively high for the community size. Additionally, the community storage tank is smaller than typical for similar populations. Water treatment must continue even during time of poor raw water quality (i.e. spring break-up), which increases backwashing frequency, reduces the life of the filters and increases cost.

**Sanitation System**

- Those households with piped water also have piped wastewater. All other wastewater is collected via septic truck.

– Wastewater is stored in community lagoon, which does not have an outflow and is reaching capacity.

**Summary**

– There is an informal relationship between the water operators in Kokhanok and Naknek for the transfer of knowledge and support during crises.
– Operating budget for drinking water breaks even almost each year. The village council expressed concern that they are not able to budget for future improvements or future surprises.

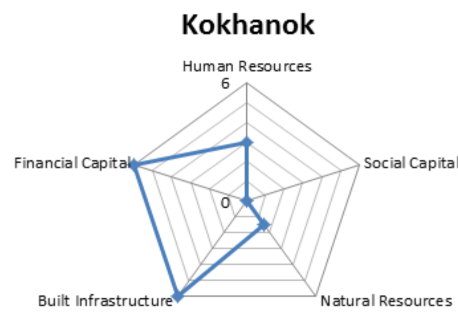



**Figure 19.** The inventory suggests that Kokhanok scores low in all categories except built capital and access to financial capital.

# 5. Cumulative Effects: People Matter

As noted in Box 1, many studies that aim to evaluate a community or region's capacity to respond to environmental challenges make the mistake of treating capacity as additive. That is, these studies assume that the mere presence of resources is sufficient for a community's ability to mobilize those resources. Following on that assumption, they also often assume that the more capital a community can claim the better off they are (or will be).

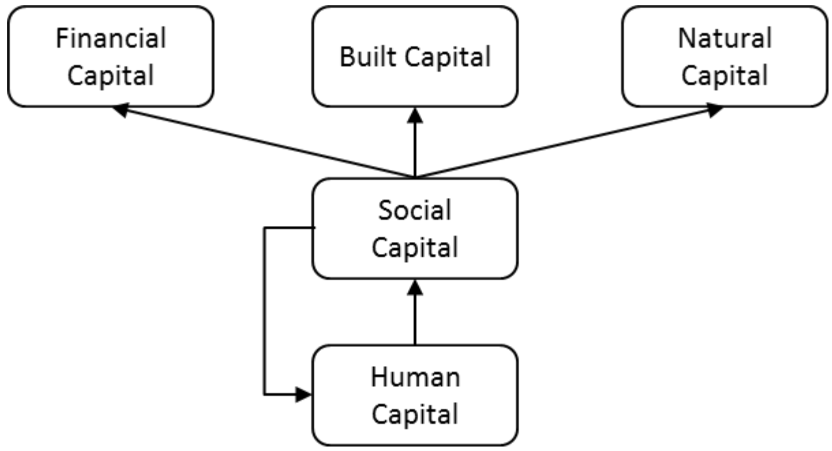



**Figure 20.** Human and social capital are at the core of how communities can make use of their other resources.

Data from our interviews suggests the contrary, however (Table 4)—that issues such as differential access to capital, trade-offs inherent to expending capital, or the sequence of actions and events necessary to fully realize capital (e.g., human resources as a prerequisite for making use of natural and built capital) all make the reality of community responses to change more complex than is captured by these mainstream indices and frameworks. If a goal is to develop regional coordination as a form of *social* capital, for example, human capital must be attended to first because human and social capital are intrinsically linked. That is, people develop networks, through which they create opportunities to train others and to make use of the other kinds of resources: shared equipment or infrastructure, grant opportunities, and collective landholdings are but three examples.

**Table 1:** Examples of barriers to community carrying capacity in rural Alaska

| Type of Capital | Example | Barrier to mobilization |
|---|---|---|
| **I. Human** | Trained personnel | Limited training and employment opportunities, highly specialized experience, seasonal loss of laborers for fishing/hunting |
| **II. Natural** | Freshwater sources | Stochastic climate impacts on hydrology, complex land/water tenure systems may limit options |
| **III. Financial** | Capital improvement grants | Discriminatory eligibility requirements based on demographics, history of infrastructure development |
| **IV. Social** | Tribal consortia & associations | Highly specialized water/wastewater systems limit regional collaboration |
| **V. Built** | State of the art water/wastewater systems | Insufficient funding for O&M, highly specialized & over-engineered solutions |

In communities with high turn-over of key employees, which characterizes many communities in rural Alaska, available funding can go untapped due to a lack of capacity for long-term planning. Meanwhile, in communities where employees have long tenure and hold a wealth of knowledge about their systems, top-down directives to use newer technologies or to meet quality standards and testing schedules that are unrealistic for rural Alaska, can limited people's ability to implement change. Moreover, despite the often well-developed human capital in rural Alaska, regional social collaboration lags in part because of the diversity of designs of water and wastewater systems from community to community.

> *It is apparent that human capital—the skills and knowledge that enable people to pursue different livelihood strategies and achieve objectives—is a prerequisite to a community's ability to respond to change*

Indeed, infrastructure varies so significantly from place to place in rural Alaska that each community remains, to some extent, an island to itself, and this can create a challenge for tribal consortia and existing regional networks that are attempting to facilitate coordination and collaboration.

Finally, what financial and/or technical support that is available is generally delivered from the state via a top-down, capital-projects model of rural development. This is a model that has proven repeatedly across the world and in Alaska to create solutions that are over-engineered and that, as such, often make communities more vulnerable than resilient to challenges like climatic change.

