Situation Assessment

Kivalina Consensus Building Project

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Prepared by

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for the

City of Kivalina

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Executive Summary

Introduction

The Situation Assessment compiles existing information about climate-related changes affecting Kivalina. It addresses natural hazards, evacuation and emergency planning, evacuation routes, and options for relocation or remaining in place. The Situation Assessment is one of the products of the Kivalina Consensus Building Project. Companion documents to this report include the Summary of the September 2009 Door-to-Door Survey, the Annotated Bibliography, and the Final Report which includes summaries of the two public meetings and two workshops held for this project.

Although the Situation Assessment does not recommend options for Kivalina's future, it identifies areas where there is a lack of information. Also, it identifies upcoming opportunities the community may wish to consider when choosing its next steps.

Context

Climate change is occurring in Arctic regions faster than in other areas, and recent climate indicators reveal that changes are occurring faster than previously predicted. Although there are year-to-year variations, a general warming trend is occurring. Climate-related natural hazards include storms, flooding, erosion, ice hazards, melting permafrost, sea level rise, and ocean acidification.

As a result of later freeze up and earlier melting of sea ice, Kivalina faces significant risks from storms, including flooding and erosion. Little is known about the coastal processes near Kivalina that erode and deposit beach sand and sediments, and additional studies may be necessary to confirm assumptions. While only a few storms have resulted in flooding of the community, government agencies are concerned that the "100-year flood" could inundate Kivalina. A new water level study estimates that the 100-year flood estimate is 7.77' above mean lower low water (MLLW). This estimate is 8.53' lower than the estimate used for the 2006 Kivalina Master Plan. Since most of the homes in Kivalina are sited 10 feet above mean high water (MHW), a reassessment of assumptions in the 2006 Master Plan for Kivalina may be warranted for both risks of flooding and costs for remaining at the current village site.

Erosion has endangered structures in Kivalina, but while there is a net erosion of sediments on the island, there are other areas where beaches are accreting. Certain practices have been attributed to increasing erosion in Kivalina, including removal of beach sand for construction projects, uncontrolled ATV traffic, and the use of inadequate erosion control structures in the past that may have accelerated erosion.

Permafrost melting has implications for Kivalina because it may affect coastal erosion, drinking water quality, subsistence access in the rivers, the ability to store food in ice cellars, and the feasibility of relocating to some of the proposed sites. While ice-rich permafrost soils could lead to significant sinking in some of the proposed relocation sites, melting of permafrost soils at Kivalina are not expected to subside due to the high sand content and lack of ice lenses (chunks of ice in the soil). A 2008 permafrost study at Kiniktuuraq predicted that gravel fill may not protect permafrost soils from melting under some conditions. Assumptions in the 2006 Master Plan about gravel fill requirements for the relocation sites may need to be reassessed to include new information from the 2008 permafrost study.

Ice hazards at Kivalina include breakup of ice in the lagoon, thinning sea ice and ice run up on the shoreline (ivu). The thinner ice affects ability to use ocean ice for subsistence because it presents significant safety hazards for subsistence users.

Evacuation and Emergency Planning

The City has prepared 2 new emergency plans: Community Evacuation and Emergency Operations. The current Local Hazards Mitigation Plan needs to be updated to incorporate new flood estimates and any reduction in erosion and flooding risks resulting from the construction of the rock revetment.

Evacuation Road and Shelter

A 2005 study evaluated 8 alternatives for siting an evacuation road, and it recommended a route across the lagoon to Simik (Simiq) continuing inland to a gravel and rock source at a cost of $21.3 million. A 2008 study reviewed 2 routes: A bridge/road to Kiniktuuraq ($38.9 million) and causeway/bridge across the lagoon to Simik ($20.3 million). The study recommended no further work on these routes until substantial funding is secured.

Options to Relocate or Remain at the Current Site

Many reports have been written evaluating options for Kivalina's future including a1994 DOWL Engineering report and reports in 1998 and 2006 by the Army Corps of Engineers. The 2006 Master Plan recommends future consideration of only two sites: Tatchim Isua and Imnakuk Bluff. Some residents have noted that these sites have poor access to subsistence uses and can be very windy. The Master Plan found that Kiniktuuraq, the site selected by the community in 2000, was subject to storm surges, erosion and melting permafrost due to ice-rich soils. New information about 100-year flood estimates and permafrost melting might merit reconsideration of findings in the 2006 Master Plan. In addition, an Alaska Division of Geological and Geophysical Services hazards study scheduled for 2010 will provide additional information about hazards in Kivalina as well as potential relocation sites.

