Climate Change in **Kivalina**, Alaska

Strategies for Community Health

ANTHC Center for Climate and Health

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Through adaptation, negative health effects can be prevented.

Cover Art:
Whale Bone Mask by Larry Adams

ANTHC would like to thank the residents of Kivalina for their hospitality during our visits and for their assistance in preparing this report.

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SUMMARY

Rural Arctic communities are vulnerable to climate change

and seek adaptation strategies that will protect health and health infrastructure. This report describes climate change impacts on Kivalina, a small Inupiat Eskimo community located on the coast of the Chukchi Sea. Data sources included the observations of local residents, reports from local and regional government officials and health professionals, and scientific evidence gathered from published sources.

This is the second in a series of community specific analyses describing climate change effects in Northwestern Alaska. It was prepared by the Alaska Native Tribal Health Consortium, Center for Climate and Health with funding from the United States Indian Health Service. The first report focused on Point Hope, the northern most community in the Maniilaq Association's health service area. Assessments in other communities are on-going and will ultimately contribute to a comprehensive report for the Northwest Arctic region.

Storm waves threaten Kivalina.
Courtesy of the Alaska Department of Transportation.

This Climate Change Health Assessment was performed based on requests from tribal health representatives and from local and regional leadership. Information about local climate, environment, and health conditions was gathered with the help of local and regional government, universities, industry, and state and federal agencies.

A failed erosion prevention effort.
Courtesy of Millie Hawley.

There are many uncertainties about the future of Kivalina, but it is obvious that climate change is resulting in serious health challenges that need to be addressed. It is hoped that this report will facilitate informed decision making, and the development of adaptive measures that encourage a sustainable and healthy future for Kivalina and other communities in the Northwest Arctic region.

Anecdotal data was collected on the observations and experience from local experts in health, wildlife, whaling, Inupiat culture, weather, subsistence, education, sanitation, local governance, law enforcement, and emergency services.

Predictions and projections on future conditions such as warming, flooding, and erosion are based on available information, and limited by the quality of current scientific data and the uncertainties inherent in climate models.

The recommendations contained in this report are, in brief:

The lack of adequate sanitation is the most immediate health threat in Kivalina. Fear of losing public investment due to climate related erosion and flooding has discouraged agencies from making long overdue infrastructure improvements. As the new rock revetment wall has a projected fifteen to twenty year design life, sanitation improvements should now be made to address basic public health requirements. An engineering feasibility study should be performed to improve sanitation, and should then be funded to construct the required improvements.

Reducing the risk of climate related mental stress, injury, and disease is another priority in Kivalina. A study should be performed to address public safety concerns as a result of a storm surge. The study should address evacuation and shelter alternatives and be funded so that options adequate to the level of risk can be realized.

The community water system is vulnerable to climate impacts. Bank erosion in the Wulik River is decreasing water quality and could compromise the ability of the existing water treatment system to deliver safe water in adequate quantities. An engineering feasibility study should be performed to develop water treatment alternatives and should then be funded to construct the required improvements.

Enhancement of the community environmental monitoring infrastructure is also needed, so as to better understand climate change impacts. A local environmental observer program should be developed to improve weather data collection, erosion and permafrost monitoring, and surveillance of biota, subsistence, and environmental change.

Unusual and unpredictable weather, snow, ice and water conditions have made travel more hazardous. Use of personal locator beacons is encouraged to enhance search and rescue personnel's ability to locate people in peril.

Climate change is affecting subsistence activities, and may result in changes to harvest and diet. Periodic dietary surveys would help monitor changes in diet, and allow health workers to assess health risks and benefits.

This report is about the effects of climate change - both good and bad - on people's lives as described by Kivalina's residents and interpreted through the lens of public health.

Children at play on a warm April day in Kivalina.
Michael Brubaker, 2010.

Policies for investing in Kivalina should be revisited in light of the fact that the revetment wall is significantly extending the life of the community.

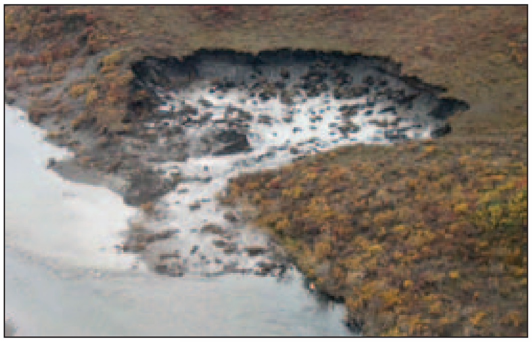
INTRODUCTION

The lifestyle and culture of the Iñupiat has adapted over thousands of years, resulting in effective methods for living in one of the harshest of Alaska's environments—the Arctic coast. Kivalina is a small community located on the edge of the Chukchi Sea. Life revolves around subsistence: the traditional lifestyle of gathering wild food from the land and sea to sustain one's family and community. Inupiat families are engaged year-round in preparation or out hunting, fishing, and gathering. The most important species are bearded seal, beluga whale, caribou, and Arctic char, which is locally referred to as "trout." Over forty other varieties of plants and wildlife are also taken (Magdanz, et al., 2010).

Climate change refers to change over time, due to natural variability or as a result of human activity (IPCC, 2008). In Kivalina, the rate of climate change is no longer measured in decades, but rather in years, months, or even hours. Elders talk about camping on thick shelves of sea ice; an astounding change when compared with the thin ice typical today. Kivalina's youth are in many ways just as insightful, a lot of change has occurred just within the span of their lives. Storm related erosion since 2000 has removed much of the beach where teenagers played on as young children.

In every season of the year, the air temperature is warmer than it was in the past. Land is thawing and then washing away into the rivers or disappearing as great chunks falling into the Chukchi Sea. Sea ice is diminishing, making travel and hunting more difficult and more dangerous. New species of plants, insects, fish, birds, and other wildlife are observed, while successful harvest of endemic species, such as walrus, is less frequent.

These changes are influencing food and water security and the potential for disease and injury. They are also raising new concerns about the effects of life-altering change on the mental health of Arctic people. Uncertainty about the future weighs heavily on the Iñupiaq. Violent storms, flooding, and the erosion of the land beneath people's homes generate fear, and the aftermath of a traumatic 2007 evacuation brings residual and reoccurring stress.



Thaw related erosion on the Wulik River.
Courtesy of Red Dog Mine.

> *"I went for a walk and saw this big slide I had not seen before. I said to my wife, 'maybe the permafrost really is melting'. I had to see climate change to finally believe it."*
>
> Joe Swan, Sr.

In July 2009 and May 2010, site visits were performed by ANTHC's Center for Climate and Health. Interviews were performed in offices of local government, in the health clinic, during excursions into the countryside, and in people's homes. Information was collected about impacts, potential health effects, data gaps, and adaptation measures. Local and regional partners reviewed the notes and provided comments on this report. Findings were presented to partner organizations in Kivalina and in Kotzebue.

The climate impacts documented in this report are predominately negative. Suggestions have been provided that hopefully will lead to effective action. Health positive effects have also been identified such as new food resources, shorter flu season, or a longer season for making water. It is hoped that this report will facilitate informed decision-making, and the development of adaptive measures that will encourage a safe, healthy, and sustainable future for the people of Kivalina.

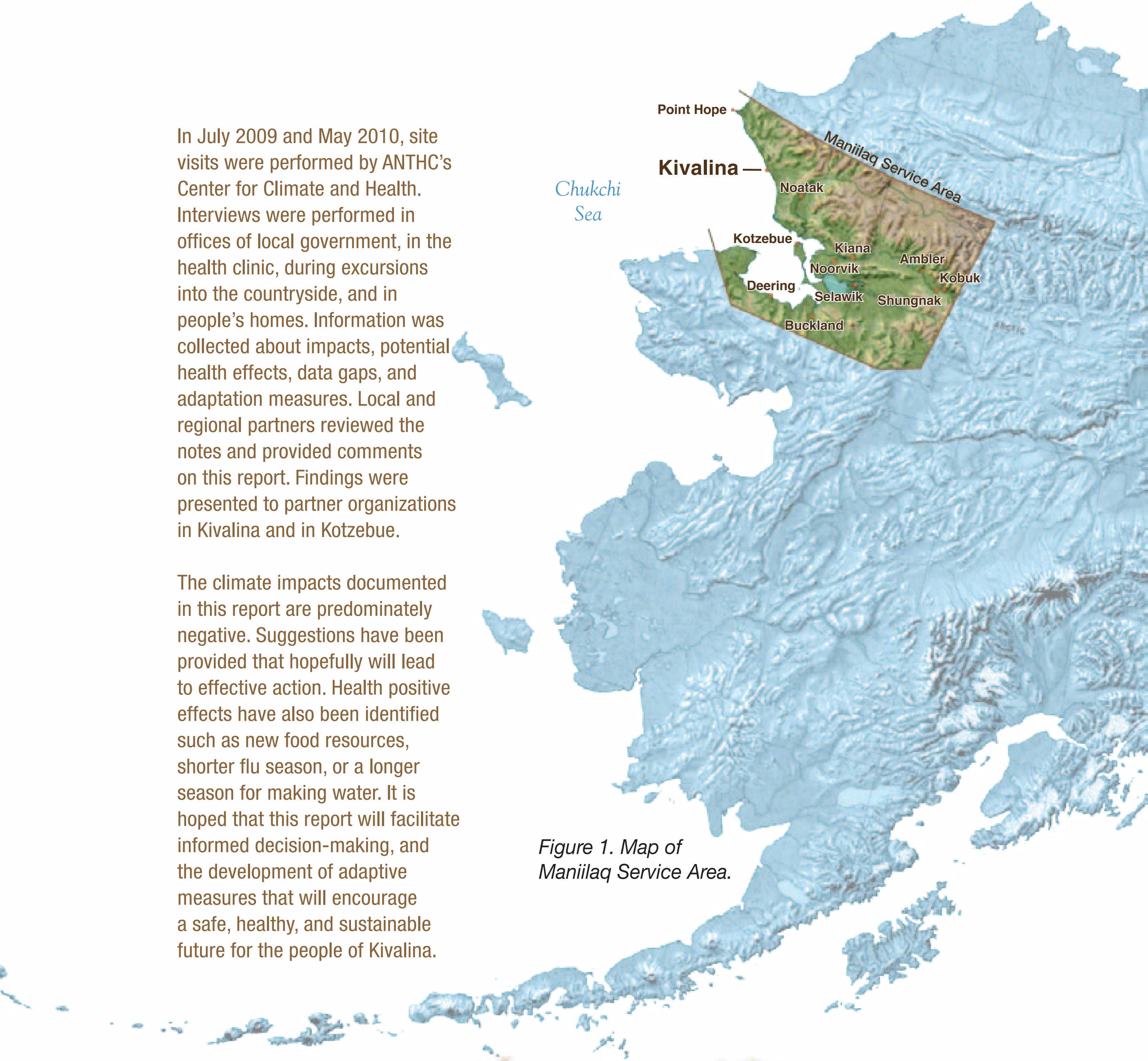


Figure 1. Map of Maniilaq Service Area.

"I finally went up the river last summer and I was totally amazed how much it had changed."

Mida Swan

PEOPLE

The story of the Inupiat is about resilience and adaptation

to a changing world. The Northern Inupiat arrived in Alaska at least 4,000 years ago. Finding abundant food resources, they settled in the Arctic regions of Alaska. The best hunting places are also often the most dynamic: rivers, estuaries, or coastal promontories subject to storms, flooding, and erosion. But the early Inupiat were accustomed to moving, quickly if needed, to find food or to move out of harms way. Some followed the rivers inland, hunting caribou and catching fish upriver. Entire communities would work together to drive the caribou into corrals, where they could be speared or shot with arrows. After spring thaw, a lake or river was substituted for corrals, and the caribou would be driven into the rivers, where they could be taken from kayaks using bow and arrow.

Historic Inupiat family.
Courtesy of The Inupiat Heritage Center.

Kids sledding.
Michael Brubaker, 2010.

The coastal Inupiat on the other hand, acquired most of what they needed from the sea: clothing, building materials for homes, boats and sleighs, and, of course, food. Bowhead whales and other sea mammals provided a surplus, one large bowhead could provide a small village with enough food for an entire year. But hauling a whale out requires a lot of hands and a community effort.

An underground cellar dug into the permafrost and framed with whalebone and driftwood provided a freezer year-round for the whale meat

> ***"I always bleach seal skins in mid-winter. It has to stay really cold. But since 2005, the weather always changes and every year it ruins the skins. I need to find a new way."***
>
> Lucy Adams

Hanging skins.
Michael Brubaker, 2010.

and maktak. For these reasons, the coastal lifestyle accommodated year-round settlements; villages with 50 to 500 people. Today, most Northwest Arctic villages are still about this size, and many of the same traditions are still practiced.

Kivalina is located in an area that has been used by the Inupiat for over 1,000 years. The people, known as the Kivalliñigmiut, were semi-nomadic traveling to the coast in the spring to hunt sea mammals, and inland to hunt caribou in the fall. These seasonal practices remain, although the people have lived in a permanent settlement for over 100 years.

"When people start talking about climate change, it really scares me."

Russell Adams, Sr.

Description of Kivalina

Today, Kivalina is a village of about 400 residents located on a barrier island, 83 miles above the Arctic Circle. It is the northern-most community in the Northwest Arctic Borough and is the only one where bowhead whale is still hunted, a defining aspect of the community and culture. Subsistence is the most important economy; with residents active year-round gathering seals, walrus, bowhead and beluga whale, caribou, polar bears, birds, fish, berries, and edible plants. Residents are employed in construction, mining, health care, education, traditional crafts, and the tribal and city services required to keep a rural Alaska community running. It is also a "dry" community, where the sale, importation or possession of alcohol is banned.

Bordered on the west by the Chukchi Sea and on the east by a saltwater lagoon, Kivalina is well positioned for hunting and fishing, and yet extremely vulnerable to ocean storms and erosion. The village sits on a sliver of sand and gravel held together by beach grass and

Aerial view of Kivalina.
Courtesy of Millie Hawley.

"Our community needs to put aside for the disasters that happen. Our older generations took care of the community, that's why it was good in those days."

Alice Adams

imported rock, and exposed to wind, current, and waves on all sides. Permafrost once made the ground beneath the island almost impenetrable, but warming is increasing the depth of the thaw layer with each passing summer.