Among these various interdependencies, it is apparent from our interviews that human capital—the skills and knowledge that enable people to pursue different livelihood strategies and achieve objectives—is almost always prerequisite to a community's ability to mobilize other kinds of capital (Figure 10). Too, if a goal is to develop regional coordination as a form of *social* capital, human capital must be attended to first because human and social capital are intrinsically linked. People develop networks, which then can provide opportunities to train new people. Through these networks, people find opportunities to make use of the other kinds of resources: shared equipment or infrastructure, grant opportunities, and collective landholdings, as but three examples.

## Planning for Seasonal Stresses

The cumulative effects perspective introduced earlier emphasized language regarding spatial and temporal "crowding". That is, that the impacts of environmental stresses differ depending on where, when, and how frequently they occur. Our ethnographic results shed important light on the temporal aspect of climate change in the discussion of water security and resources management in rural Alaska. In the simplest terms, we find that there are multiple factors that play into whether and how a community will be impacted by some climatic or environmental stress, and that this is largely related to the highly seasonal aspects of life in rural Alaska. These include: important hunting and fishing activities that take place during certain times of the year, rapid and often dramatic "break up" and "freeze up" seasons, and strongly seasonal patterns of weather.

The cultural and ecological importance of the seasons in Alaska is evidenced in both historical and contemporary foodways and traditions, which are often illustrated with a "seasonal round" calendar (figure 11). Alaska Natives have lived and planned around strongly seasonal environments for millennia, and on an individual basis, the seasonal aspect of new environmental stressors is not particularly noteworthy. However, what we and others have found is that the new challenges associated with climate change, in concert with some modern changes to local life ways, such as more permanent residences which are reliant on extensive built infrastructure, and natural resource governance and management structures that are largely dictated from people living in urban areas, are now limiting peoples abilities to cope with seasonal challenges. For example,

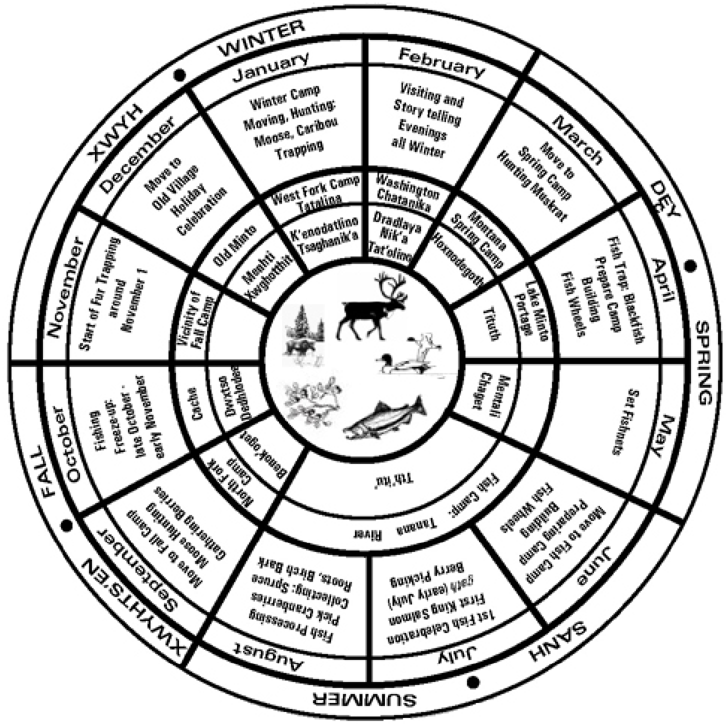



**Figure 21.** A typical "seasonal round" calendar of subsistence activities. Courtesy of the Alaska Native Knowledge Network

- The seasonal influx of outsiders for jobs in fisheries, mining, and other industries puts stress on community infrastructure, often at times when community offices are understaffed because local people are also busy with subsistence or commercial fishing.
- Because of winter weather and sea ice, the window during which supplies, equipment, and fuel can be shipped to rural communities can force local people to put off important municipal projects for one or more years, and greatly diminishes their ability to respond to surprise failures during the winter.
- Fiscal calendars and reporting and grant deadlines are not necessarily coordinated and can create gluts of work for local municipal workers; often the first activities to be sacrificed are planning and grant writing.

In the literature on climate change, these issues are often described as climatic and non-climatic stressors. Below, we propose a visual framework (figure 12) for mapping how these stressors interact on a temporal scale. This framework draws from the subsistence round shown in Figure 11, and we propose that it provides a culturally-relevant model for capturing and communicating data on forecasts regarding the timing and seasonality of potential hazards, as well as sociocultural details such as planning cycles, fiscal years, and seasonal changes in human resources.  Table 5 provides additional detail on how the stresses on the seasonal calendar are organized by category