Situation Assessment

Kivalina Consensus Building Project

1. Introduction

The purpose of the Kivalina Consensus Building Project is to work towards a consensus on steps the community will take to respond to climate-related impacts, including increased threats from erosion, flooding and storm surges. This document provides an assessment of the most important reports that relate to Kivalina's short-and long-term responses to these threats. In addition to an assessment of previous studies, this report identifies information gaps and opportunities for future investigations.

The *Situation Assessment* is one aspect of the Kivalina Consensus Building Project. Other parts of the project include a door-to-door survey, community meetings, and community teams established to identify next steps the Kivalina should take. Companion documents to this report include the September 2009 *Summary of the Door-to-Door Survey*, an Annotated Bibliography, and the *Final Project Report*.

This project was funded by an appropriation from the Alaska State Legislature resulting from a recommendation by the Immediate Action Workgroup (IAW) of the Governor's Subcabinet on Climate Change. In its 2009 report to the Subcabinet, the IAW identified the need for community planning efforts by Kivalina because its preferred relocation site has been deemed inadequate due to permafrost soils (Immediate Action Workgroup 2009).

The remainder of this document summarizes reports about Kivalina according to the following topics.

2. Context
3. Natural Hazards
4. Evacuation and Emergency Planning
5. Evacuation Road and Shelter
6. Options to Relocate or Remain at the Current Site
7. References

Where additional information may be needed by the community, options for further investigation are outlined in headings titled "information needs and opportunities." Kivalina may wish to address these issues during the next phase of the community planning grant.

2. Context

Kivalina is an Iñupiaq community located 83 miles above the Arctic Circle within the Northwest Arctic Borough. The estimated population of 406 (2008) live in houses clustered around the southern end of a 5.5-mile barrier island bordered on the west by the Chukchi Sea and on the east by Kivalina Lagoon (Alaska Division of Community and Regional Affairs 2009). Historically, the marine waters around Kivalina have been ice free from early July through late October, but later freeze-up and earlier melting has resulted in longer ice-free periods during recent years. During January 2010, a lead opened up directly in front of the community extending south to Kotzebue Sound and north to Point Hope. According to village elders, this is the first time in their memory a lead has opened so close to shore during the month of January.

The remainder of this section provides the following information: Community background, history, current living conditions, funding, and Arctic climate change.

2.1 Background

Kivalina is the only village in the Northwest Arctic Borough that hunts bowhead whales, and it is a member of the Alaska Eskimo Whaling Commission. The Native Village of Kivalina is the tribal government for the community, and the City of Kivalina incorporated as a second class city in 1969.

The community occupies about 27 acres not including the airport (DOWL Engineers 1994). The State of Alaska owns the 3,000’ airstrip and adjacent area which extends 6,700’ from the northern edge of town. The dump site and area for disposal of human waste, completed in 1996, is located north of the airstrip.

The residents of Kivalina discussed moving off the island because of concerns of erosion as early as 1910 (Replogle 1911). In recent years, accelerated erosion has been attributed to climate change because of later freeze up of the Chukchi Sea (Kivalina 2009). The community has held 5 elections related to relocation issues. A special election in 2000 resulted in a majority of voters wishing to move to Kiniktuuraq, a site located one-mile south of the current community site. The 2006 Master Plan recommended against further consideration of this site, however, due to ice-rich soils and threats of coastal erosion (U.S. Army Corps of Engineers 2006a).

Significant storms that occurred in 1970, 1976, and 2004-2007 caused significant erosion and in some cases flooded part of the community. In response to these storms, the Northwest Arctic Borough oversaw construction of an erosion control project on the ocean side of the community in 2006. Days before it was to be dedicated, a storm caused severe damage to the structure. In 2007, the Northwest Arctic Borough and community leaders decided to evacuate the village in response to an oncoming storm. Over growing concerns about erosion, Congress made special appropriations to the U.S. Army Corps of Engineers (Corps) for coastal erosion projects in Alaska starting in 2006. Using that funding source, the Corps constructed 1,600' of rock revetment on the ocean side of Kivalina in 2008 and 2009. The State of Alaska funded an additional 400'of rock revetment towards the airport that is planned for construction in 2010.