The flat coastal lands to the east are punctuated with small tundra lakes and cut by narrow rivers that flow from the Delong Mountains to the coast. No roads lead to Kivalina, but beaches provide natural byways to the north and south. The Kivalina, Wulik and others rivers provide passage inland. In winter, if snow and ice conditions are good, travel is possible in all directions across the frozen land and sea. A gravel airstrip provides the only year-round access. Fuel and supplies are brought in by barge twice each summer.

"Kivalina … is very beautifully situated when the weather is nice and calm. But when the wind blows from the south, it raises the water in the ocean until it sometimes comes over the banks, it washed out the south east bank of the island and the natives are beginning to talk of moving."

Clinton Replogle, School Teacher, 1911.

The village itself is separated by two parallel gravel streets. Beaches on either side of town provide space for work and play, and an avenue for the movement of snowmachines and four-wheelers. A tall arch made from the rib bones of an enormous bowhead whale is an important local landmark, where wedding parties and visitors alike pose for pictures. On nice days, the streets of the village are buzzing with activity, people visiting, dogs barking, children playing, and vehicles roaring up and down the streets.

In many ways, Kivalina looks like many other Arctic villages: there are houses, a few churches, administrative offices, a health clinic, water plant and washeteria, a school, a Native store, and a bulk fuel storage facility. Snowmachines, dog sleds, and ATVs are parked around the houses. In summertime, small skiffs line the bank of Kivalina Lagoon. The City provides all local utilities including electricity, water, the washeteria, and operation of the dumpsite. Fuel is sold

"Our evacuation site is the school. We don't have another evacuation site."

Andrew Baldwin, Jr.

from a pump located outside the Native store. In the summer of 2009, the price for gasoline was over $9.00 per gallon. The McQueen School provides K-12 education for 129 students. The health clinic is operated by Maniilaq Association and is staffed by two community health aides. For more health care, residents fly to the regional hospital in Kotzebue, or to the Alaska Native Medical Center in Anchorage, 540 air miles from Kotzebue.

Because of the rate of beach erosion, the area occupied by Kivalina is much smaller today than it was even a decade ago. Since 1952, there has been a loss of over 19 acres in the Kivalina area with an average loss of 10-35 feet along the Chukchi coastline (NOAA, 2004). Despite this loss of land, the community is growing, doubling in population since the 1970s. Without room for new housing, this increasingly means crowding and growing demand on aging infrastructure.

From the air, the island and village resemble a harpoon, pointing south along the Chukchi coast. The shaft of the harpoon is a narrow stretch of land occupied by a 3,000-foot gravel airstrip. Halfway down the airstrip, a cluster of wooden crosses mark the location of the village cemetery with a view across the lagoon and east to the Delong Mountains. The harpoon point is the village with the tip terminating where a narrow channel flows into Kivalina Lagoon. A new rock revetment wall is the sharp edge, cutting west into the Chukchi Sea.

South of the harpoon tip and beyond the small channel, family subsistence camps line a sandy spit that eventually rejoins the mainland. Here, during the cooler months, meat is hung to dry on wooden racks, and beach seines are put out at right angles, to catch migrating fish. Several traditional ice cellars rise from the tundra, driftwood poles appear teepee-like, holding a block pulley used for raising and lowering whale meat and blubber into the cellars below.

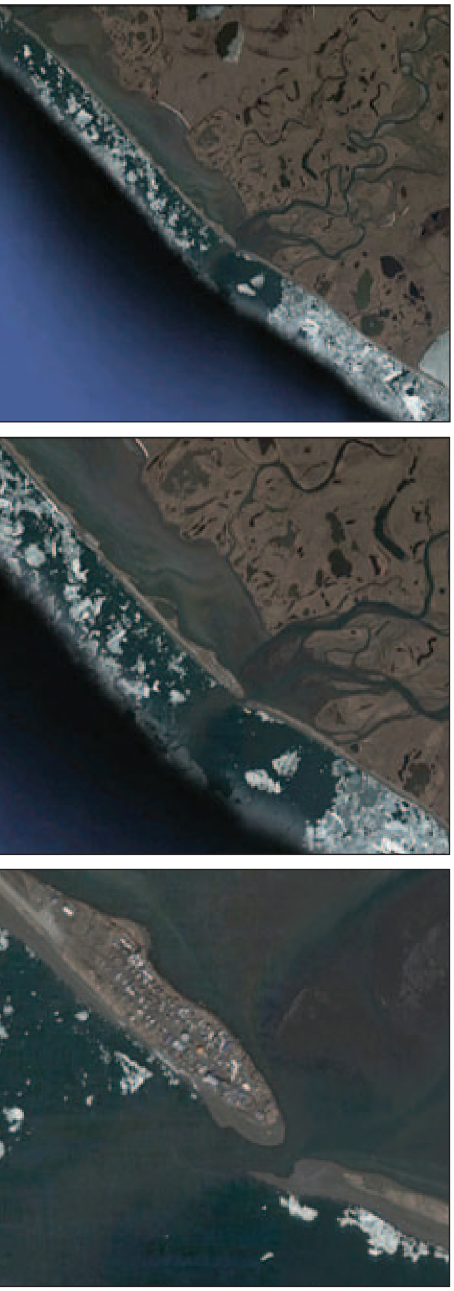


Figure 2. Zooming in on Kivalina, the tip of the harpoon.
Google Earth.

"My 10 year old son was worried the house would blow away."

Alice Adams

History of Kivalina

Prior to 1900, Kivalina was called Ualliik, one of many places used as temporary or seasonal camps by the Kivalliñigmiut Inupiat. Kivalina soon became a year-round settlement because the beach provided good off-loading for barge shipments and in 1905, supplies were brought in for construction of a new school. A mission, sod homes, and an economy based on subsistence and reindeer herding was soon to follow. The population also included families who had moved from the Upper and Lower Noatak, and from Kotzebue. From the start, there were concerns about the location of the village and its vulnerability to flooding. In a letter dated June 30, 1911, school teacher Clinton Replogle wrote about the risk of flooding and the talk among residents about moving the village inland.

But the community did not move. A post office was constructed in 1940, the same year that the Native Village of Kivalina was established under the Indian Reorganization Act of 1934 (IRA), and an airstrip in 1960. Shortly thereafter, Kivalina achieved national attention as

Early Kivalina.
Courtesy of Hawley Family and City of Kivalina.

Kivalina, originally located north of the island, was founded at its present location when the Federal Government constructed a school in 1905.

Fighting the storm.
Courtesy of Millie Hawley.

A home on the edge of eroded bank.
Michael Brubaker 2010.

New rock revetment wall.
Michael Brubaker 2010.

one of the communities located near Project Chariot, a project planned by the Atomic Energy Commission to test thermonuclear bombs for non-military purposes (O'Neill, 1994). At the time, half of Kivalina's residents were living in sod houses (Saario, D. 1962). Project Chariot aimed to create a deep water harbor at the mouth of Ogotoruk Creek, 50 miles north of the village. Protests ultimately caused President Kennedy to cancel the program in the fall of 1962. Kivalina was incorporated as second class city in 1969.

In the fall of 1970, a storm with a 13.57-foot sea rise inundated the streets with seawater. Then another fall storm in September 1976, flooded 20 to 30% of the town. Despite the storms and the beach erosion, Kivalina continued to develop with new housing, a high school, and a new community-wide electrical system. In 1982, the regional Native corporation, NANA, signed an agreement with Teck Cominco Alaska, Inc. to develop the largest open-pit lead and zinc mine in the world. The Northwest Arctic Borough was established to help manage the development, and to provide the benefits of borough government to a previously unorganized area. The opening of the mine brought unprecedented opportunity, jobs, and development to the region. But for Kivalina, the sole downstream community, it also bought new concerns about pollution and possible impacts on subsistence, the environment, and community health.

By the 1990s, erosion in Kivalina was becoming critical. Residents realized that the safety and sustainability of the community was at stake. The community responded by reinforcing the lagoon shore with sandbags. Realizing that relocation was inevitable, a special election was held in 2000 in order to decide on a new village location. Kiniktuuraq, a site on the beach about one mile south of Kivalina, was selected. But Kiniktuuraq is located at the same elevation as Kivalina and is also vulnerable to storm surge (USACE, 2006). Kiniktuuraq was also identified as an area with ice rich soil, that may not be able to support buildings if warming trends continue. (Gray 2010). The future of Kivalina remained uncertain.

"The sea wall was not a waste of money, people feel protected during big storms."

Alice Adams

In October 2002 and 2004, storms again battered the village, the latter resulting in the loss of 40 feet of shoreline. Both resulted in state disaster declarations and the General Accounting Office (GAO) determined that Kivalina was in immediate need of relocation. In September and October 2005, storms again resulted in disaster declarations. Residents of Kivalina scrambled to construct a beach wall out of anything that was on hand: 55 gallon drums, scrap from storage tanks, even the fuselage of an abandoned cargo plane. Despite the efforts, erosion continued with the loss of 70 feet of shore.

The following summer, work proceeded on construction of a new beach wall. One-meter square metal baskets were filled with sand and rock and then connected like gabians into a protective wall. By October, the new wall was finished and a celebration was held to mark its completion. The next day another storm mangled the wall; again leaving the community exposed. In 2007, the sea wall was reinforced using sand filled super sacks provided by the Army Corps of Engineers. On September 12, 2007, another storm prompted the evacuation of the village. This began with an air evacuation, but when aircrafts were no longer able to land, the evacuation was continued by skiff across Kivalina Lagoon, and then by ATV down the stormy beach to the Red Dog Mine Port Site. Red Dog then bused residents to the mine, which served as an emergency shelter. Six major storms occurred over as many years. The urgency of finding a new village location remains a focus of conversation in Kivalina to this day.

High water in October of 2004.
Courtesy of City of Kivalina.

Kivalina relocation discussion.
Michael Brubaker 2010.

Residents in Kivalina understand that relocation is inevitable. But moving a community is difficult, even when there is funding, and consensus about where to go. Estimates for moving have been placed between 100 and 400 million dollars (Gray, 2007). For Kivalina there are several site options, but there is not a consensus on where to move. There is, however, agreement about the need for protection from natural hazards, for basic services, and for housing for community expansion (Gray, 2009). Currently, a consensus-building project is underway to try to resolve the differences.

Estimates for moving Kivalina have been placed between 100 and 400 million dollars.

Observed change: *later freeze up; warm winters; early, rapid thaw; hot, dry summers.*
Health concerns: *injury; extreme weather; dangerous travel conditions; interrupted water service.*
Potential adaptation: *local observers; evacuation shelter; search and rescue technology.*

"Weather" is temperature, precipitation, humidity, wind, and other conditions that we experience on a daily basis. "Climate," on the other hand, is based on long-term weather trends. Over the past 50 years, Alaska has experienced a lot of temperature change and warming at more than twice the rate of the rest of the country. The annual average temperature in Alaska has increased 3.4°F, with winters warming by 6.3°F (Fitzpatrick et al., 2008). Average annual temperatures are projected to rise another 3.5°F to 7°F by the middle of this century (U.S. Global Change Research Program, 2009).

The climate of Kivalina is arctic, characterized by short and cool summers with temperatures averaging around 40 to 50°F. Since 2001, winter temperatures average around zero, and sometimes get as cold as -50°F, but generally remain between -5 and -15°F. Precipitation is light, 10 to 12 inches annually, with about 36 inches of snowfall that becomes hard-packed. Strong northern surface winds bring storms of blowing snow. Though people in Kivalina live on the coast, they also range far inland in search of subsistence resources. The coast benefits from the cool maritime weather that provides good conditions in spring and fall for drying fish, seal, and caribou. There is also more precipitation and wind on the coast, while inland the summers tend to be hot, dry and less windy. Despite this, residents report summers that are increasingly hot and dry even on the coast, and winters that are more variable with sudden

Snow piled up in front of local church.
Courtesy of Millie Hawley.

Warm summer day in Kivalina.
Courtesy of Millie Hawley.

> *"There was a big snowfall in March 2009. It lasted for three days. We had people injured from shoveling snow."*
> Millie Hawley

and dramatic temperature swings. The winter of 2008/2009 was notable with extreme high temperatures then low temperatures, and then record snowfall and snow accumulation.

The Community Charts developed by the Scenario Network for Alaska Planning (SNAP) at the University of Alaska Fairbanks (UAF) provides down-scaled temperature and precipitation data as well projections for the future. For temperature, two snapshots of past trends are available: 1961 to 1990, and 2001 to 2010 (see Figure 3). Between these periods, the average monthly temperature in Kivalina increased in every month of the year. The biggest temperature increases occurred in winter; January temperatures increased by 5 to 6° F. Smaller increases occurred in other seasons with the least, 1° F, occurring in June. The precipitation record is not as complete and so only modeled data is provided. Assessing precipitation