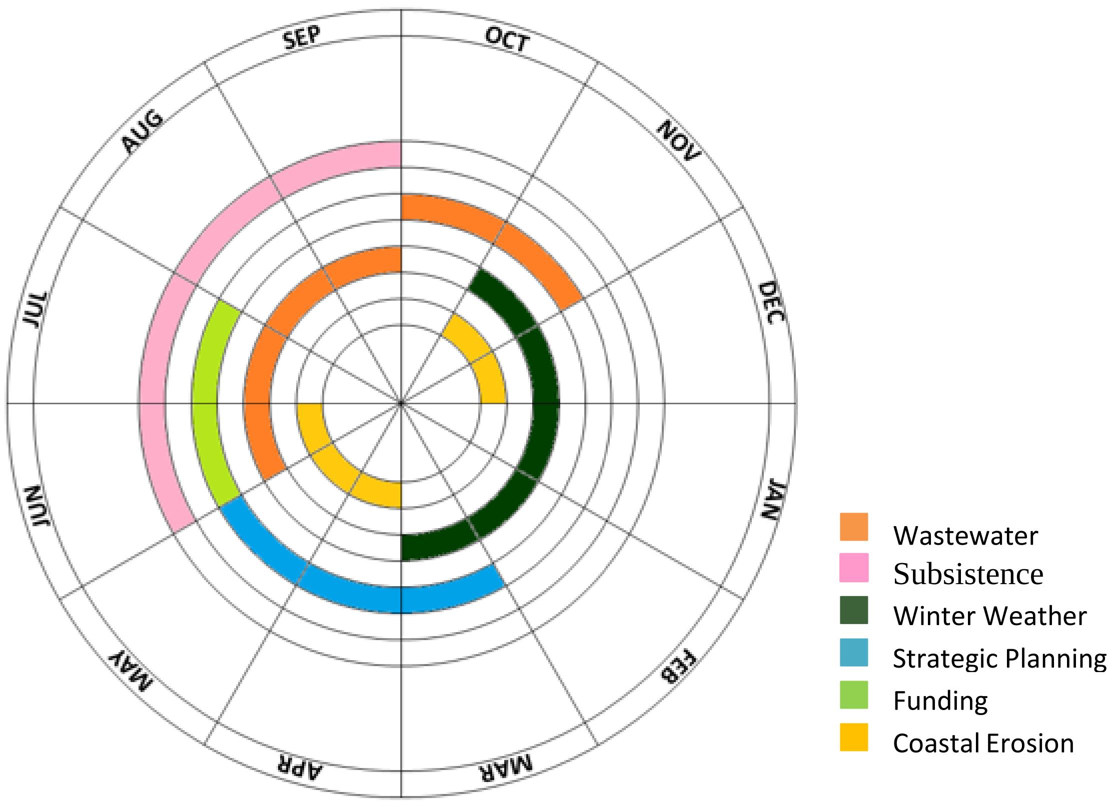



**Figure 22.** The seasonality calendar displays the seasons in which climatic and non-climatic stresses impact a coastal Alaskan community. See also Table 5.

**Table 2**. Description of seasonal stresses facing rural Alaska water systems.

| Seasonal stress | Description |
|---|---|
| **Wastewater treatment system** | The calendar identifies the seasons when usage is highest due to seasonal population increase (Jun-Sep), and when effluent quality is lowest (Oct-Nov) |
| **Subsistence activities** | This refers specifically to a typical salmon fishing season |
| **Winter weather** | Season when exposure to severe winter weather storms is greatest |
| **Strategic planning** | Season when communities typically complete planning, resource allocations or community elections. |
| **Community funding activities** | Season in which many agency funding application deadlines are situated |
| **Coastal erosion** | Season when exposure to coastal erosion is greatest |

The Seasonal calendars illustrated here were been found to be useful as a visual planning heuristic by several of our community partners. We believe that it is complementary with vulnerability analysis as well, and especially with participatory approaches to vulnerability analysis (Figure 13). As described earlier, vulnerability is commonly understood as having three phases: exposure to a stress, sensitivity to the stress, and ability to respond. With the help of local experts, each of these phases can be mapped on the seasonal calendar for one or even multiple stressors. Additional detail could be added by asking local experts to rate when exposure or sensitivity is highest, or when ability to respond is low. Hence, a community can generate an understanding of its vulnerability to stress on a local temporal scale.

For example, the figure below is a visual representation of the vulnerability of a community to a failure of wastewater systems, taking into account coastal erosion, usage of wastewater infrastructure, and diminished human capital because people are on leave for fishing and other subsistence activities. When viewed together, late spring appears to be the time when the community is most vulnerable. Multiple variables could be considered when crafting these calendars; for example, ports being closed to shipping in winter months is another source of diminished capacity to respond to a failure.