The remainder of the rock revetment has not yet been funded. The Phase II of the Corps' project will involve armoring of the lagoon-side of the community.[1] The Alaska Department of Transportation and Public Facilities plans to continue the revetment along the ocean side of the airport with funding from the Federal Emergency Management Agency (FEMA). At the time this report was finalized, adequate funding for the airport armoring project was not secured.

2.2 History

Before the current community was settled in 1905, the Iñupiaq people of the region, known as the Kivalliñigmiut, spent summers on the coast and winters inland. According to Burch (1998), traditionally, there were 20 winter settlements along the Kivalina and Wulik rivers and 14 summer settlements along the coast. Four coastal settlements were located adjacent to the Kivalina Lagoon including Kiniktuuraq to the south and three smaller settlements at the north end of the lagoon.[2] During the great famine of 1881-1883 about half the people in the region died, and the remaining Kivalliñigmiut moved out of the area. After the famine, some of the Kivalliñigmiut returned and shared the area with Iñupiaq people who migrated north from Shishmaref. The community became a year-round settlement in 1905 when a school was built. The new community represented families from the Kivalliñigmiut and Iñupiat from other areas, including Shishmaref, the Upper and Lower Noatak, and Kotzebue.

According to some sources, the current site of Kivalina was selected in 1905 when a boat arrived with materials for the school (City of Kivalina 2009). As the story goes, the captain offloaded the building supplies at the southern end of the island because he saw people there and assumed it was occupied as a settlement. According to Saario (1962), however, the U.S. Bureau of Education reported there were 12 sod homes in the immediate vicinity of the school site. Burch (1998) indicates that a settlement called Ualliik was located at the present site of Kivalina in 1895. A recent archaeological discovery provides evidence that the site of present day Kivalina had been occupied an estimated 1,000 years ago by the Ipiutak people.[3]

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[1] Congressional legislation passed in October 2009 establishes authority for federal funding of climate-change related improvements, but additional appropriation will be required. A policy issued by the Corps in 2010 establishes 65% federal and 35% non-federal funding requirement and requires a positive cost-benefit finding. Because the Kivalina Phase II revetment project was previously approved, a cost-benefit analysis will not be required.

[2] The present site of Kivalina was not a traditional summer camp for the Kivalliñigmiut.

[3] Human remains found during excavation for a wastewater treatment plant in July 2009 are thought to be at least 1000 years old and may be of the Ipiutak people who are not directly related to the Iñupiat (Barber 2009). Radiocarbon dating will provide additional information about the age of the remains.

Significant changes to the way of life occurred in Kivalina beginning in the 1960s. Access to the community expanded in 1960 with the construction of an airstrip. A 1962 subsistence study for Kivalina reported that about half the dwellings were sod houses, and 80% of the residents depended on wood for heating fuel (Saario 1962). A 1985 study found that significant changes occurred in the prior 20-year period including construction of a new high school and a larger store, introduction of electricity, and replacement of dog teams with snow machines (Burch 1985). Burch found the level of social continuity was high during this period. Subsistence remained important, and all of the families present in the 1960s were represented in the community during the 1980s. The population of Kivalina more than doubled between 1970 (188) and 2008 (406).

2.3 Current Living Conditions

Kivalina residents share a desire for improved living conditions. There is no room for community expansion at the current townsite, and the water, human waste and solid waste systems pose human health and safety concerns.