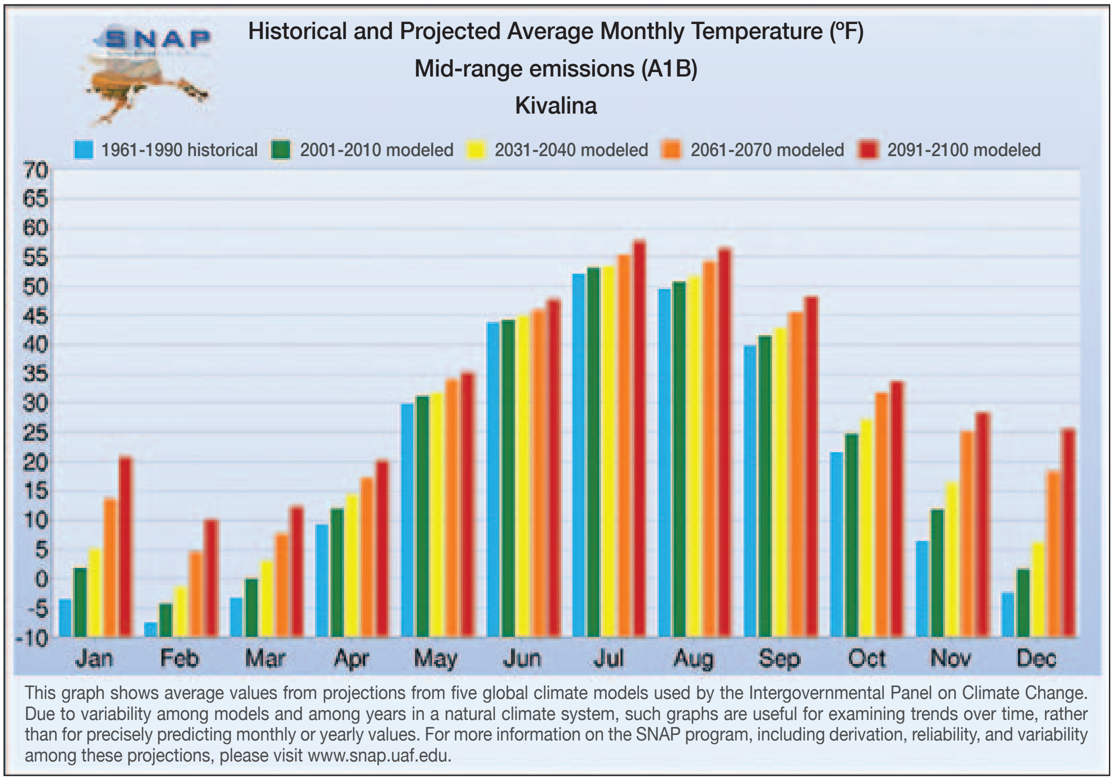


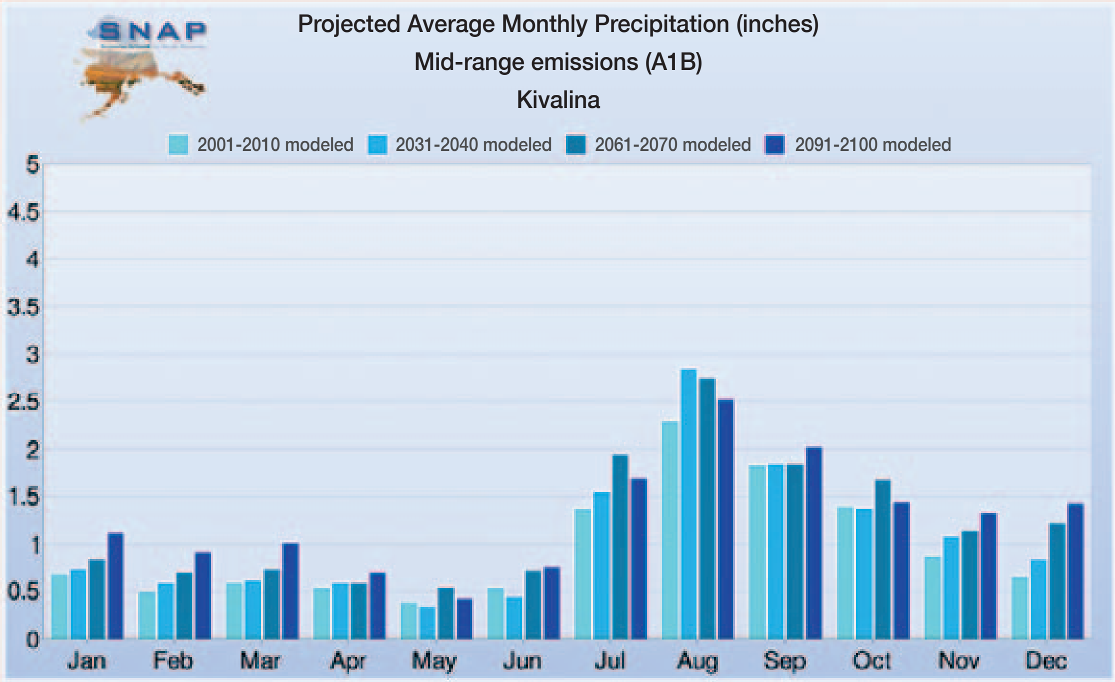
Figure 3. Historic & Projected Temperature, Kivalina, Alaska.
UAF, Scenario Network for Alaska Planning 2010.

"It is too warm now to dry fish on fish racks in June."

Mida Swan

changes for Kivalina will have to wait for more data, but Kotzebue has good precipitation records and we know that there has been a gradual increase in annual average precipitation since about 1950.

SNAP Community Charts also provides future "projections" based on five global models used by the United Nations Intergovernmental Panel on Climate Change (IPCC). There are three scenarios, based on high, low, or medium future global CO2 levels. The graphs included in this report are the medium CO2 level projections (SNAP 2010). In all scenarios, the monthly warming trends are expected to continue with the biggest changes occurring in the winter. Despite higher annual precipitation, a generally drier summer environment is expected with affects on hydrology, wildlife, and human communities.



This graph shows average values from projections from five global climate models used by the Intergovernmental Panel on Climate Change. Due to variability among models and among years in a natural climate system, such graphs are useful for examining trends over time, rather than for precisely predicting monthly or yearly values. For more information on the SNAP program, including derivation, reliability, and variability among these projections, please visit www.snap.uaf.edu.

Figure 4. Past and Projected Average Monthly Precipitation, Kivalina, Alaska.
UAF, Scenario Network for Alaska Planning 2010.

"When there are storms people are very anxious, some people walk all night."

Alice Adams

Sunset over the beach revetment wall.
Photo by Jacob Bell, 2010.

One persistent question not directly addressed by climate models is whether the future will bring more snow or less. Adequate snow is important for winter travel by snowmachine. Too much snow and all travel comes to a standstill; too little and it becomes limited to ice on the rivers, or by ATV along the coast.

Recommendation: Residents rely upon local knowledge to make decisions about where and when to hunt and travel. They also rely upon weather data from the automated weather station at the Kivalina airstrip, and observations from the National Weather Service. The capacity to measure, interpret, and forecast weather conditions is critical for safety, but automated data is limited. Collaborations with federal agencies on an observer program could provide a method of combining scientific measurements and traditional knowledge for improved forecasting and climate change measurements. To do this, local observers will be needed to collect snow and other precipitation data, and to serve as National Weather Service Spotters for extreme weather events. Kivalina could participate in the National Weather Service "Storm Ready." program. Storm Ready helps communities develop plans to respond to severe weather events and provides advise on improving hazardous weather operations.

> *"It probably won't even be long before we have to adapt from trout to salmon. I would like to know which fish has a chance of survival in warmer temperatures."*
>
> Mida Swan

SEASONS

Observed change: *later freeze up; early thaw; change in timing of wildlife migrations.*
Health concerns: *dangerous travel conditions; change in wildlife availability.*
Potential adaptation: *local observers; travel condition advisories; wildlife monitoring.*

The meaning of "season" in coastal Inupiat communities is different than in the western context. Though also tied to changes in the weather and natural landscape, in Kivalina it is equally tied to timing of subsistence and important cultural activities. Understanding seasons as described by residents is important for recording local observations and measuring seasonal change. There are at least seven seasons (see figure 5) for

Season	Month(s)	Description	Observed Change
Tom-cod	January	Men and women chop holes in ice near shore and jig for Tomcod.	Delayed sea ice development.
Winter Caribou Crab	February March	Men go caribou hunting inland. Women and elders use baited wire to catch crab through ice.	Variable weather conditions.
Whaling	April May	In late March or early April flocks of snowbirds are migrating and in the ice leads, bowhead and beluga.	Thin ice conditions interrupt sea ice based hunting.
Bearded Seal Seal Ducks Geese	June July	Sea ice breaks up and hunters switch to open boats to hunt bearded seal (Ugruk) and seal species. Bird hunting.	Poor ice conditions.
Summer Caribou Egg Gathering Salmon Arctic Char	August	Caribou often come down to the coast in summer and can be hunted by boat. Catch fish and trout with beach seine nets.	Temperature is too hot for drying fish and meat.
Fall Caribou River Fish	September October	Hunting for caribou until river freeze up, also time in fish camps, berries picking, and hunting ptarmigan and other birds.	Delayed caribou arrival.
Seal Polar Bear	November December	Men are venturing out onto the sea ice hunting seal and occasionally polar bear.	Delayed sea ice development.

Figure 5. Traditional Subsistence Seasons. *Foote, 1992.*

> *"In October, we had three or four snowgos fall through the ice. Two machines were lost."*
>
> Andrew Baldwin, Jr.

subsistence activities in Kivalina. How seasons may change in the future is an important public health question and a baseline is needed to measure change throughout the year.

Recommendation: Active monitoring of seasonal weather, ice conditions and subsistence activities are important for understanding climate change and for developing effective adaptation strategies. A community-based monitoring program with a local observer would be invaluable in documenting change based on local seasons. Possible resources would include the staff of the Kivalina IRA Environmental Program. External resources could include the National Phenology Network through the United States Geologic Survey. ANTHC and the UAA Institute for Circumpolar Health can provide assistance in developing methods for monitoring seasonal change and for documenting local observations.

Ice seals.
Courtesy of Eric Regehr, USF&W.

"I do not like the thin ice. When the wind blows, we have to run for shore."

Joe Swan, Sr.

AIR

Observed change: *hot, dry summers; lightening and wildfire; increasing numbers of trees & shrubs.*
Health concerns: *asthma; allergies; and respiratory problems from smoke, dust, and pollen.*
Potential adaptation: *fire and dust management; improve treatment for allergies.*

In the summer of 2009, residents could smell smoke in the air.

It was not from the village or even the surrounding area. It was from wildfires burning throughout Interior Alaska, and the smoke was traveling for many miles. It was a nuisance more then anything, but for those susceptible to respiratory problems, even low levels of smoke can be a problem. Climate change impacts air quality in the Northwest by increasing three kinds of air pollutants: dust, smoke, and allergens such as pollen. All of these pollutants are worse in the summer, and exposure can increase risk of respiratory infections, incite asthma attacks and acute bronchitis, and compromise people with respiratory disease and other ailments.

Lighting strike next to the Health Clinic.
Video still courtesy of Tina Swan.

"We get thunder now and lightning in town for the first time ever."

Mida Swan

Historically, wildfires have been rare in the cool damp coastal climate of the Northwest Arctic. That, however, is changing. Both regionally and near Kivalina, wildfires are burning more land. Between 1950 and 2007, the number of wildfires increased significantly (Joly et al., 2009), the result of warmer and drier summer conditions, more frequent lightening strikes, an increase in woody plants, and tinder dry conditions on the tundra and in the taiga (Duffy et al. 2005). Big fire seasons typically occur every 10 years, but recently the period has been about every five. In the Northwest Arctic, more then 10.5 million acres burned between 1950 and 2007, including 24.1% of boreal forest and 9.2% of the tundra (Joly et al., 2009). In 2007, the largest tundra fires on record occurred on the North Slope, burning over 240,000 acres in a single season.

Dust levels are also a big concern. The streets in Kivalina are sand and gravel. In the summer, when conditions are dry, billowing clouds of dust, kicked up by wind, heavy equipment, or passing ATVs drift across the village. There is no suppression system and the dust covers food drying on racks, drifts into homes, and settles in rainwater collection barrels. In 2001, the State of Alaska Department of Environmental Conservation tested the air quality in six Northwest Arctic communities—Ambler, Buckland, Kiana, Kotzebue, Noatak, and Noorvik. These communities have road and traffic conditions similar to Kivalina, and all six had summer dust levels that exceeded the EPA national standard for particulates. Dust suppression is currently being tested by the Alaska Department of Environmental Conservation (Barber V., 2010).

Allergens are also a problem. Typically the Arctic has been a haven for people with hay fever, as tundra plants do not produce as much pollen as do the grass and forest lands further south. But as new vegetation becomes established, allergies have become a bigger concern. This spring, Alaska communities had record pollen levels; Fairbanks had one of the highest tree pollen levels ever recorded (personal communication Dr. Jeffery Demain).

Recommendation: As increasingly dry and hot summers are expected, air quality will likely be a growing concern for Kivalina. Clinical staff will need adequate resources to monitor and address summertime respiratory problems. Collection of baseline pollen levels would provide a measure for assessing future change. Funding should be acquired to develop program based upon recent dust suppression research at the University of Alaska and ADEC pilot projects.

Climate change impacts air quality in the Northwest by increasing three kinds of air pollutants: dust, smoke, and allergens such as pollen.

SEA

Observed change: *delayed freeze up; early thaw; thin ice.*
Health concern: *injury; exposure; drowning; diminished diet; mental stress.*
Potential adaptation: *apply condition-appropriate equipment and methods.*

In the spring of 2010, Kivalina hunters were out on the sea ice looking for whale, walrus, and seals, but the ice was too thin to allow them to travel safely. Whereas shore ice will ground to the shallow bottom and stay anchored, sea ice is floating. Unless sea ice is very strong it can break free, setting whaling crews and their equipment adrift or plunging them into the sea.

Ice conditions are the most pronounced climate impact in the Chukchi Sea. Kivalina hunters have easy access to open water in winter, or to ice floes in the spring, and depend upon the sea ice as a work platform and as a pathway to their ocean hunting grounds. But warming is changing the sea ice. Since the early 1980s, the time between spring breakup and autumn freeze-up along Arctic shorelines has increased from barely three months to as much as five months. In 2009, the freeze-up occurred 30 days later than average (Harry Lind, NWS personal communication).

The Chukchi Sea has typically been ice-free from late June until mid-September, when the slush ice would form along the shoreline. In recent years, ice-free conditions have been occurring as late as December and January. This means a shorter season for over-ice travel and ice-based hunting. It also results in an longer season when storm waves can cause shore erosion and salt water spray can cause damaging icing and corrosion on machinery and utilities in the community.

Sea ice has also been getting thinner. During the past two decades, temperatures have not always been cold enough to allow for thick multiyear ice to form. Instead there is thin first-year ice, just developed over the winter. Over large areas of the Western Arctic the ice depth has decreased by up to one to three feet (Shirasawai et al., 2009). Hunters recall years when the ice was 12 feet thick. Today they are fortunate if it is four. The ice is also important for guiding the whales. When the ice is thick, distinct leads (areas of open water) form in the ice, providing a migration path for the whales to follow, and a vantage point for hunters to spot

> ***"The sea ice used to be 12 feet thick, and there was just one lead. Now it is four feet thick and there are many leads."***
>
> Russell Adams, Sr.

and hunt their prey. In the past, there were generally two distinct leads: one parallel to the coast leading north towards Point Hope; and a second, detour lead, that would sometimes divert whales towards Kivalina (Joe Swan Sr., personal communication, 2010). Recently there have been no large leads, instead the thin ice has shattered like a broken mirror, disrupting travel for hunters and turning the once narrow leads into a maze. No bowhead whales have been taken in Kivalina in over a decade.

Waiting to whale.
Michael Brubaker, 2010.