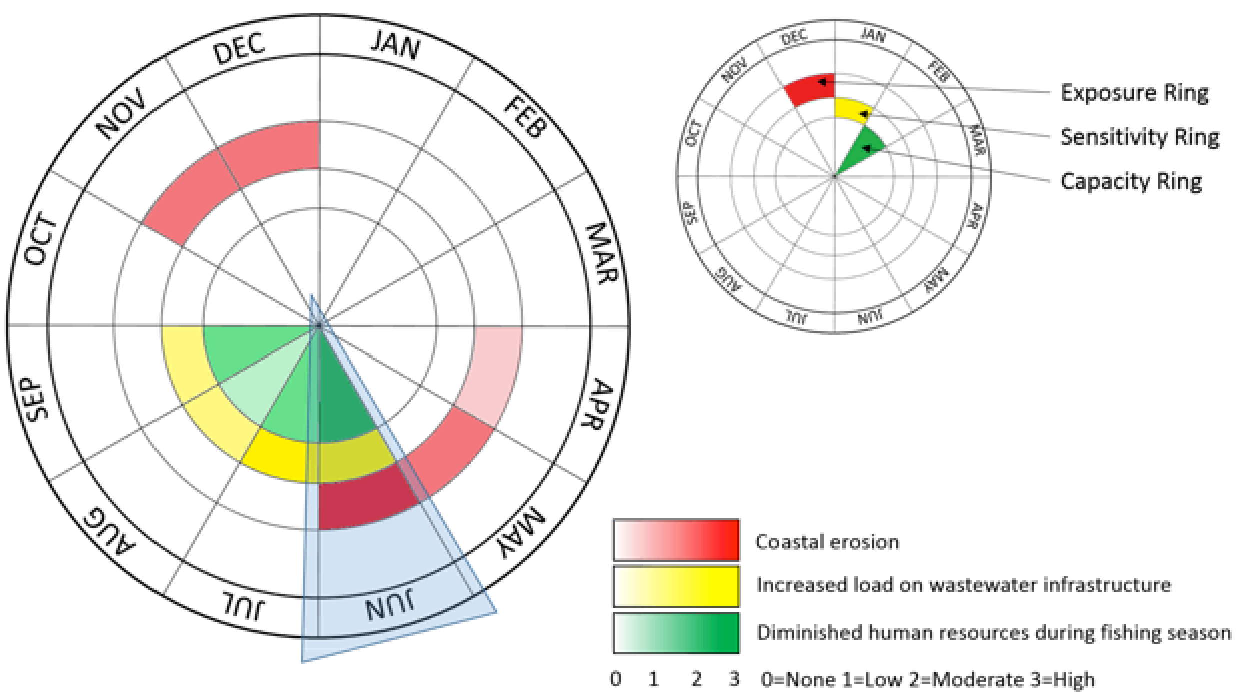



**Figure 23:** Simple seasonal stress calendar with components of vulnerability highlighted.

## Best Practices for Reducing Cumulative Effects

In addition to their revelations about the often-seasonal nature of stresses and vulnerabilities in rural Alaska, our community partners also had several ideas for best practices related to engineered systems design that they believed would help to mitigate or even eliminate some of the various challenges reported above. Specifically, we repeatedly encountered the sentiment that more should be done by engineers and agencies with respect to assessing and understanding community needs and the challenges of O&M in the remote north when designing engineered systems. Specifically, two design principles emerged during our discussions: modularity and standardization of equipment; and, the avoidance of "over-innovation", that is, the deployment of over-complicated or over-engineered solutions.

> *We don't need or even want high tech. We just need something that works, and that we can fix when it breaks.*

### Modularity

Modularity is a design principle mentioned by nearly all of the operators and managers whom we interviewed. We observed multiple cases of operators unable to conduct O&M because components of their water and wastewater system rely on disparate technologies that are not interchangeable. One community visited operates six lift stations, all of which use a different model pump. This lack of standardization both increases O&M costs and reduces capacity to respond to failures, especially when communities are logistically isolated due to winter weather and sea ice.

Future engineering design decisions that take a more holistic view of a region can rapidly increase modularity and increase regional capacity. When new systems are designed, it would be ideal that, in addition to such factors as cost, ease of acquisition and lead in time (alongside other typical engineering parameters), decisions also take into consideration the kinds of infrastructure and equipment already deployed in nearby communities. The goal being to reduce a community's sensitivity to equipment failure, but also develop regional capacity for coordination and support.

### Avoiding "Over-innovation"

Over-innovation describes when decisions are made to make use of technologies, usually cutting edge, that do not make notable contributions toward whether an engineered system meets place-based design criteria. Community operators with whom we worked were quick to demonstrate to us where new products or technologies installed in their systems had unnecessarily increased their workload. Operators called such devices "black boxes"; referring to a typically sealed unit that when broken could not be fixed in the community, was shipped to an outside company, and returned many months later at great expense. Examples included newer models of heavy equipment (e.g., front loaders) as well as state of the art HVAC equipment in water treatment facilities. Whilst community operators recognized that new technologies can in many cases increase local capacity, they cautioned that without proper installation and consideration of their additional O&M burden, these new technologies are more often a nuisance or worse.

## Toward Regional Coordination

Finally, we find it important to comment on the question of regional coordination for water security in Bristol Bay. When we originally scoped this project, a primary goal was to explore if and how communities work together, whether via pooling resources and expertise or some other mechanism, to ensure water security in the face of environmental and climatic change. We were initially surprised to find less in the way of existing collaborations than we expected, but the causes for this became clear very quickly. No two communities face identical challenges, nor do they have equal access to the same resources needed to solve the problems. Some communities  must contend with changing hydrological cycles while others are impacted by storms; some are eligible for funding and engineering support from organizations such as ANTHC while others are not; some can levy taxes to fund O&M and some cannot. Finally, while many communities are members of one or more regional associations that can facilitate collaboration among communities, infrastructure varies so significantly from place to place that coordination, whether of purchasing or training, would have limited short-term returns.

The two design principles described above would go far toward improving the potential for regional coordination and collaboration. We believe that a model for what this might look like already arguably exists in Alaska, in the form of regional healthcare services. Across Alaska, regional health corporations use an innovative model for providing health services in rural areas.

Bristol Bay Area Health Corporation, the regional health care provider, serves 34 villages and employs over 360 people, with 29 village clinics, two sub-regional clinics and once hospital in Bristol Bay. Each village clinic is staffed by at least 2 full time staff, who manage day to day community needs and provide triage care in emergency situations. Various specialists, e.g., dentists, optometrists, GPs, also visit the clinics on a periodic basis. Needs such as purchasing of equipment and supplies are centralized through the corporation, meeting local needs while also providing an important economy of scale. Telemedicine, the use of telecommunication and information technologies in order to provide clinical health care at a distance, is also an essential component of effective healthcare delivery in rural Alaska.