- **Lack of Housing:** Since state land in the vicinity of the airport is not available for housing, and the rest of the village is surrounded by water, there is no room for community expansion. Houses are crowded together along the southern tip of the island. The community has about 80 houses, and in some cases up to 15 people may live in a single house.[4]
- **Human Waste:** Homes are not connected to a sewer system. Individual households must make their own arrangements for storage and collection of "honey buckets" that are dumped in a metal containment basin next to the dump. This system presents a health hazard due to accidental spills that occur during collection and storage and suspected leaching from the containment basin into the lagoon.
- **Solid Waste:** Each household is responsible for collecting its waste and bringing it to a 3.4 acre dump site, located just north of the airport. The site is located at a thin portion of the island that is subject to winds, erosion and flooding. The dump site appears to be beyond capacity, and wind has distributed materials outside the site. There is no active management of the dump, no burn box, no system for collection of hazardous waste, and the trash is not capped with gravel. The close proximity to the airport raises safety concerns for aircraft because it is an attractive nuisance for birds.[5]
- **Water System:** Water is obtained from the Wulik River using a seasonal 3-mile surface transmission line. This is necessary because wells drilled near the school produced only salt water. Water can be collected only during a short period of the year when the river is ice free and clear of silt. Water is initially stored in a 700,000 gallon tank where it is then

[4] A new site with adequate room for expansion would likely lead to doubling of the population in 20 years (U.S. Army Corps of Engineers 2006a).
[5] FAA regulations require a 5,000' separation between landfills and airports.

treated and stored in a 500,000-gallon tank. Households purchase water from a pay box on the eastern side of the washeteria, and they must haul it to their homes using small containers or tanks on trailers towed by ATVs. The only buildings with piped water include the washeteria, school and clinic. Only one-third of the homes have tanks that provide running water for kitchens. The limited capacity of the system results in rationing of water, and in the past when tanks ran dry, residents were forced to haul ice as a water source (Golder Associates 1997). The lack of an adequate water supply results in health concerns that are amplified by overcrowded houses and lack of a central sewer system.

- **Transportation:** A 3,000' by 60' runway provides access by aircraft. Approximately 1.5 miles of roads and trails are located in the community, but these roads were not engineered to any standards and are not maintained. They are in need of grading and surfacing (ASCG 2005). Barges serve the village during the summer.
- **Subsistence:** Kivalina residents depend on subsistence resources for healthy foods including caribou, fresh water and marine fish, and marine mammals. Impacts from a warming climate have changed availability and distribution of resources and increased safety hazards such as traveling over thin sea ice. In addition to changes in distribution of marine mammals due to changes in sea ice, Kivalina residents have linked climate change to a reduced availability of waterfowl and Arctic char (Braund and Associates 2005).

2.4 Funding

The prospect of relocating the community has resulted in a reluctance of some agencies to fund community improvements. The overcrowded conditions, inadequate water and sewer facilities, and lack of room to accommodate future generations affect the disposition of community residents. The lack of progress with the community relocation and the continuing threat of natural hazards have serious implications for the mental health of the community. As one resident stated during a public meeting for the Kivalina Consensus Building Project, all of the community's dreams have been repeatedly crushed.

Federal funding for the U.S. Army Corps of Engineers to address erosion problems in Alaska at full federal expense, known as Section 117 funding, was repealed in early 2009.[6] Congress replaced this funding authorization in October 2009 known as Section 116 funding.[7] This act provides no more than a 35% match requirement of non-federal funds for Alaska erosion control and relocation projects, but it does not appropriate any funds for this purpose. Agency guidance requires a positive cost-benefit analysis for new projects, but this requirement will not apply to completion of the Kivalina rock revetment project since that project was previously approved

[6] Section 17 was authorized by the 2005 Energy and Water Development Appropriations Act.
[7] Section 116 is part of H.R. 3183: Energy and Water Development and Related Agencies Appropriations Act, 2010 that was passed by Congress on October 28, 2009.

(U.S. Army Corps of Engineers 2010a). A positive cost-benefit analysis would be required, however, for future Kivalina projects, including relocation efforts.

The high costs associated with proposed solutions for Kivalina provide a challenge because of a lack of adequate state and federal funding available for Alaska communities at risk from the effects of climate change. A growing number of communities are asking for assistance to respond to increased risks of flooding and erosion. A clear plan of action with widespread community and agency support will increase Kivalina's chances of funding.