Climate change is having other impacts on the sea. Increased snowfall can influence the amount of ice that builds within a season. More snow cover means less ice. If projected increases in precipitation result in more snow cover, it could further reduce the thickness of the sea ice. The decrease of sea ice in the summer has increased the fetch of the wind and wave size, and has made travel in small boats more dangerous. Travel on ice can be dangerous but necessary, and hunters are concerned about the harvest implications of ice change. Kivalina households report a decline in sea mammal harvest. In 2007, 26% of households did not get enough sea mammals (Magdanz et al., 2007). Poor ice conditions was the reason most frequently provided.

Recommendations: Ice conditions are increasing the risk of injury, effecting diet, and resulting in fear and anxiety that could affect mental health. An analysis of frequency and seasonality of falls-though-ice is needed for Arctic communities including Kivalina. A broader regional discussion about changes in ice hunting is recommended to explore ways to improve safety. Technology may help to reduce risk, like the personal locator beacons that are used in neighboring Point Hope. This technology can reduce the response time for people who have been stranded or are otherwise in peril. University of Alaska Fairbanks (UAF) researchers have been studying ice safety in Barrow Alaska and some applications may be useful in Kivalina, and other Arctic coastal communities.

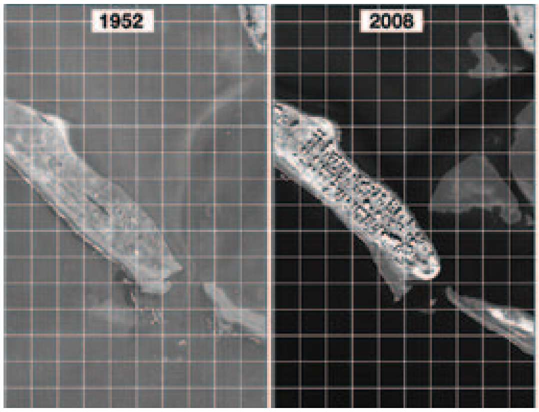
> ***"The ice used to push migrating whales in close. That was why we could hunt them. But now the ice is too thin, they can go anywhere."***
>
> Joe Swan, Sr.

COAST

Observed change: *delayed fall freeze-up; increased storm intensity; accelerated erosion.*
Health concerns: *storm-related injury; damage to infrastructure; storm-related anxiety and fear.*
Potential adaptation: *erosion prevention; improved emergency planning; and evacuation facilities.*

Erosion

Kivalina is located on a narrow barrier island consisting of sand, gravel and beach grass. The average elevation is little more then 10 feet. The coast is constantly changing, eroding in some areas and building in others. Sediments are transported from the rivers to the coast, and the shore is carved away or built up by the action of wind, current, and waves. But because of the impacts of climate change, (permafrost thaw, increased storm intensity, and delays in winter coastal ice formation) erosion processes are happening more quickly. The frequency of major storm events is also increasing. Seventy-five percent of the major storm events (since 1970) have occurred during the past eight years (Gray, 2009). According to the U.S. Army Corps of Engineers, Kivalina is at high risk from erosion hazards. Coastal storms can erode up to 100 feet of shoreline in a single event.



Land erosion comparison.
Ben Jones, USGS.


Storm surge erodes beach.
Courtesy of Millie Hawley.

Sea Level Change

As water around the world is transferred from glaciers to the oceans, the sea level is rising. In the Northwest Arctic, sea level rise may be compounded by subsidence (sinking) of the land caused by thawing permafrost and erosion. Efforts have been made to develop projections for Kivalina, so that flood risk can be better

> *"My husband has a level he uses to check the height of the sea. I always get very worried when he gets out that level."*
>
> Alice Adams

Emergency erosion control.
Courtesy of Millie Hawley.

estimated. The Kivalina Master Plan (USACE, 2006) used a one-to-two-foot estimate of sea level rise for the next 100 years, which is in line with the United Nations global estimates (IPCC, 2007). The current melting rate of glaciers in Greenland suggest that sea level rise could occur much more quickly, resulting in a three-to-five-foot rise in the next 100 years.

Flooding

Kivalina is at high risk from storm surge (City of Kivalina, 2008). Winds from the southeast have generated large waves and flooding many times in the past (USACE, 2006). A fall storm in 1970, resulted in a 13.57-foot surge that inundated the village. Several studies have predicted flood hazards and they include varying estimates of the 100-year flood risk. The most recent study by the U.S. Army Corps of Engineers estimates that there is a one percent chance in any given year that a storm surge would reach about 7.8 feet above mean lower low water (USACE 2010). Further site-specific studies may be necessary to verify this estimate.

If an evacuation is needed, the National Weather Service notifies Northwest Arctic Borough Emergency Management to provide warning to the at risk communities But sometimes the weather occurs so quickly that there is little time for warning, resulting in an evacuation after the event strikes (Kivalina 2009). Evacuation is generally considered a last resort, taking place only when the local shelter is not adequate to the risk.

> *"My nine-year-old son always asks if it will flood."*
> Colleen Swan

Evacuation is a challenge. There are no roads to Kivalina, and weather conditions can prevent air service for days. The only other way off the island (in summer) is by boat. When ice conditions are bad, there is no other way. There is also no off-island evacuation site. If another 13-foot storm surge was to occur, the closest shelter is 17 miles south at the Mine Port Site. When considering flood adaption, at-risk communities have three options: 1) create protective barriers; 2) evacuate and rebuild; or 3) relocate. Kivalina has already used the first two, and is pursing the third. With funding from a congressional appropriation, the U.S. Army Corps of Engineers began constructing a rock revetment wall in 2008, to protect the community until relocation. Once completed, the revetment on the ocean side of Kivalina will extend for approximately 2,000 feet.

Residents right a utility pole during a storm.
Courtesy of Millie Hawley.

The vulnerability of Kivalina to storm events may put residents at higher risk for negative health effects including certain types of disease , injury, and behavioral health problems, especially during the storm season. The delay in winter shore ice is climate-related, and has caused residents to labor in hazardous storm conditions on several occasions, erecting erosion barriers and protection for the shoreline. Six storms of record occurred between 2001 and 2008, mostly during the months of September and October.

A review of selected IDCD-9 (patient visit) codes from the Kivalina Health Clinic (2000-2010) was performed at the request of the city and the tribal council, and in collaboration with the Maniilaq Association. The purpose was to evaluate the potential relationship between storm events and health effects. The results are preliminary and limited statistically by population size, the number of visits to the clinic and variation in case coding. The data does, however, provide information on number of visits for specific health codes during specific time periods, seasonal trends, and clues to potential associations.

ANTHC sorted clinic visit codes by month to identify potential trends. One possible indicator is leg injuries, potentially related to the movement of heavy drums in the storm surf. Between 2000 and 2009, October had the highest number of clinical visits by men for lower leg injuries. Another indicator is chest pain, possibly related to muscle pain or pain of cardiovascular origin. Again, September and October had the highest incidence of chest pain related visits.

"Sometimes the ice stays open until January. It keeps blowing away. Whenever it forms it disappears."

Mida Swan

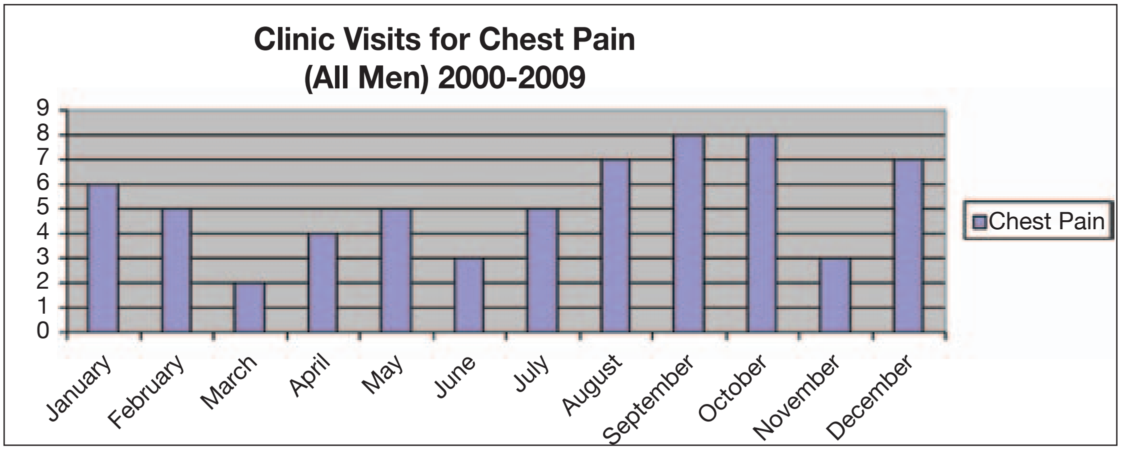


Figure 6: Kivalina Clinic ICD-9 Codes, Graph by ANTHC Center for Climate and Health.

On the topic of behavioral health, local health workers reported heightened stress, fear and anxiety during the storm season. A grouping of behavioral health related codes (men and women) indicates increased behavioral health clinical visits during the storm season (2001-2008). Further analysis, including a review of patient charts and hospitalization records, would provide a better analysis of these and other health outcomes as they relate to storm events and other seasonal influences.

Recommendation: The new sea wall is slowing the pace of erosion and easing people's minds. It is also preventing damage to infrastructure and should reduce incidence of injury by minimizing resident involvement in hazardous storm damage mitigation efforts. Completion of the sea wall will not, however, diminish community vulnerability to storm surge during high sea events. A major problem is completing an evacuation before escape routes are compromised. The construction of evacuation facilities and evacuation routes adequate to the level of risk is a priority. This would increase public safety and decrease mental stress and risk of death or injury, and provide residents with an option for shelter, outside of a full community evacuation. Finding a suitable location on the mainland is a significant challenge. Flood and storm surge projections should incorporate climate change processes such as storm patterns, sea level rise, and coastal change, and be based on sound geologic, sea level and land elevation data. Emergency planning, evacuation drills, and communication plans would help prevent injury and damage to infrastructure by providing more time for preparation and an effective process for safe, organized, and timely evacuation.

> ***"During the evacuation, children were afraid because they were separated from their parents."***
>
> Alice Adams

LAND

Observed change: *rapid permafrost thaw; erosion; subsidence; drying; vegetation change.*
Health concerns: *hazardous travel; reduced subsistence harvest; dietary change.*
Potential adaptation: *environmental observation program.*

The lands around Kivalina are characterized by tundra:

treeless regions with sub-soils that are frozen year-round. But shrubs have been moving northward for decades, and since the 1970s the rate of colonization by woody plants has increased. The tree line of the boreal forests or taiga to the south has been pushing northward and to higher elevations, encroaching on an estimated 11,600 acres of tundra in the last 50 years (Strum, 2010). In the Kivalina area, the shrubs are spreading out from the rivers, becoming established and growing into trees.

Shrubs and trees trap snow, insulating the ground, and retarding ground freeze. Thawing of ice-rich permafrost results in subsidence with significant effects on ecosystems and infrastructure (USARC, 2003). Hundreds of sink holes (thermokarsts) have been observed in the Northwest Arctic and extensive erosion has been observed in coastal and river systems. Within 50 years, decreases of between 20% to 50% or more are expected in the active (seasonally freezing) permafrost layer.

Willow trees along the Wulik river.
Michael Brubaker, 2010.

> ***"When I was a child there were no trees here, the only trees were on the Noatak."***
>
> Russell Adams, Elder

In the near term, thermokarsts conditions are expected to continue, resulting in erosion and changes to hydrology, vegetation, and wildlife (Martin et al., 2008).

The color of the Arctic is also changing, at least in the growing season. Analysis of NOAA satellite imagery has revealed that the Arctic tundra is in fact greening, a result of the encroachment of woody shrubs into tundra lands (Verbyla et al., 2008). But south of Kivalina, boreal forests are browning, especially further inland, a result of drought conditions causing stressed trees to grow more slowly, dry up, die, or be consumed by infestations or forest fires.

As warming temperatures move northward, associated plants and wildlife will follow. Some models suggest that the "Arctic" biome that extends from the Norton Sound to the North Slope (including Kivalina) will be replaced by a "Western Arctic" biome that currently occupies Western Alaska from the Alaska Peninsula north to Norton Sound (Murphy et al., 2009). Kivalina residents may witness transformation to an environment more like Nome or Bethel.

Recommendation: Kivalina IRA environmental staff could collaborate with tribal environmental offices throughout the region to establish a network of environmental observers. These observers would monitor climate impacts, develop and manage partnerships, and explore option for community adaption. ANTHC will provide regional training for observation programs in 2011.

Two sides of the Wulik: one tundra and one overgrown with Willows.
Michael Brubaker, 2010.

In the Kivalina area, the shrubs are spreading out from the rivers, becoming established and growing into trees.

RIVERS

Observed change: *Changing lake size; methane seeps; river bank erosion; warming water.*
Health concerns: *injury from dangerous travel conditions; changes to diet.*
Potential adaptation: *improve local weather observations; injury prevention.*

The Wulik River winds 90 miles from the Chukchi coast

east to the Delong Mountains. For the Inupiat, it is the byway that connects their coastal community with subsistence resources located inland: caribou, salmon, Dolly varden, white fish, waterfowl, and wild berries. Most of the river is underlain by permafrost, and on the banks, the frozen ground acts as a barrier, holding water and keeping the tundra soils bound together. With warming has come widespread thawing of shallow permafrost, and an increase in the zone that thaws seasonally.

Though the lands along the Wulik were once tundra, now willow and alder have become established. Some of the stands have grown to the size of trees. With new vegetation comes wildlife: moose, and porcupine among others. Some are beneficial and can provide a new source of food. Others, like beaver, are known for the impact that they can cause to river systems. Residents report more difficulty getting upriver. It was once possible to go as far as 30 miles, but now the water in many areas is too low. Beaver dams may be part of the problem, and the thawing bank creates new obstacles, hazards for navigation.

Roger Hawley and beaver-chewed willow.
Michael Brubaker, 2010.