Adapting this regional healthcare model for water and wastewater management presents a number of possible benefits that would address the various challenges described in this report. Its tiered approach to human capital, specifically, would be effective; local operators who specialize on the specific circumstances of a community’s water and wastewater system could find support from a team of roaming specialists with more broad engineering and hydrological expertise. Too, purchasing of supplies and equipment could be centralized where possible; though, this would also hinge on the ability of communities to move toward some degree of standardization and/or modularity in system design.

The capacity for knowledge sharing is also essential, and can provide each community with greatly increase capacity to manage extreme events. Similar technologies to that used by telemedicine could be used to make engineering support available when needed.

### A Note on Agencies

Much of the discussion above has focused on the need to develop regional coordination in Bristol Bay. It is important to note, however, that a wide array of agencies[1] and support groups operate in the region and across Alaska as a whole. It is essential that these groups be involved in any efforts to improve regional coordination. For example, water and wastewater systems are subject to a wide variety of regulation. Periodically these regulations change or are updated, and agencies such as the BBAHC and ANTHC are best placed to disseminate the fallout of new policy to communities. Agencies are also best placed to inform communities of future policy changes and their implications in terms of required changes to existing systems and procedures. Agencies also often conduct assessments on behalf of the community or some higher legislative entity. We have observed such assessments, and noted that such activities are particularly successful when carried out by known persons who have previously worked in the community. Finally, agencies are routinely contacted by communities for technical assistance. Examples of this type of support include grant writing assistance, operational procedures, and training.

## 6. Conclusion

The general, overriding premise of this work is that local and regional water security, especially in the face of uncertainty and change, is a process that is highly dependent on a community and/or region's capacity to manage their water and wastewater infrastructure and resources. This is not necessarily a new observation, but what we show here is that building local capacity, whether for managing water security or food security or any other environmental concern, requires a level of coordinated design that does not usually accompany the top-down, capital projects model of rural development. We therefore argue for an approach focuses on the identification of strategies for enhancing local and regional collaboration concerning water security, with a primary goal and desired outcome being that the community water and wastewater systems of the future do not perpetuate the isolation, fragmentation and other challenges that they exhibit today.

Water security is indeed a place-based challenge in rural Alaska, one driven largely by unique hydrological and socioeconomic circumstances of individual communities, but this need not require solutions that lock communities into isolation from one another. Indeed, we propose that attempting to devise solutions that are individually designed for each community in respect to a discrete set of parameters is wholly unrealistic and unachievable. Instead, solutions for enhancing water security should be developed through collaborative efforts which identify groups of communities that can share resources. This is not as much a challenge of developing new water security technology, as it is of how to implement existing technologies, with best practices such as modularity, portability, interoperability, and, as much as possible, standardization, emerging as important for enhancing the capacity for intraregional collaboration.

[1] We use the term agency to represent any non-community entity operating in a support capacity in the region.

It is noteworthy that most villages in rural Alaska are relatively new, established in the last century primarily for the purposes of building schools and churches, in areas with access for aircraft or barges, and at places that were historically only used seasonally. That people today live in these “fixed,” permanent communities and lack the seasonal residential mobility that they once had, clearly creates both a new set of challenges, and perhaps opportunity as well. As such, it can be argued that the water security challenges described above are less a product of climate change and the unique parameters of living in remote north, and more the result of a rapid and largely ad-hoc social transition from highly mobile to fixed patterns of residency. Moving forward, and recognizing that this is a transition that is unlikely to be reversed, solutions for water security that are more closely tailored to the dynamic and highly-seasonal nature of Alaska’s landscapes and communities are necessary. Strategies for coordination, support, and enforcement from higher levels, e.g., tribal, state, and federal agencies, should address water systems and security not just as products to be engineered, installed, and walked away from, but as an ongoing and adaptive process of environmental management. The many organizations that actively support Alaska’s rural communities working to manage their water security, such as ANTHC, do important work in this regard. A question, however, is whether existing policy-driven mandates and jurisdictional boundaries serve to enhance or limit their impact and the potential to realize more effective regional collaboration toward enduring water security.

## Acknowledgements

We wish to express our sincerest thanks to everyone who took the time to fill out our survey, and all of those individuals who went out of their way to make this project possible (listed in no particular order): … and anyone else that we may have unintentionally omitted. This research is yours, and we hope that it contributes in some small way to your lives and livelihoods.

This research was funded by a grant from the Climate Program Office of the National Oceanic and Atmospheric Administration (NOAA), Climate-Society Interactions Program Grant #NA11OAR4310135. Preparation and publication of this report was also supported by a grant from the National Science Foundation Arctic Science, Education, and Engineering for Sustainability (Arctic SEES) (grant #1263853)