2.5 Arctic Climate Change

Arctic communities, such as Kivalina, are experiencing increasing impacts that have been associated with climate change, and climate change impacts appear to be magnified in the Arctic. The Intergovernmental Panel on Climate Change (2007) found that all but one year between 1995 and 2006 represented the warmest surface temperatures since 1850. The 2004 *Arctic Climate Impact Assessment*, prepared by the 8-nation Arctic Council, found that increased concentrations of greenhouse gases have led to significant changes:

- Global temperatures are rising faster than ever before,
- Average Arctic temperature is rising at twice the rate of the rest of the world,
- Glaciers are melting at an increasing rate which will result in sea level rise,
- Permafrost temperatures are rising,
- Sea ice has decreased about 8% during the past 30 years,
- A reduction in sea ice poses increased risk of flooding, erosion and storm surges,
- Reduced sea ice will open Arctic areas to new shipping traffic, and
- Climate change will have health impacts including impacts to subsistence from changes to the distribution and availability of subsistence resources.

A 2009 update to the *Arctic Climate Impact Assessment* (Arctic Monitoring and Assessment Programme 2009) found that climate indicators show changes are occurring at a faster rate than previously expected. These indicators include an increasing rise in Arctic air temperatures, a sharp decrease in sea ice with a record low during 2007, and ice-free conditions for the first time in the Northeast and Northwest passages during 2008.

The web-based *Arctic Report Card* by the National Oceanic and Atmospheric Administration (NOAA) provides updated information about climate change (Richter-Menge and Overland 2009). The 2009 report includes the following conclusions:

- Warming ocean temperatures lead to summer sea ice loss that in turn is affecting air temperatures and Arctic atmospheric circulation,
- The 2009 summer sea ice extent was the third lowest on record and 25% lower than the 1979 -200 average,

- An unprecedented amount of fresh water on the surface of Arctic sea ice contributes to warming air temperatures in the fall,
- Although there is year-to-year variability, warming trends have resulted in changes to vegetation, permafrost, river discharges, snow cover and mountain glaciers, and
- Future broad changes in wildlife abundance and distributions are expected, and current effects to polar bears and walruses have been observed.

Responses to the impacts of climate change involve mitigation or adaptation (Arctic Climate Impact Assessment 2004). Mitigation involves efforts to reduce greenhouse gas emissions to decrease impacts from continued changes in climate. Adaptation involves measures to respond to effects of a changing climate such as changing subsistence use practices or relocating a community.

3. Natural Hazards

This section addresses reports about natural hazards that threaten the region, including storms, flooding, erosion, ice hazards, melting permafrost, sea level rise, and ocean acidification. After some introductory information, this section continues a discussion of what is known about geophysical processes followed by a description of individual hazards.

While natural hazards are not new to Kivalina, climate change trends may amplify the occurrence and impacts of natural hazards. A recent report that updated the 2005 *Arctic Climate Impact Assessment* found that some indicators of climate change show “extensive climate change at rates faster than previously anticipated” (Arctic Monitoring and Assessment Program 2009). Specific natural hazards that may be aggravated by climate change include increased severity of storms later in the year, higher storm surges, increased erosion, sea level rise, and melting permafrost and associated subsidence.

The Request for Proposals for this project requested the consultant identify an official document outlining risks to the community that was prepared by a registered professional. While none of documents about hazards reviewed for this report included the stamp and signature of a registered engineer, some documents were prepared with the assistance of engineers. There are many documents that address hazards facing the community, including the 2008 Local Hazards Mitigation Plan (City of Kivalina 2008). That document identifies the following natural hazards for Kivalina: High flood hazards, high storm hazards, high erosion hazards, and low earthquake hazards.

Erosion has been a concern of the community since soon after it was founded. In recent years, climate change has been attributed to accelerated erosion and risks of higher storm surges. Later freeze up of the Chukchi Sea results in greater damage from fall storms, especially when storms from the northwest generate large waves due to increased fetch, that is, the distance over water where wind can generate waves (City of Kivalina 2008, U.S. Army Corps of Engineers 2006b). Later freeze up makes the community vulnerable to fall storms when winds can generate higher waves over longer fetches. Since the 1980s, the ice free period has increased from 3 months to as much as 5 months. It should be noted, however, that increased erosion in one area will result in deposition of those eroded materials in another area. Therefore, it is extremely important to understand coastal processes and where the "net drift" of coastal sediments occurs in a particular area.