One section near the community water intake has washed away, allowing the cut bank to collapse. Under the bank, tunnels extend inland, the remains of thawed ice wedges. The tunnels create a conveyor, moving water and soil from deep under the bank into the river. Changes in river flow including increased discharges into oceans have been recorded (Syed et al., 2010) and

Traveling this river is becoming more challenging each year. For miles, the banks are undercut on both sides, and fallen chunks of the bank line the river. The river is rapidly becoming wider, shallower, warmer, and dirtier.

relate to, changes in precipitation, and permafrost thaw. River ice is also changing. Breakup in the spring is occurring earlier. This means less time for ice travel, but also earlier boat access. Ice data for the nearby Kobuk River indicates that since 1939, the spring ice breakup date has become gradually earlier, occurring an average of one week earlier then it did 70 years ago (NOAA River Forecast Center).

Lakes are also changing, some expanding with water from thawing permafrost, others shrinking as an underlying lens of ice thaws and allows the perched waters to dissipate. Warmer water allows new vegetation to grow such as algae, moss, and aquatic plants. Residents observed water that appeared to be boiling in a lake located five miles south of Kivalina, the result of seeping methane gas, a by-product of the rapid decomposition of old organic material thawing from the permafrost (Anthony, K., personal communication). Methane seeps can pose a safety hazard for a walking person or animal, when it prevents proper freezing of lake ice during the winter. There can also be a benefit, if the methane is of good enough quality and located where it can be captured and used as an energy source. Analysis of the methane gas collected near Kivalina is pending and UAF is engaged in demonstration projects on the North Slope capturing methane seeps for use in home heating.

Recommendation: An erosion assessment that identifies vulnerable infrastructure and habitat near Kivalina is recommended. Erosion along rivers is threatening water quality, river navigation, and critical habitat. A review of satellite and aerial photographs would help document changes including methane seeps, and identify new vegetation, beaver dams, sedimentation, and erosion. This could be accomplished through research partnership with the USGS. Observations of ice thickness on Wulik and Kivalina rivers, including determination as to dates when the ice is no longer safe for snowmachine travel may help to reduce fall-through-ice incidents.

Bank erosion on the Wulik river.
Michael Brubaker, 2010.

Tunnel resulting from thaw of ice wedge.
Michael Brubaker, 2010.

A bubbling methane seep.
Courtesy of Katey Walter Anthony.

"There are three water springs just shooting out of the ground."

Tillman Adams

BIOTA

Observed change: *invasive wildlife; changing patterns of fish and sea mammals; new stressors.*
Health concerns: *mental health; diet change; infectious disease.*
Potential adaptation: *assess diet; explore adaptive subsistence practices; disease surveillance.*

In the summer of 2010, an unusual fish washed up on the beach in Kivalina. It was collected by a local resident and sent to a fisheries laboratory for analysis. It was eventually identified as a large skate, Bathyraja parmifera, the first of the species and the first skate of any kind ever reported from the Chukchi Sea (Mecklenburg, C. 2010). Whether the skate was resident or just a drifting carcass originating from further south remains a mystery, but it joins the list of unusual creatures collected in Kivalina in recent years.

Kivalina's first skate.
Courtesy of Mida Swan.

Some species benefit from the changes; others do not, and are compelled to adapt, migrate, or perish as habitats or conditions change. Residents voiced concern about changes in availability of species that are important for subsistence such as walrus, bowhead whale, trout, and caribou. They also described new animals that are moving into the region such as porcupine and beaver; and remark on the frequency of seeing unusual insects, birds, and fish. Mild and snowy winters over the past decade have been associated with increased survival of wasps and dramatic increases in visits to northern Alaska clinics due to insect stings (Demain, 2008). Changes in water quality in the Wulik River may be a factor impacting trout. During major river bank slump events in 2005 and 2006, fish kills of numerous trout were observed up river. High turbidity was thought to be preventing some fish from entering the river (Jim Kulas, personal communication, 2010).

Uncommon sighting of a Black-legged kittiwake.
Courtesy of Mida Swan.

Hot dry conditions in the boreal forests and tundra, and the increased frequency in lightening has resulted in more wildfires.

On the land, plants once limited by frozen soil are beginning to flourish, aided by a longer growing season and warmer temperatures. On the tundra, the size and number of woody shrubs are increasing and the rivers provide natural corridors to spread from the mountains to the coast. A U.S. Fish and Wildlife model suggests invasive reeds such as the reed canary grass could become established in pockets through out the Northwest by 2090 (Murphy et al. 2009). Reed canary grass has received notoriety for its ability to grow rapidly and crowd out other vegetation, clogging streams and lakes.

Wildfires are another important driver of change, influencing the range and population of wildlife including caribou. Despite projections of increased precipitation, significantly more water will be leaving the Arctic landscape in the future and most of Alaska is expected to become 10 to 30% drier by the end of the century (O'Brien & Oya, 2009). Summer warming combined with decreased precipitation has caused tundra ponds to dry up, impacting water availability and quality. . Fires consume fruticose lichen, the primary winter forage food for caribou, which takes decades to recover (Jandt et al. 2008).

Red fox.
Courtesy of Eric Regher, USF&W.

As a result, caribou may shift their range. The Western Arctic Herd has already moved their primary winter range from the Buckland Valley and Selawik Refuge to the Nulato Hills and Seward Peninsula (Joly et al. 2010). Some climate projection models suggest that suitable habitat for caribou is retreating (Murphy et al. 2009), moving northward and eastward. Warming in winter can be equally harmful. Freezing rain events in winter encapsulates the tundra in ice, making foraging difficult and creatng potential deadly conditions for caribou.

The emergence of new plants and wildlife also raises questions about the potential for new diseases. Increases in temperature, precipitation, and humidity affect rates of infectious diseases in domestic and wild animals, and in people. Interactions between invasive and endemic animals can spread disease among similar populations or from one species to another. Climate change can affect natural cycles by altering seasonal weather patterns. By changing timing

"I've not even heard about echinococcus parasite until we saw that in our own residents, that it cost them their lives. Is that because of changing climate?"

Mida Swan

Musk ox.

Arctic char.

for migration, calving, mating and other behavior, animals can become more susceptible to diseases they were once able to avoid or resist. Stress related to changes in habitat, forage conditions, weather, or water availability can make animals more vulnerable. Extreme heat in the Interior may be affecting caribou, musk ox, and other large land mammals. When moose become heat stressed (Lenarz and others, 2009), they are at greater risk from parasites and infectious diseases (Murray, 2009).

Vector-borne diseases require a special agent to pass the disease along. Biting insects like mosquitoes and ticks are good examples. West Nile Virus has swept across the Lower 48, and high into the mountains carried by mosquitoes and infected birds. Ticks are carriers of Lyme disease (Ogden and others, 2009), and climate change has provided an opportunity for them to spread the disease by hitchhiking on animals as they move into new territories. As the Arctic becomes warmer, a vast new territory is opening for these diseases. Sometimes, like plants, the diseases benefit from a longer growing season. One example is the lung nematode, a type of parasitic worm often found in muskoxen. It affects wildlife but is not known to cause human disease. Warmer summer temperatures have allowed the lung nematode to develop more quickly, reducing their life cycle from two years to one year (Kutz and others, 2005). This is bad news for muskoxen because it means the lung nematodes can reproduce more quickly.

Recommendations: Understanding how climate change is affecting plant and animals is important because of their place in the coastal Arctic ecosystem, because of their value as subsistence resources, and because of the potential as a source of infectious disease. Observations are best made at the community level, and the tribal government in Kivalina is well positioned to expand observation programs. Additionally, local partnerships are necessary so that surveillance can be performed for disease in animals, plants, or in people. Communication and education is also important, as the risk of most diseases can be significantly reduced through preventive actions. A water and food-source monitoring program is recommended.

> *"Salmon are becoming stronger and there are less trout in the Wulik. Trout is what we prefer and they taste different because they are eating salmon eggs."*
>
> Mida Swan

WATER

Observed change: *reduced drinking water source quality and quantity.*
Health concerns: *water shortages; water availability; water quality; increased cost for treatment.*
Potential adaptation: *source water monitoring and assessment; emergency water shortage plan.*

Climate is having a range of affects on water resources

and on water and sanitation services in Kivalina. Precipitation is changing, both in type (more rain less snow), in quantity (more year-round, less in summer), and in the way water is moving through the changing Arctic landscape. Reduced winter snowpack, rapid spring thaw, reduced summer precipitation, and warm summer temperatures impact the amount and movement of water into the area, and through the Wulik River watershed.

Along the Wulik, rapid thaw of permafrost is increasing bank erosion and turbidity (sediment) in the river. The frozen state of the soil was what provided strength and cohesion. Once thawed, all types of erosion (water, wind, wave, gravity) act to increase the rate of movement from the bank into the river. Along the beach, erosion and late shore ice development has damaged the central facility (washeteria) waste water system, resulting in closures and expensive repairs. The dumpsite is susceptible to flooding, transferring large quantities of solid waste and sewage into Kivalina Lagoon. Finally, Kivalina's ability to pursue a higher quality of health for its residents is compromised. Climate change is causing serious challenges for water and sanitation in Kivalina.

The Water System

The Wulik River is used as a community and tradition source of water; "traditional," meaning that people collect water from the river and drink it untreated. The community water system, however, provides treatment; first through a sand filter, then finer filtration with bag filters, and finally the water is chlorinated to inactivate any pathogens. During the summer, water can be collected when turbidity in the water is low. Collection usually begins in July, and can continue throughout the fall until freeze-up. Turbidity is an important limiting factor for water collection, because the existing treatment system cannot remove the small particles that cause turbidity and because turbidity can interfere with the chlorine disinfection process.

> ***"People get drinking water by collecting rainwater from the roof, ice from the ocean side, and from the river while at fish camp."***
>
> Janet Mitchell

Warmer conditions in the watershed that serves the Wulik River allow organic materials to decay more rapidly than in the past increasing concentrations of dissolved organic materials entering the river. The existing treatment system in Kivalina is not effective at removing dissolved organics materials leaving them to react with chlorine. The reaction between the dissolved organic materials and chlorine can produce unwanted by-products in then community's water supply.

The water collection point is a small skiff, tethered to the bank of the Wulik River about three miles from the village. From the skiff, water is pumped through a pipeline that crosses overland to Wulik Lagoon, and then through a temporary hose across the lagoon to the water plant. The length of the entire transmission line is about three miles. Erosion of the river bank at the collection point, and of tundra along the course of the water line, raises concerns about possible damage to water infrastructure.

Water system intake, Wulik River.
Michael Brubaker, 2010.

Upon reaching Kivalina, the raw water is initially stored in a 700,000-gallon steel tank, and then treated and stored in a 500,000-gallon tank. Residents purchase water from a watering point at the washeteria. They can fill up a garbage can, a tank, or other container and then haul it by hand or tow it back home on a snowmachine or an ATV. Only one-third of the residences have home tanks that when filled can provide running water to their kitchens. In most homes water is hauled by hand, laundry is done by hand washing, and bathing is done in a tub. As water is expensive and hauling water is difficult and time consuming, the wash water is often recycled: first for hand washing, then for body washing, then laundry, and so on. This means that the quality of water diminishes with each use, making cleaning all the more difficult.

The only buildings with piped water and sewer are the school, the teacher housing, and the washeteria. Efforts are underway to extend water service to the Health Clinic as well, which currently relies upon a plastic garbage can in the lobby for water storage. Residents also collect rainwater, untreated river water, sea ice, and lagoon ice to supplement their water needs.

"A lot of people do not have washers and thus rely on the washeteria."

Andrew Baldwin, Jr.

Water Quantity

The community water capacity of 1,200,000 gallons is not enough to meet the needs throughout the year. It is also inadequate for fighting fires (USACE) or for other community use such as dust control. Water shortages in the spring (before the river thaws) result in rationing.

The average person in the United States uses about 50 gallons of water per day. This includes water for drinking, flushing the toilet, bathing and hygiene, laundry, kitchen and housekeeping. In Kivalina, there are seasonal periods when water is rationed and each household is limited to 30 gallons per day (Gray 2009). If you factor lack of household appliances and in-home plumbing, then the daily water use is even lower. Even so, the City of Kivalina still must implement water rationing almost every spring.

e for fresh water.
chael Brubaker, 2010.

etting water from the washeteria.
chael Brubaker, 2010.

So what does 30 gallons of water per household mean? As of 2000, the average household size in Kivalina was 4.83 people, higher then the Northwest Arctic Borough average of 4.36 (DCCED, 2010). Crowding has long been a problem, as there is a growing population and no land for new houses. Come spring rationing, each person in an average household would receive a little over 6 gallons per day. In larger households, the amount of water would be even less. WHO has established a minimum water quantity standard of 13.2 gallons per person per day. This standard was also adopted in a resolution by the Alaska Native Health Board in 2006 (Rural Alaska Sanitation Coalition, 2006). Based on this estimate, the average Kivalina resident receives less then half of the WHO recommended minimum daily water supply.

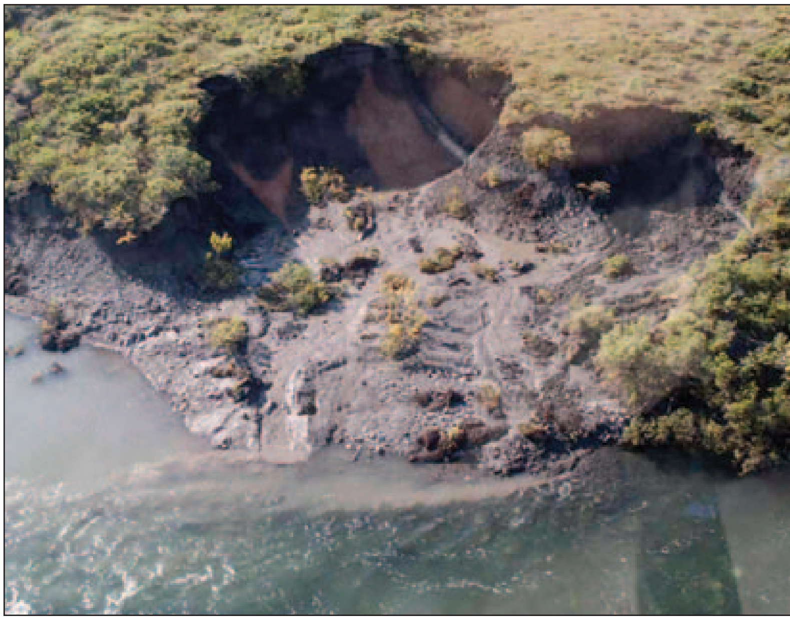
Inadequate water quantity is known to affect public health in rural Alaska communities. Community health aides at the Kivalina Clinic state that during periods of water rationing, they see an increase in mouth sores, strep throat, gastroenteritis, vomiting and diarrhea, cellulitis, abscesses (boils), impetigo, MRSA skin

Come spring rationing, each person in an average household would receive a little over 6 gallons per day. In larger households, the amount of water would be even less.

infections, ear infections, and respiratory syncytial virus (RSV). Funding agencies will not fund a piped water or sewer system because of the community vulnerability to flooding and erosion, and because of the expectation of a future community relocation.