## Appendix I. Rapid Water Management Capacity Assessment

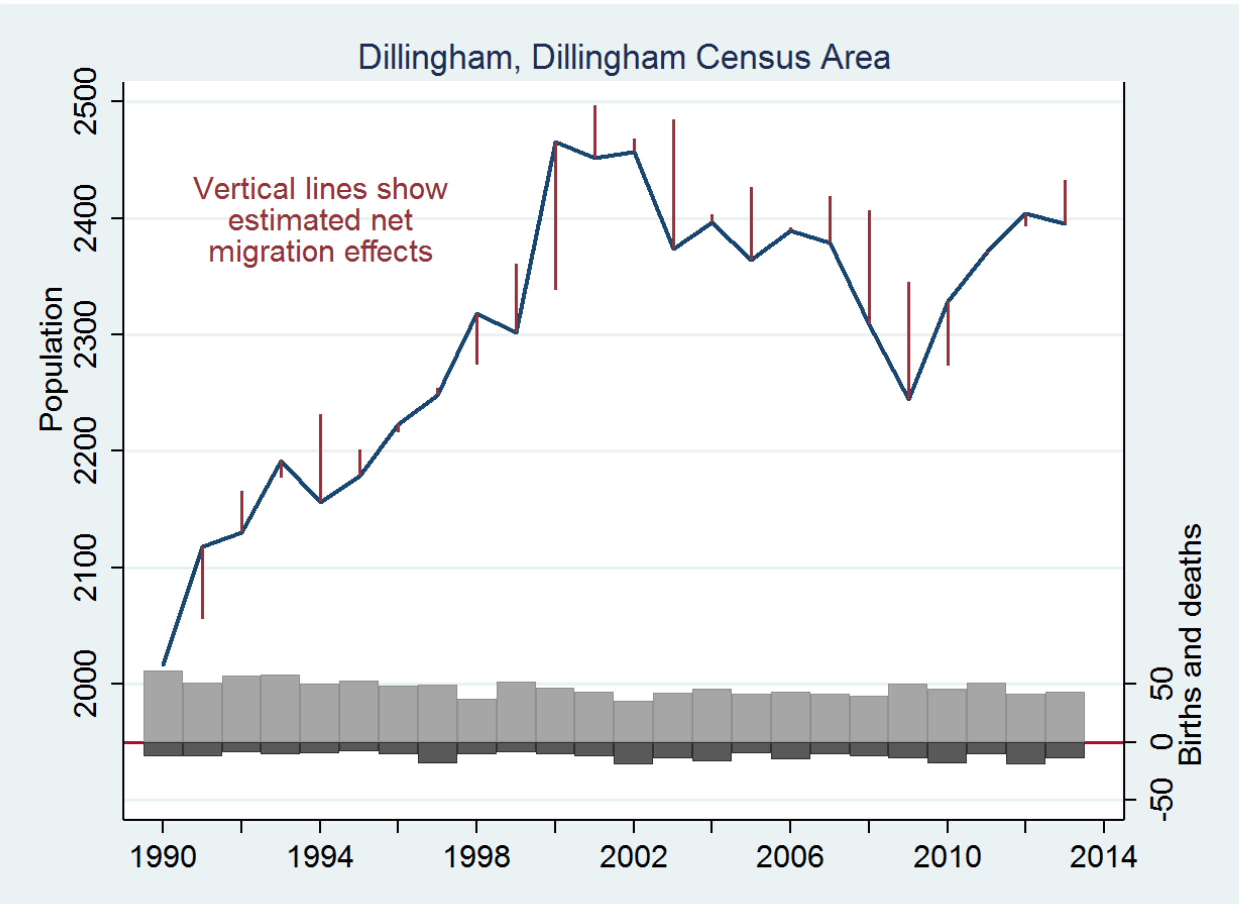
| Water Security Criteria | Presence | Absence |
|---|---|---|
| Human Resources | | |
| a. Employee redundancy | | |
| b. Multiple years of experience | | |
| Social Capital | | |
| a. Planning documentation in place and up-to-date | | |
| b. Existing experience with grant writing / previous success | | |
| Natural Resources | | |
| a. Absence of existing or projected threat to water source | | |
| b. Back-up water source | | |
| c. Absence of environmental challenge due to community action | | |
| d. Absence of underlying environmental challenge | | |
| Built Infrastructure | | |
| a. Majority of community on piped water system | | |
| b. Majority of community disconnected from wastewater | | |
| c. System operating within: | | |
| 1. Budget | | |
| 2. Available O&M time | | |
| d. System operating within normal conditions can meet community needs | | |
| e. O&M available when required | | |
| Financial Capital | | |
| a. Grants are not required for normal operations | | |
| b. Community budget exceeds requirements for normal operations | | |