In 2003, the General Accounting Office (GAO) of Congress identified Kivalina and 3 other Alaska villages as being in immediate need of relocation. An update to this report in 2009 found that other than for the village of Newtok, little progress has been made to relocate these villages. Regarding Kivalina, the report notes that the U.S. Army Corps of Engineers completed the Relocation Planning Project Master Plan in 2006 and construction of a rock revetment began in 2008. The 2009 update stated that Kivalina, Shaktoolik and Shishmaref have not found relocation sites that are safe, sustainable, accessible to subsistence resources, and acceptable to government agencies.

A 2007 congressional field hearing in Anchorage identified obstacles faced by federal agencies and villages: Inability of many villages to meet criteria for federal assistance, high cost of protection and relocation projects, and the lack of scientific erosion data for sound decision making. The report found that the lack of a lead federal agency is a major impediment to progress in village relocation. In 2009, the U.S. Army Corps of Engineers (2009) included Kivalina in its list of Priority Action Communities.

3.1 Geophysical and Ocean Processes

As a result of natural processes, beaches along the coast are constantly changing. Through a process called longshore drift, sand and other materials are either deposited (accreted) or removed (eroded) along the coast. Generally, fall storms cause the most erosion and sediments accrete during the spring and summer. While one storm may deposit materials along Kivalina's barrier island, another storm may erode it away. Rivers provide an important source of sand and silt as they continually change their course. The materials eroded from the stream banks are transported downstream and eventually deposited in lagoons and along the coast.

Little is known about the specifics of long distance transport of beach materials in Northwest Alaska, and the ocean processes at one site might be different than dynamics at another site. Ocean currents involve complex dynamics associated with flows between the Bering and Chukchi seas (U.S. Army Corps of Engineers 2006a).

There have been no site-specific studies of the oceanography at Kivalina, but some assumptions have been made. According to the Corps, although coastal waters flow northward, "the net longshore drift of gravel on the beach at Kivalina is southward because of large storms from the northwest that overpowers the surface flow and directs it southward along the beach" (2007a, p. 14). So in other words, while currents generally flow north, the Corps assumes the net effect of storms deposits sediments in a southward direction. Sediment deposition and erosion can vary from year-to-year, and sediments that remain offshore are available for rebuilding the beach under the action of smaller waves (U.S. Army Corps of Engineers 2006a).   Additional studies may be needed to confirm assumptions about net sediment transport along Kivalina's shoreline. [8]

The natural processes of the Kivalina and Wulik rivers also affect the community. The point where the two rivers converge has eroded a portion of the lagoon side of the community. The sediment transported from the rivers deposits in the lagoon and along coastal beaches. The outgoing flow from the rivers results in changes to the connections between Kivalina Lagoon and the ocean. In 1838, three entrances into the lagoon were reported, and the Wulik River outlet was located at the southernmost part of the lagoon (Burch 1998).[9] The U.S. Army Corps of Engineers found geomorphological evidence that Wulik River once entered Chukchi Sea three-quarters of a mile south of the current location of Singuak Entrance (U.S. Army Corps of Engineers 2007a). A comparison of aerial photographs taken in 1954 and in 2003 found that the northern entrance to the lagoon (Kivalik Inlet) migrated about 625' to the south (NOAA 2004). Residents have also noticed changes throughout time around Singuak Entrance which is located next to the community.

Community members expressed concern about the threats of erosion to Kivalina just a few years after the community was founded. A 1911 report by school officials indicated residents were concerned about erosion and they wanted to relocate the community. Since that time, many studies have been completed about the hazards facing Kivalina and options for relocation.

While natural processes continually change the coast, there is evidence that climate change has exacerbated coastal erosion and increased the intensity of storms. As a result of warming trends, the ice-free period in the Chukchi Sea has increased from 3 months in the 1980s to 5 months (ASCG 2005, U.S. Army Corps of Engineers 2006a). With later freeze-up, fall storms have led to higher storm surges, a longer fetch and increased erosion. These storms are occurring more frequently, and because of a later freeze up, they are doing more damage (Michels 2006, U.S. Army Corps of Engineers 2006a).

[8] Studies have confirmed that the net longshore drift for the Red Dog Port Site is southward. Since the net sediment transport for Pt. Thompson (north of Kivalina) is reported to be northward, it would be important to study further the dynamics at Kivalina.