Microbial Water Quality

Warming climate has increased the growing season and optimized conditions for woody shrubs, which today are growing into full sized trees on the Wulik River. The first documented observation of beaver in the Wulik come from a public meeting in May 2004, when a local resident raised concerns about the impact of beavers to officials from Red Dog Mine. The first mention of giardia in the clinical setting appears in Kivalina in fall 2006 (Kivalina Clinical Data). Alvin Ott from the State of Alaska Department of Fish and Game reported that there were very few beavers in the watershed but that a lodge and dams had been seen on a tributary to Bons Point and in Lower Ikalutkrok Creek (Jim Kulas, personal communication, 2010). Beaver are known to carry giardia lamblia, a microscopic protozoa that can cause an infection in the small intestines of humans. It is the most common waterborne parasitic infection in the United States and well known in other parts of Alaska, but new to the Wulik and other Arctic rivers. Proper chlorination and filtration at the water treatment plant are required to reduce the risk of giardia. In water sheds that have an established beaver population, it is advised that water be properly treated prior to drinking. For residents collecting river water for upstream fish and hunting camps, boiling or treating water properly is recommended.



100-foot wide Wulik River slump.
Courtesy of David Harbke.

The River Slump

As ice-rich permafrost thaws, the banks of the Wulik River crumble, collapse, and fall into the channel, to be washed downstream to Kivalina Lagoon and out into the Chukchi Sea. Mile upon mile of the riverbank is eroding, resulting in a loss in some areas of as much as

> ***"There was a major slumping a couple miles south of Drivers Camp. The downstream water was very turbid with high sediment load."***
>
> Jim Kulas

10 feet on either side every year. In some areas, thermocarst slumps create huge craters in the riverbank converting frozen tundra into sinkholes. For several years, a large slump has been developing 17 miles upstream of Kivalina, contributing to the sediment load in the river and raising questions about the impact on operations at the community water facility.

On August 3, 2005, operators at the Kivalina water plant were making water, filtering, and chlorinating prior to transfer to the storage tank. Turbidity levels in the raw water (the amount of suspended sediment) coming into the plant were recorded, as is routine. But the levels on this day were two to three times higher than normal, exceeding the regulatory limit. The levels dropped again four days later and then spiked again even higher on August 17. Something was making the river very cloudy. This is expected after heavy rain fall, when runoff carriers sediment into the river. But there had not been rain for over a week.

On August 18, 2005, environmental technicians from Red Dog Mine investigated a report of a sewage smell coming from the Wulik River. The smell was reported by Jerry Norton near his upriver camp. Mr. Norton had occasionally noticed the smell for the last few years, usually on warmer August days after it rained. Jim Kulas, Devin Harbke, and Joe Swan flew by helicopter

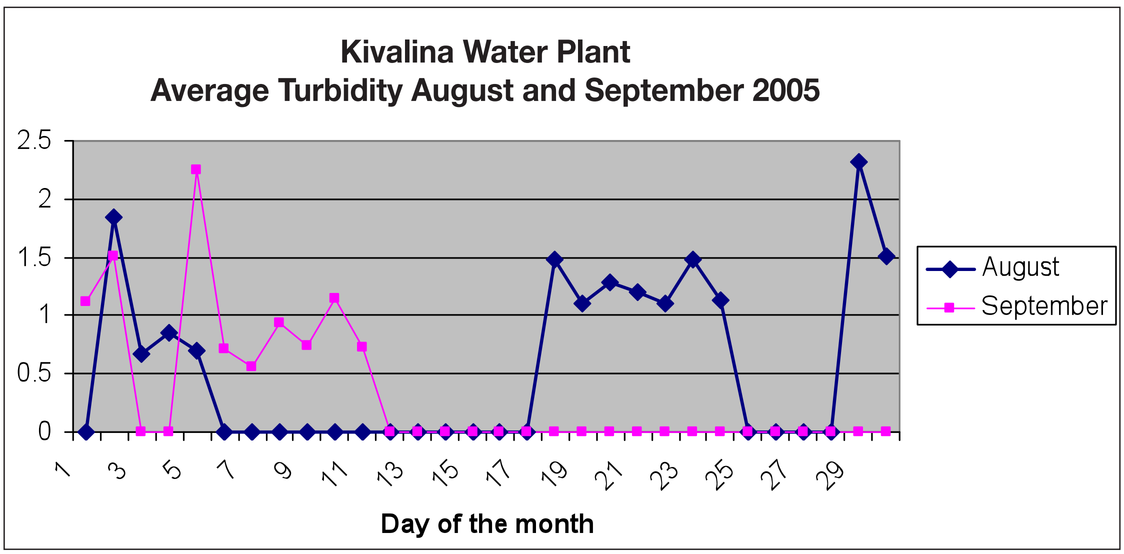


Figure 7: Kivalina Water Treatment Plant Daily Log. *Graph by ANTHC Center for Climate and Health.*

> ***"The water gets turbid when there is big erosion, big rain, or when the wind comes from the south or west pushing salty water from the lagoon upstream."***
>
> Joe Swan, Jr.

to inspect the site and to collect samples. The samples revealed normal levels of fecal coliform and metals, and they concluded that the smell was not related to the mine, but rather part of a natural process.

Hydrogen sulfide gas is one likely explanation. It smells like sewer gas and is produced from the decomposition of organic material. With the rapid thaw of permafrost that has been occurring along the Wulik, it is possible that hydrogen sulfide was the odor that Jerry Norton smelled on those warm days. But what had caused the river disturbance, and was it related to the smell? Upstream of Jerry Norton's cabin an ice lens had melted out of the eastern bank causing sediment to flow into the river and noticeably increasing the turbidity. A similar ice lens and slump was noticed another half-mile upstream, but was not adding much turbidity to the river (Jim Kulas, personal communication, 2010).

According to correspondence from Alvin Ott (ADF&G), melting ice lenses and associated sediment increases have been reported in several streams in the Red Dog area. A similar massive bank slumping had occurred in Dudd Creek about 10 years before, and for the last five or six years had been observed in the upper North Fork Red Dog Creek basin. At a subsequent public meeting, concerns were raised about fish schooling in the lagoon, as if reluctant to enter the river.

Both of these slumping events (August 2005 and September 2006) changed the river water all the way down to the intake pumping water into the transmission line for Kivalina. We know this because of the high corresponding turbidity levels that were recorded by the operators in the Kivalina treatment plant, levels that forced the interruption of water treatment activities on those days and the days following. High turbidity in the filtered water interferes with the ability of chlorine to inactivate dangerous organisms.

High suspended sediment levels in raw water, including the organic constituents that were washing out of the ancient permafrost, are considered contaminants in a public water system. Those constituents that are not captured by the sand filters and post filters travel along through the treatment process to the chlorination point, where chlorine is injected through a small pump at a predetermined rate into the water line. Here, if the level of organics is too high, they can react with the chlorine resulting in chlorine by-products that can be harmful.

Where once river water quality was predictable, now sudden bank slump events can turn the water muddy at any time.

For this reason, there is a "disinfection by-product rule" and the Kivalina operators use turbidity levels as an indicator to tell them when the river's water quality is compromised. This can occur in the spring or after a big rainstorm when a lot of runoff is discharged into the river, or when an ocean storm with big on-shore winds has churned up the lagoon and surged inland pushing salty sediment up into the river. By summer, the water quality in the Wulik River has improved and reliable turbidly can generally be expected. Now with advent of climate change, a new confounding factor for turbidity has emerged. Where water quality was once predictable, rapid erosion and bank slumping events can now turn water from clear to turbid at any time.

An improvised honey bucket sled.
Michael Brubaker, 2010.

Honey Buckets

Kivalina is one of two communities in the Northwest Arctic Borough without a piped water system. Alaska communities without piped water and sewer have been shown to have higher rates of skin, gastrointestinal, and respiratory infections (Hennesey et al. 2008). The sewage system for most residents consists of a honey bucket with disposal in a combined dump/sewage lagoon located at the end of the airstrip. A honey bucket is a bucket lined with a garbage bag with a plastic seat on top. Once filled with waste, the garbage bag is removed, tied in a knot, and then put in an empty cardboard box (if available) and placed outside the house until it can be hauled one mile to the dump. Think for a moment about the average 4.83 persons per household in Kivalina, and how many times each person uses a honey bucket each day, and you will get an idea of the scale of this problem. Hauling a honey bucket is loathsome work and in Kivalina there is no public haul service, so the boxes sometimes pile up. In time, the boxes and bags are loaded onto a sled or cart and hauled by snowmachine or ATV to the dump. The lagoon and dumpsite are both susceptible to storm surge which has increased in recent years and can deposit waste into the lagoon where people fish and swim. The current solution to the sewage lagoon problem is relocation.

When a storm hit in October 2004, there was no natural ice barrier. The storm damaged the leach field system for the washeteria. Kivalina went an entire winter without any public washing facilities.

The sleds and carts take a beating on bumpy roads and sewage frequently slops out onto sleds and onto the road. This is not such a problem in the winter when it is freezing (and the sewage is frozen), but in the spring and summer the bags and boxes leak, creating open cesspools throughout the community. Consider a child's fascination with puddles, and the scale of the health problem becomes clear. Also, not everyone has a designated honey bucket sled, so contamination of other things or people carried in a sled is a real concern. Combine the honey bucket situation with the lack of running water, and the disruption of community washeteria services, and you have the potential for a community health crisis.

Kivalina water storage tank.
Michael Brubaker, 2010.

Storm Damage

In November 2000, shore ice on the beach of Kivalina was late in forming, the result of unusually warm fall temperatures and a shift in seasons. Usually, shore ice develops by early November and provides a cushion that dissipates the full force of crashing waves. If no ice, there is usually icy slush, which reduces the wave energy and wave energy. But when a storm hit Kivalina in October 2004, there was no natural ice barrier and no slush. The loose sand, gravel, and beach grass met the waves directly, and huge chunks of the coast washed into the sea.

Community washeteria.
Michael Brubaker, 2010.

The storm damaged the leach (waste water drain) field system for the washeteria. In a community without piped water and sewer, the washeteria provides the only public facilities: three washing machines and three small bathrooms serving a population of 400 residents. As a result of the storm, Kivalina went an entire winter without any public washing facilities. Since the storm, the washeteria has never worked properly, causing more closures as the damaged drain field froze, thawed, and re-froze.

Combine the honey bucket situation with the lack of running water, and the disruption of community washeteria services, and you have the potential for a community health crisis.

The community is currently repairing the new waste water system. ANTHC is currently performing a review of IDCD-9 (patient visit) codes from the Kivalina Health Clinic (2000-2010) at the request of the City of Kivalina, the Kivalina IRA, and in collaboration with the Maniilaq Association and the U.S Centers for Disease Control, Arctic Investigations Program. The purpose is to evaluate the potential relationship between storm related damage to the community washeteria and patient visits to the Kivalina clinic for skin, gastrointestinal, and respiratory infections. The results are pending.

Recommendation: Kivalina's existing water and sanitation challenges are being exacerbated by climate change. To provide a healthy community environment, residents need access to safe water. Additionally, they need a sanitary solution for the disposal of waste. Some estimates suggest that it could be 20 or more years before the village is relocated. Despite the extended life provided by a new sea wall, few funding agencies are willing or able to invest money in what is perceived as a temporary community. As such, Kivalina presents a unique challenge to the public health community.

Although Kivalina residents continue to debate the location of a future village site, they speak with one voice when it comes to the need and desire for improving community health. This report recommends that they not have to wait for a relocation to receive the basic health services that they have needed for years.

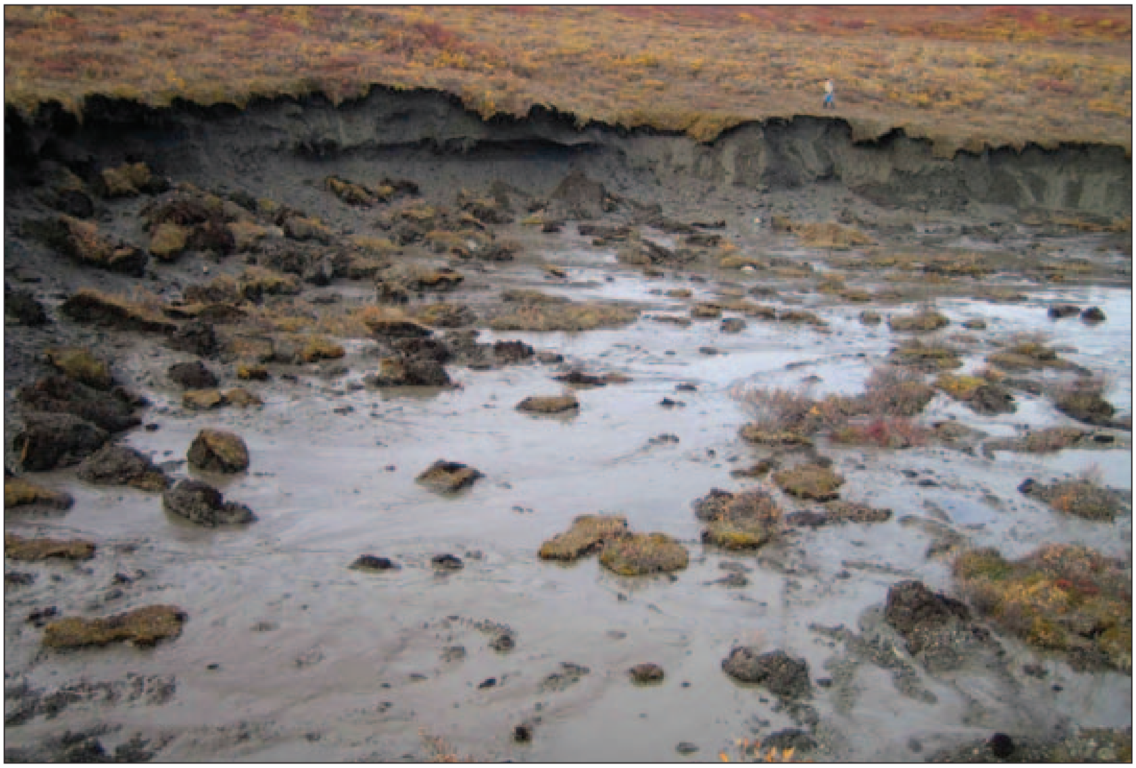
Public education is needed so that residents will know to treat water from traditional sources, and to prevent exposure to waterborne illnesses such as giardia. Research is needed to understand the changing dynamics of the water shed, and what it will mean for water quality in the river and the water security of the future. Monitoring of river water for turbidity, organics, temperature, pH, flow, and water level should be established. Vulnerability of the water distribution line to erosion should also be assessed.