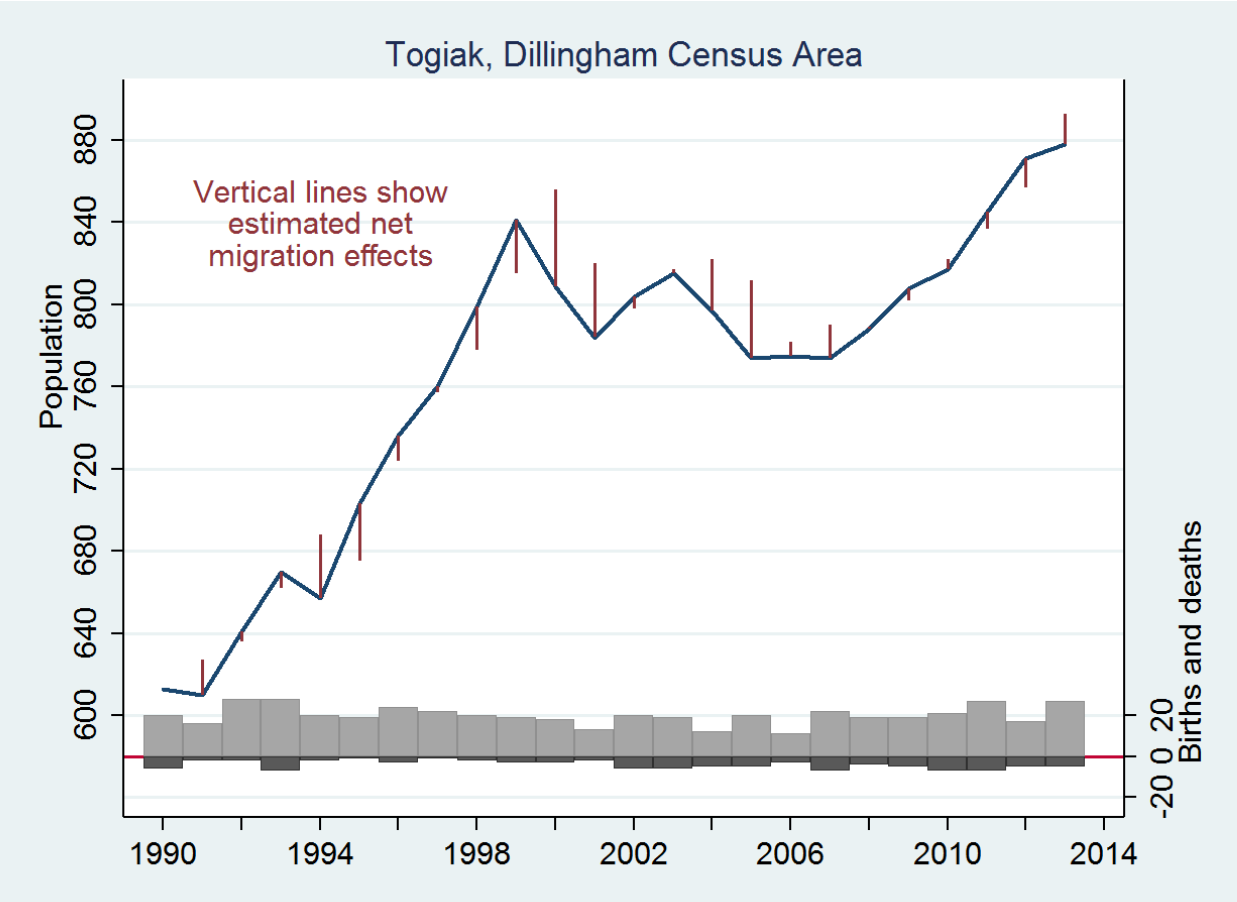
# Appendix II. Demographic Trends for Study Communities

Overall trends regarding in and outmigration are an important component to community sustainability, especially for anticipating needs and impacts on community infrastructure. Note that this annual view of population does not capture the high seasonal influx of people to some study communities such as Dillingham during fishing season.

The entire dataset for Alaska can be found here:

Hamilton, Lawrence; Lammers, Richard; Glidden, Stanley; Saito, Kei; Sustainable Futures North (2014): Population Dynamics of Arctic Alaska A graphical library of demographic change in 43 towns and villages, 1990–2013. http://dx.doi.org/10.6084/m9.figshare.1044226