The location of beaver lodges in the river system should be identified, potentially by using satellite images. If the beaver population is posing a significant threat to river navigation and community water supply, then discussions should be entered into with Alaska Department of Fish and Game and a management plan should be developed that will keep the beaver population in check, and the river flowing. Baseline water samples to assess the implication

Although Kivalina residents continue to debate the location of a future village site, they speak with one voice when it comes to the need and desire for improving community health.

of organic loads and other contaminants in the river water should be performed. Continued monitoring of the physical, chemical, and biological condition of the source water is recommended.

A comprehensive engineering plan is required to address the unique challenges faced in Kivalina that is adequate to bridge the transition period from their present community to that of the future. This engineering plan must address the changing water quality in the Wulik River with respect to the provision of safe potable water and must address the safe collection and disposal of human waste from the homes. An assessment by the State of Alaska, Rural Utility Business Assistance program (RUBA) would provide support to the city for improving operation of the water system and other critical health infrastructure.



Wulik river slump.
David Harbke.

A comprehensive engineering plan is required to address the unique challenges faced in Kivalina to transition from their present community to that of the future.

FOOD

Observed change: *warming is affecting harvest of fish & sea mammals; traditional cellars are thawing.*
Health concerns: *changes in food quality and harvest may contribute to hunger, malnutrition.*
Potential adaptation: *assess community diet, food storage, and food distribution.*

Two of the underground ice cellars where sea mammal meat and muktuk are stored throughout the year have frozen shut. They are completely inaccessible. As the permafrost thaws water percolates inside the cellar and intermittently drips and freezes, forming icicles that extend from the cellar ceiling 20 feet down to the floor. Only two cellars are still in use. The others are either too wet, too warm, or have been abandoned for lack of use. The cellars were originally used for the storage of whale, but it has been over a decade since a bowhead whale has been harvested in Kivalina. Some residents believe that the sea ice condition is one of the reasons for not getting a bowhead.

Food safety refers to the practice of harvesting, preparing, and storing foods in ways that prevent foodborne illness. Food security means having nutritious foods and not having to live in hunger. In Kivalina, climate change is increasing exposure to unsafe foods and risk of food insecurity. The traditional subsistence lifestyle and diet provides protection against cardiovascular disease, hypertension, type 2 diabetes, stroke, obesity, osteoporosis, and some cancers. Traditional foods provide a wide range of essential micronutrients including iron and vitamins A, D, and E (Bersamin et al., 2007). The fruit and leaves of Arctic berries contain high levels of antioxidants (Thiem, 2003) and may help reduce incidence of obesity and type 2 diabetes. Northern fish and sea mammals are also high in omega-3 fatty acids, an important anti-inflammatory substance (Murphy et al., 1995).

Millie Hawley harvesting Sourdock.
Michael Brubaker, 2010.

The local diet can be divided into three categories: food gathered from the sea and coast; food collected upriver or inland; and food that is purchased in a store. Although there are other economies and social influences, life revolves around

"On June 25, 2007, my father went to the storage cache. What he discovered there was five feet of water covering the whole bottom of the storage area."

Janet Mitchell

subsistence, the traditional lifestyle of gathering wild food from the land and sea to sustain ones family and community. People are tied to seasonal migration patterns of wildlife and are engaged year-round in preparation, or in hunting, fishing and gathering.

The percentage of wildlife harvested for subsistence in rural Alaska is about 60% fish, 20% marine mammals, 14% land mammals, 2% shellfish, 2% birds, and 2% wild plants (ADFG, 2000). There are substantial regional differences, but harvest percentages have remained fairly consistent since the 1980s, although the amount harvested has decreased. A 2004 statewide dietary study documented an Alaska Native trend toward increased use of market foods (Ballew et al., 2004). Inupiat communities have the knowledge about a high number of food species (Kuhnlein et al., 2004).

The most harvested species are bearded seal, beluga whale, caribou, and Arctic char, which is referred to locally as trout. Over 40 other varieties of plants and wildlife are also taken (Magdanz, et al., 2010). Caribou is a staple of the diet and has become more important as whale harvests have declined. Climate change is making the harvest of many subsistence species more difficult, either because the season or the conditions have changed, or because the wildlife themselves have adjusted their range or the time of their migration.

Kivalina residents expressed concerns about the decline in walrus, bowhead and beluga whale, caribou and trout in the Wulik River. Mortality events including fish kills have occurred on several occasions, corresponding with large slumps in the river and high turbidity levels. These were also at times when strong "sewer" smells were reported along the river, which may be associated with methane and associated hydrogen sulfide gas released from thawing permafrost. One dead trout was submitted to the National Marine Fisheries for analysis. But the cause of death was inconclusive (Jim Kulas, personal communication, 2010). Kivalina households report a decline in sea

Uncovering ice cellar.
Michael Brubaker, 2010.

Passage blocked by flood-freeze cycle.
Michael Brubaker, 2010.

Normal ice cellar.
Michael Brubaker, 2010.

"We barely put meat into cold storage anymore, because it is always flooded."

Joe Swan, Sr.

Drying salmon.
Courtesy of City of Kivalina.

Spawning salmon.

Sleepy dog after caribou meal.
Michael Brubaker, 2010.

mammal harvest. In 2007, 26% of households did not get enough sea mammals (Magdanz et al., 2007) and poor ice conditions was the reason most frequently provided.

The population of the Western Arctic Caribou Herd is at about 401,000, down from a record high of 490,000 seven years ago (ADF&G 2009). During this period, wildfires have increased, and destruction of lichen on winter grazing land may be one explanation for the caribou decline. Climate change is expected to dramatically alter the species that are available for harvest in the Arctic coastal plain and the coastal marine environment (Martin et al., 2008).

As temperatures rise, methods for traditional food preparation and storage are less likely to prevent pathogens that cause illness. Just as the useful period for ice cellars has shortened, so also has the period when fish, seal, and caribou can be preserved on drying rack. The most common types of foodborne illnesses are caused by bacteria such Clostrididum botulinum, campylobacteria, salmonella and e-coli, and viruses such as norovirus. A review of clinical data from Kivalina showed no evidence of unusual rates of foodborne illness, nor was such a problem reported by health aides. Still, given the environmental changes occurring in Kivalina, residents should exercise continued care in the preparation and storage of wild foods. Pregnant women, infants, the elderly, and those with weakened immune systems are at higher risk for severe infections, such as those that result from eating wildlife diseased with zoonotic infections.

Cases of zoonotic diseases may be increased by climate change. These are diseases that are passed from animals to people through a cut in the skin, by hand to mouth contact, or by eating infected foods. Echinococcus is a parasitic worm that can infect caribou and other land mammals, including fox, dogs and wolves. People in Kivalina and other Northwest Arctic communities have become sick with

"The first week of March, they had to throw all of the food out because it had spoiled."

Isabelle Booth

echinoccocus, and there have been some recent cases and death from the disease. Brucellosis and trichinosis have also affected wildlife and people in the region. Identifying people who have been exposed or who are sick from these diseases is very difficult. Symptomatic cases where people are actually showing illness of the disease are uncommon, and when they do occur they often mimic other diseases such as common symptoms of influenza, and are easily misdiagnosed. Blood, urine or other testing is usually required. All of these diseases, however, can be prevented by taking precautions such as wearing gloves when harvesting game, cleaning cooking surfaces, and by cooking meat prior to consumption (Brubaker et al. 2010).

Recommendation: A food survey would be beneficial to establish baseline conditions and food security issues, including analysis of adaptation strategies that could improve community food storage and distribution. Based on concerns about declines in trout populations and the importance of trout as a subsistence species in Kivalina, research should be performed to evaluate trout populations and potential impacts from rapid river erosion, as well as the possible causes (such as natural gas seeps) for fish kills. Continued research is needed on food security and safety including causes of resource decline and susceptibility to zoonotic diseases. Kivalina tribal staff could work with public health officials, researchers, and wildlife managers to improve capacity for observation and monitoring of subsistence resources.

Summer caribou. *Courtesy of APIA archives.*

Climate change is affecting subsistence activities, and may result in changes to harvest and diet.

RECOMMENDATIONS

In Kivalina climate change is resulting in serious threats to public safety and public health, including behavioral health problems, injury, disease and food and water insecurity. Appendix B summarizes the health assessment findings. To address the most immediate threats, funding should be obtained to study alternatives for short term evacuation and long term shelter, and to perform an engineering feasibility study for basic sanitation needs including water treatment, water distribution, wastewater collection and wastewater disposal alternatives. An assessment by the State of Alaska, Rural Utility Business Assistance program (RUBA) would provide support to the city for improving operation of the water system and other critical health infrastructure. *Contact: Center for Climate and Health, Maniilaq Association, State of Alaska Department of Community Commerce and Economic Development.*

Capacity to adapt to climate change would be improved by establishing a local environmental observer program. This would involve individual(s) who would monitor environmental change related to climate including coastal conditions, weather, soil temperature, erosion, wildlife change, pollution events, and emerging climate concerns. The observers would help build local capacity to assist in coordination of climate change related activities. *Contact: Center for Climate and Health, UAF Permafrost Laboratory, NOAA Coastal Observer Program, National Weather Service.*

Water conditions in the Wulik River are changing. This has implications for the community water supply. Monitoring of river water conditions is needed to understand impacts. Better turbidity data is needed to understand trends and to develop water collection and treatment protocols. Baseline water sampling would help to determine the changes in metals, solids, organics, and pathogens. Remote sensing instruments would allow operators to identify source water turbidity levels. Monitoring soil temperature would help prevent thaw related damage or disturbance to water and sanitation infrastructure. *Contact: Center for Climate and Health, Maniilaq Association, UAF Permafrost Laboratory.*

Warming has increased the beaver population in the Wulik River watershed. Beavers introduce giardia protozoa and other waterborne disease into the river, and also build dams that reduce water flow. With satellite imagery, the locations of dams could be confirmed and changes to the water flow assessed. Advisories about waters where giardia

Monitoring of river water conditions is needed to understand impacts. Better turbidity data is needed to understand trends and to develop water collection and treatment protocols.

is occurring, and how users of traditional sources can prevent exposure should be provided through the clinic and tribal environmental and natural resource programs. *Contact: United States Geologic Survey, Maniilaq Association, Center for Climate and Health.*

Wildlife diseases that can affect human health are not well understood in the Northwest Arctic. Echinococcus is a parasite that is carried by lemmings and can be passed on to dogs or through hand to mouth exposure to people. In people it can take years to develop symptoms, but can result in serious liver or lung disease.
A local monitoring program can be performed targeting dogs and or lemmings. A de-worming program could also be used to help control the disease in dogs. Blood testing of local residents who are concerned about exposure could be performed in the context of a research effort. *Contact: Maniilaq; AK Health and Social Services; Center for Climate and Health, CDC, Arctic Investigations Program, UAA, Institute for Circumpolar Health.*

Thawing permafrost is resulting in river erosion and changes in the ground surface. This may result in damage to the water line that extends from the river to the lagoon. How permafrost is responding to warming today and in the future is important for understanding changes to the land and river. Borings for monitoring soil temperature are recommended at appropriate locations, such as along the water line and riverbank. Monitoring temperatures in food cellars is ongoing. *Contact: UAF Permafrost Laboratory.*

A community honey bucket haul system is recommended. Kivalina could apply for startup funding from ANTHC's Community Environmental Demonstration Program. A similar demonstration project was performed in Newtok and the findings are available through ANTHC's Healthy Village Environmental program. *Contact: EPA, Maniilaq Association, ANTHC.*

The Wulik River Watershed is undergoing dramatic change. Better understanding of how temperature, precipitation, permafrost thaw, erosion, human activities, and wildlife affect the amount of water, water quality, and the pathway that water follows from a drop of rain to the water tap would be of value in understanding water security today in Kivalina. Development of a water model for the Wulik River would be of value. *Contact: UAF Permafrost Laboratory.*

Periodic dietary surveys would help establish what people are actually eating, how diet is changing, and health implications.

Climate change is affecting subsistence activities, and may result in changes to harvest and diet. Periodic dietary surveys would help establish what people are actually eating, how diet is changing, and potential health implications. Additionally, a detailed survey of subsistence activities and observations in the context of climate change would help describe specific impacts, and assist in understanding effects on food safety and security. *Contact: Maniilaq Association, Center for Climate and Health, UAA Institute for Circumpolar Health.*

Unusual and unpredictable weather, snow, ice and water conditions have made travel more hazardous. Injuries could be prevented by use of geographic, remote sensing, and communication technology. A loaner personal locator beacon program, such as used in Point Hope, would enhance search and rescue's ability to locate people in peril. *Contact: Northwest Arctic Borough.*

Mapping of methane seeps would identify locations where ice strength may be compromised in frozen lakes. Additionally, sampling of methane seeps could help to identify whether there is natural methane being produced that could be used for small-scale energy project, such as home heating. *Contact: UAF Geophysical Institute.*

To prevent disease, water from traditional sources should be monitored, and guidance on treatment provided as needed. Additionally, surveillance for infectious disease in subsistence foods should be developed and region appropriate methods, established for reduce risk of exposure to zoonotic disease. *Contact: Maniilaq Association, Center for Climate and Health, UAF, CDC Arctic Investigation Program, AK Department Health and Social Services.*

Residents will be vulnerable to flooding as long as people live in the flood zone without access to safe shelter. Developing an evacuation shelter above the flood zone will get people out of harms way, reducing risk of injury, and reduce anxiety and fear. Planning for the evacuation route and shelter must also include an interim plan while the evacuation route and shelter are completed. Education about weather and climate related mental health stressors would be of value to behavioral health staff in their counseling services. *Contact: Northwest Arctic Borough, Maniilaq Association.*

Developing an evacuation route and shelter above the flood zone will get people out of harms way, reducing risk of injury, and relieving anxiety and fear.

ANTHC recommends the development of a local Climate Change Surveillance Program. The purpose of a surveillance program is to provide measures of climate change specific to the needs of Kivalina. The examples of possible measures (Figure 8) were developed based on the local conditions. The intent is to provide targeted surveillance measures to help fill data gaps. By understanding local impacts, appropriate adaptation actions can be developed.

Example Climate Change Surveillance Program

Impact Issue	Local Measure	Local Observer
Water Quality	Source / raw water turbidity	Water Operator
Water Quality	Source / raw water temperature	Water Operator
Water Quality	Permafrost temperature	Water Operator
Water Season	River freeze up/break up date	Water Operator
Food / Water Safety	Clinic visits for prolonged fever.	Community Health Aide
Food / Water Safety	Clinic visits for persistent abdominal pain/diarrhea.	Community Health Aide
Risk of Injury	Climate related clinic visits (e.g. storm injury).	Community Health Aide
Behavioral Health	Number of visits during storm season.	Behavioral Health Aide
Behavioral Health	Number of visits citing climate condition as stressor.	Behavioral Health Aide
Safety	Number of falls through ice.	Village Public Safety
Safety	Number of extreme weather rescues.	Village Public Safety
Safety	Measure of ice thickness in key locations.	Village Public Safety
Coastal Change	Erosion and coastal change (GPS) observations.	Village Public Safety
River Change	Evidence of river change such as thermal slumps.	Environmental Staff
Weather	Local precipitation measure	Environmental Staff
Weather	Extreme weather observations.	Environmental Staff
Subsistence / Wildlife	Observation of stranding/ disease / new species etc.	Environmental Staff
Subsistence / Wildlife	Quality (good/bad etc)/ quantity of harvest.	Environmental Staff
Subsistence / Wildlife	Changes in phenology / timing of harvest season	Environmental Staff
Erosion - River	Status of Thermal slumps	Environmental Staff

Figure 8: Local Environmental Observation (LEO) Program Recommendations.

ANTHC is currently preparing a Local Environmental Observer curriculum and handbook to assist Kivalina and other communities in the development of their local surveillance program. These could also be integrated into the regional and statewide monitoring framework.

The purpose of a surveillance program is to provide measures of climate change specific to the needs of Kivalina. By understanding local impacts, appropriate adaptation actions can be developed.

CONCLUSION

Climate change is altering the Arctic environment at a rate never before recorded in human history. Kivalina is in the climate impact zone, experiencing rapid change and negative outcomes for mental health, injury, disease, food and water security, and health infrastructure. Only through equally rapid adaptation efforts can further health consequences be prevented.

This report raises awareness about current, emerging, and potential future climate change. It is hoped that this will help Kivalina make informed planning decisions, find community appropriate development strategies, and pursue a safe, healthy, and sustainable future. The qualities that have served the Inupiat for over 4,000 years will serve them well again now, as changing climate mandates a new chapter of resilience and adaptation.

For more information, contact the Center for Climate and Health by e-mail at akaclimate@anthc.org or by phone (907) 729-2464.

Holding back the waves: a tiny seawall built by local children.
Michael Brubaker, 2010.

Kivalina is experiencing rapid change and negative outcomes for mental health, injury, disease, food and water security, and health infrastructure. Only through equally rapid adaptation efforts can further health consequences be prevented.

APPENDIX A

Community / Regional Contributors – Kivalina, Alaska

Anecdotal data was collected on observations and experiences from local experts in health, wildlife, whaling, Inupiat culture, weather, subsistence, education, sanitation, local governance, law enforcement, and emergency services.

Type	Position	Name	Association
Health / Clinic	Health Aide / CHAP	Susan Beck	Maniilaq
Health / Clinic	Health Aide / CHAP	Isabelle Booth	Maniilaq
Health / Mental Health	Village-based Counselor	Alice Adams	Maniilaq
Health / Mental Health	Mental Health Aide (retired)	Lucy Adams	Maniilaq
Health / Mental Health	Mental Health Therapist	Kevin Settles	Maniilaq
Health	Medical Records	Minnie Iyatunguk	Maniilaq
Education	Principal	Zoe Theoharis	NWASD
Education	Teacher	Cheryl Vanderpool	NWASD
Education	Counselor	Mark Turner	NWASD
Youth	Students 2nd,3rd, 5th, 6th	McQueen School	NWASD
Elder	Elder	Russell Adams Sr.	Resident
Elder	Elder	Tillman Adams	Resident
Elder	Elder	Lucy Adams	Resident
Environment	Water Operator	Mida Swan	Kivalina IRA
Environmental Health	Water Operator	Brad Bergsrud	City of Kivalina
Environmental Health	Water Operator	Joe Swan Jr.	City of Kivalina
Environmental Health	Regional Director	Racheal Lee	Maniilaq
Environmental Health	Washeteria Manager	Hilda Knox	City of Kivalina
Governance	Mayor	Burt Adams	City of Kivalina
Governance	Tribal Council President	Millie Hawley	Kivalina IRA
Governance	Tribal Administrator	Colleen Swan	Kivalina IRA
Governance	City Administrator	Janet Mitchell	City of Kivalina
Governance	Tribal Council	Rappi Swan	Kivalina IRA
Governance	Tribal Council	Austin Swann	Kivalina IRA
Natural Resources	Coordinator	Attamuk Shiedt	Maniilaq
Subsistence	Marine (seal / whale)	Joe Swan Sr.	Resident/ Elder
Subsistence	Land (plants/ birds/ caribou)	Stanley Hawley	Maniilaq
Subsistence	River (plants/ birds/ caribou)	Roger Hawley	Resident
Public Safety	VPSO	Andrew Baldwin Jr.	Maniilaq
Wulik River / Mine Activities	Environmental Manager	Jim Kulas	Teck Cominco

APPENDIX B

Climate Change Health Assessment Findings, Kivalina Alaska

Category	Observation	Impact	M	I	D	W	F	Health Effect/Adaptation
Temperature	Increased temperature since the 1950s. Biggest increase during winter months.	Warmer average temperature every month. Earlier spring thaw and later winter freeze up.	*	*	*	*	*	Various Weather/Climate Observer
Precipitation	More annual precipitation but drier summers.	Increased wildfire. Less snowpack.	*	*	*	*	*	Various Weather/Climate Observer
Sea Level Sea Change	Vulnerable to storm surge. No information on sea level change, though rise expected. No acidification data.	Increased storm surge and flooding resulting in contamination of lagoon and village with sewage, fuel, and solid waste.	*	*	*	*	*	Increased stress and fear related to flood. Injury related to storm events. Infection due to washeteria interruption. Evacuation Route/ Shelter
Erosion	Increased due to delayed freeze up and permafrost thaw.	Land and infrastructure damage and loss. Water interruption.	*	*	*	*		Increased stress related to storm threat. Service interruption Observer/Monitoring
Permafrost	Rapid thaw along rivers. Increased active thaw layer. Methane seeps in tundra lakes.	Increased erosion, turbidity. Decreased water quality. Decreased navigability. Thawing ice cellars.	*	*		*	*	More water system maintenance. Increased risk of injury from river travel. Less food storage space. Monitor source water, cellars, soil temps. Assess methane seep and watershed change.
Snow and Ice	Variable and extreme conditions. Diminished multi-year sea ice.	Increased snow load. Reduced season and conditions for ice-based hunting and travel.	*	*		*	*	Travel and subsistence interruption. Increased risk of travel-related injury. Route monitoring. Emergency beacons.
Plants	Increase in trees and shrubs. Decrease in tundra. Longer growing season.	More snow collection along rivers. Habitat for new plant and animal species. Potential for algae blooms (cyanobacteria).	*	*	*		*	Increase in allergens. Decrease in berry picking and tundra plant habitat. Baseline assessment and monitoring for vegetation and phenology. Baseline pollen counts.
Wildlife	New fish, insects, land mammals. Reduced sea mammals.	Beaver population established. More moose and porcupine. Possibly new salmon species. Invasive insects (wasps, dragon flies, beetles).	*	*	*	*	*	Potential for increased zoonotic disease and increase in insect bites. Decrease of some traditional foods. Education/Harvest Precautions Environmental Monitoring

Note: M (mental health), I (Injury), D (disease), W (water safety/security), F (food safety/security)

APPENDIX C

Kivalina Climate and Health Web Resources

Topic	Resource	Location
Kivalina Profile	State of Alaska Community Database	http://www.commerce.state.ak.us/dca/commdb/CF_BLOCK.htm
Kivalina Erosion Data	USACE Community Erosion Report, 2009	www.poa.usace.army.mil/AKE/Home.html
Kivalina Permafrost	UAF Permafrost Laboratory	www.gi.alaska.edu/snowice/Permafrost-lab/
Kivalina Flood Data	USACE Flood Hazard Database	http://www.poa.usace.army.mil/en/cw/fld_haz/kivalina.htm
Kivalina Temperature Precipitation Projections	Alaska Center for Climate Assessment & Policy	www.uaf.edu/accap/
Kivalina Climate and Health Impacts Reports	ANTHC, Center for Climate and Health-	www.anthc.org/chs/ces/climate/links.cfm
Local Weather Observations	NWS Extreme Weather Spotter Program	http://www.weather.gov/skywarn/ Contact: Harry Lind, NWS in Kotzebue. (training and equipment).
Local Weather Observations	Community Collaborative Snow Rain and Hail Program	http://www.cocorahs.org/ Contact: Harry Lind, NWS in Kotzebue.
Regional Climate Data	Temperature and Precipitation Data, Kotzebue 1930s-present	climate.gi.alaska.edu/
Regional Climate Data	Center for Global Change and Arctic System Research (UAF)	www.cgc.uaf.edu/
Regional Climate Data	Global Climate Research Center (Barrow)	www.arcticscience.org/
Regional Climate Data	Google Earth climate impact layers	earth.google.com/intl/en/index.html
Regional Weather Data	Extreme Weather Watches, Warnings Advisories, National Weather Service	www.arh.noaa.gov/
Regional River Flood Data	Advanced Hydrologic Prediction Service National Weather Service	http://aprfc.arh.noaa.gov/ahps2/index.php?wfo=pafg3
Regional Health Data	Maniilaq Association, Kotzebue	www.maniilaq.org/
Regional Health Profile	Alaska Native Tribal Health Consortium EpiCenter	www.anthc.org/chs/epicenter/upload/Regional_Health_Profile_Maniilaq_0408.pdf
Federal Climate Response	Alaska Climate Change Response Center	http://alaska.usgs.gov/
State Climate Response	State of Alaska Climate Strategy	www.climatechange.alaska.gov/
Community Based Monitoring - Coastal	National Weather Service Weather/Coastline Observer Program	www.nws.noaa.gov/om/coop/index.htm
Community Based Monitoring - Diet	Nutritional and Food Security Baseline Survey	www.anthc.org/chs/epicenter/upload/traditional_diet.pdf
Community Based Monitoring – Seasonality	U.S. Geological Survey-National Phenology Network	www.usanpn.org/
Community Based Monitoring – Wildlife	National Oceanographic and Atmospheric Administration – Marine Stranding	www.fakr.noaa.gov/protectedresources/strandings.htm

APPENDIX D

Kivalina Health Effect Severity / Vulnerability Table

		Community Vulnerability to Health Effects		
		Beneficial	***Detrimental Less Vulnerable***	***Detrimental More Vulnerable***
Likelihood of Occurrence	***Uncertain***	Improved diet from new subsistence resources (e.g. improved salmon, moose harvest). Improved mental health due to decreased environmental stressors (e.g. warm, sunny days).	Illness from consuming food stored in thawing ice cellar. Increased exposure to heat /cold event injury (e.g. hypothermia or heat exhaustion) Increased incidence of allergic reaction (e.g. plants, insects stings).	Increased acute or chronic disease (e.g. infections from contaminant exposure). Increased acute or chronic disease from a less healthy diet. (e.g. substituting hot dogs for whale).
	Likely	Shortened infectious disease season (e.g. cold/flu). Improved aspects of health service.(e.g. extended season for water treatment).	Increased respiratory problems related to diminished air quality (dust, pollen, smoke). Impacts to water system operation from diminished source water quality.	Injury or illness from extreme events (e.g. flood, storm-surge). Increased respiratory infection (e.g. water service interruption).
	Certain	Warmer summer conditions for children to play on beach.	Decreased food security (e.g. inadequate food storage). Decreased access to upriver subsistence resources due to river change. Food spoilage due to high summer temperatures.	Diminished health services from stressed public resources or damaged infrastructure (e.g. operation of water system). Impaired mental health (e.g. stress related to flood risk or changes in food availability). Increased (e.g. brucella) or new (e.g. giardia).infectious disease Injury from changes in physical environment (e.g. cold water exposure, falls through ice). Impaired functioning of health infrastructure (e.g. decreased water availability/quality).

APPENDIX E

General Recommendations for Climate Adaptation Planning

Local and regional government is challenged with preparing for climate-related impacts, and the need to develop comprehensive adaptation plans. The following are 10 basic principals that are recommended for integrating climate change planning into local decision-making. Other principals may be developed by the community as local residents engage in the planning process.

1. Protection of human life and health is the top priority.
2. Traditional values should guide local and regional decision making.
3. Development should follow the principles of sustainability "meeting the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987).
4. Community Adaptation Plans should identify valued local resources, such as subsistence areas, cultural sites, critical water sources, and develop plans to protect them.
5. Critical ecological systems, wetlands, and subsistence resource areas should be protected where possible.
6. Considerations for climate impacts on erosion, flooding, subsistence, water availability, and transportation should be incorporated into planning, and new infrastructure siting and design.
7. Cost-benefit analyses should be applied to evaluate the social and environmental costs of building and maintaining coastal protection structures.
8. Phased abandonment of at-risk areas should be considered.
9. Coastal emergencies are inevitable and disaster response and recovery capacity, including evacuation routes, emergency response plans, drills, and shelters, should be reviewed.
10. Building capacity to participate in monitoring, research, and advocacy is critical to facilitate development of effective adaptation strategies.

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Aerial view of Kivalina.
Courtesy of Millie Hawley.

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The Selawik National Wildlife Reserve
The Alaska Ocean Observing System.

For more information please contact:
Center for Climate and Health
Alaska Native Tribal Health Consortium
(907) 729-2464

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