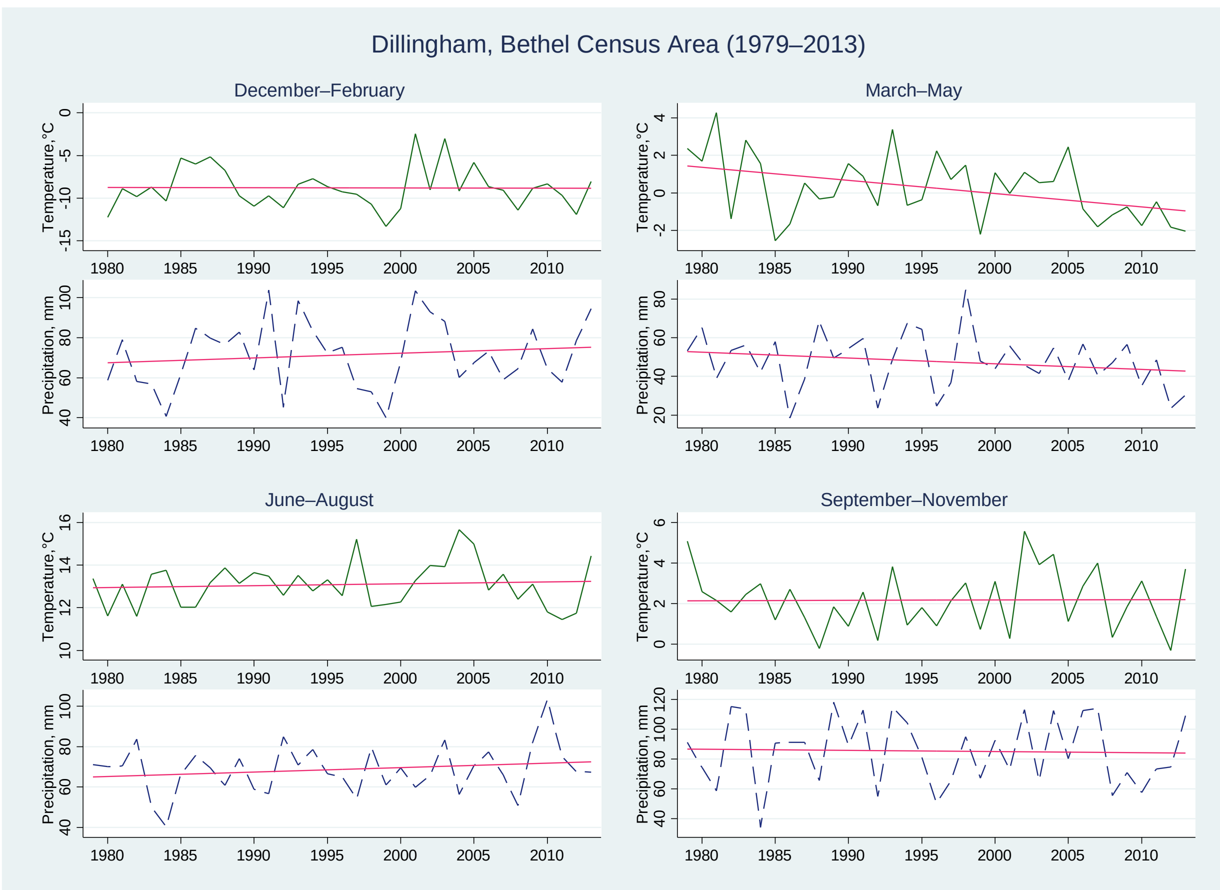

Togiak, Dillingham Census Area
Vertical lines show estimated net migration effects
Population
600
640
680
720
760
800
840
880
Births and deaths
-20 0 20
1990
1994
1998
2002
2006
2010
2014

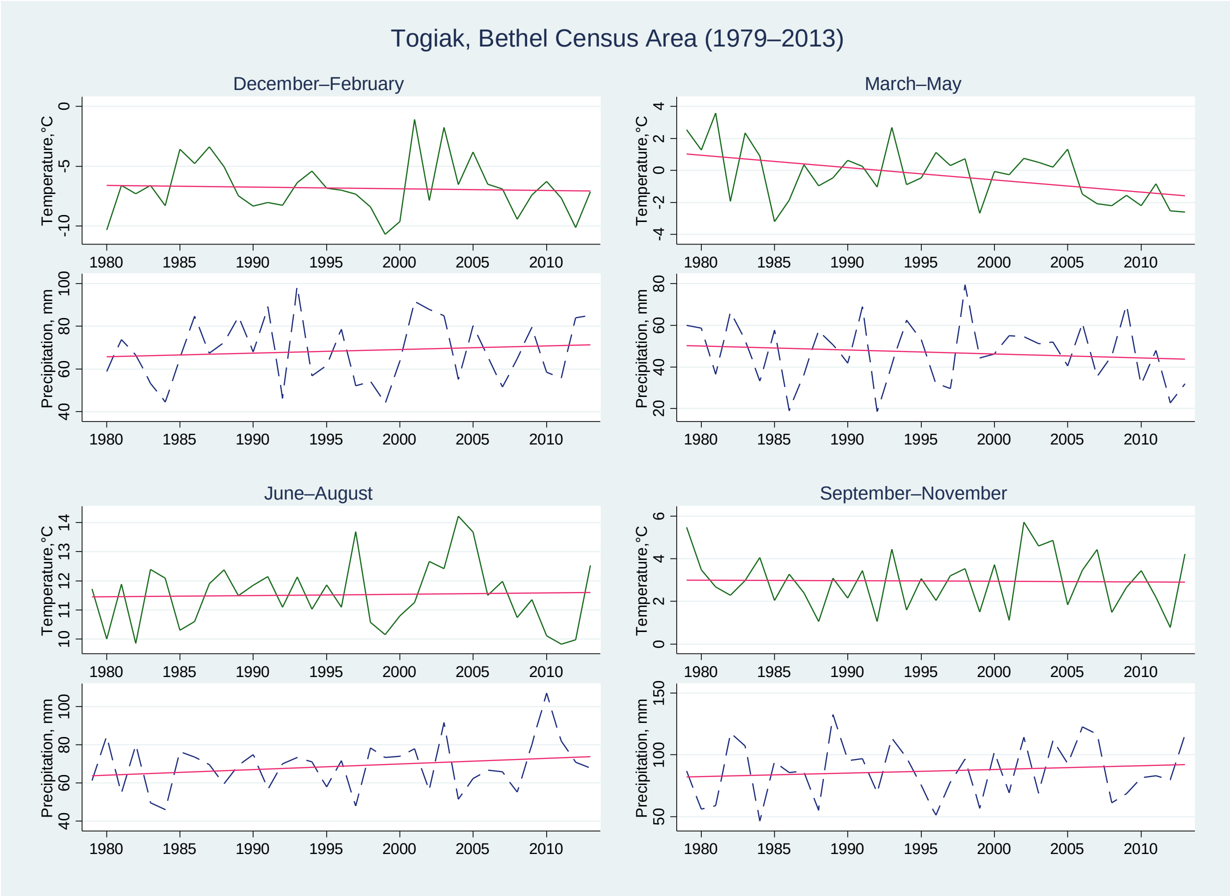
# Appendix III. Historical Temperature and Precipitation for Study Communities

Past and future trends and changes for temperature and precipitation in the region will have important impacts on regional hydrology and therefore water security.

The entire dataset for Alaska can be found here:

Hamilton, Lawrence; Lammers, Richard; Glidden, Stanley; Saito, Kei; North, Sustainable Futures (2014): Temperature and precipitation in Arctic Alaska : A graphical library for 43 communities, 1979–2013. [http://dx.doi.org/10.6084/m9.figshare.1051815](http://dx.doi.org/10.6084/m9.figshare.1051815)




Togiak, Bethel Census Area (1979–2013)
December–February
March–May
June–August
September–November
Temperature, °C
Precipitation, mm
1980
1985
1990
1995
2000
2005
2010

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