[9] Currently, there are only two outlets from Kivalina Lagoon: Kivalik Inlet at the north end of Kivalina's Island and the Singuak Entrance located at the southern end of the community.

3.2 Storms and Flooding

The 2008 Local Hazards Mitigation Plan determined there are high flood hazards, high storm hazards, high erosion hazards, and low earthquake hazards (City of Kivalina 2008). While the prevailing winds are from the northeast, the highest wind velocities come from the southeast. The report characterized the following dangers from storms.

- Winds from the south to southwest generate waves that expend their full energy on Kivalina's beach.
- Flood hazards are almost exclusively from storm surges from south to southeasterly winds. Waves from this direction are more destructive because they can ride atop a storm surge (e.g., October 2004 storm).
- Less common waves from the northwest can be higher, longer and more destructive that waves from other directions.

The U.S. Army Corps of Engineers (2006a) found that waves from the south and southeast are almost exclusively responsible for flooding.

Storm History: Table 1 summarizes the major storms that have affected Kivalina in the past 40 years. Two storms in the 1970s resulted in flooding in portions of the town. Increased impacts from storms have been felt during the past 7 years. After an October 2002 storm, the Alaska Governor declared a disaster area for Kivalina. An October 2004 storm caused significant erosion, and again the Governor declared a disaster area for Kivalina. During October 2005, Kivalina residents used 55 gallon drums, a derelict airplane and scrap sheet metal to protect the community from rapid erosion. In response, the Northwest Arctic Borough coordinated construction of an emergency erosion control project that failed during an October 2006 storm, one day before year it was to be dedicated. During September 2007, fears about damage from a developing storm led to the evacuation of the city.

Storm Surge Estimates: Scientists have developed various estimates for the height of expected storm surges in the Chukchi Sea using different models which has resulted in dissimilar flood level estimates. Further study of local ocean conditions around Kivalina may be warranted to ensure that assumptions in the models reflect actual conditions.

When evaluating potential flood levels for onshore areas, it is important to note how water level studies reference flood levels to onshore elevations.[10] Heights on topographic maps usually base measurements from mean sea level (MSL), while heights on nautical charts base measurements from mean lower low water (MLLW).[11] The 1999 Kivalina Community Map prepared for the State of Alaska, however, based its elevation data on mean high water (MHW) (Department of

[10] Some reports reviewed for this study have misinterpreted results of water level studies by misapplying the reference to onshore elevations.
[11] MSL is the average height of the ocean's surface usually determined using hourly height readings.

Community and Economic Development 1999). Water level studies may reference MLLW or mean tide level (MTL) or not reference onshore heights at all.[12] In cases where a study does not reference an onshore elevation, the tidal stage must be considered in order to determine if an onshore area will be flooded.[13]

Table 1: Summary of Reported Storms in Kivalina

Date	Description
1970	A 13.57' "storm of record" inundated portions of the community (ACOE 2006a).
September 1976	Storm surge resulted in water inundating 20-30% of the town, likely due to wave run up (Wise et al. 1981).
October 2002	As a result of an October 8 storm, the Governor declared a disaster area for Kivalina and Kotzebue.
October 2004	Waves from an October 18 storm overtopped the bank resulting in flooding of the community in several locations. Area in front of principal's house eroded which required relocation of the structure. A single storm resulted in erosion of 40 feet of the beach. The Governor and FEMA declared as a disaster.
September 2005	September 22 storm estimated to have a storm surge of 8.5 feet above mean sea level.
October 2005	Storm results in erosion of 70 feet of land near school and erosion of the beach to with 12' of the airport. Residents place 55-gallon drums and sandbags in front of principal's house and use materials from a derelict plane and sheet metal used to protect the area near the airstrip. FEMA and the Governor made a disaster declaration.
October 2006	One day before the planned celebration for completion of an erosion control structure using HESCO baskets, a storm severely damages the structure.
September 12, 2007	Voluntary evacuation of Kivalina due to a severe storm predicted by the U.S. Weather Service.

Sources: City of Kivalina 2008 and 2009, U.S. Army Corps of Engineers 2008, U.S. Army Corps of Engineers 2006a Wise et al. 1981

As a result of different reference points for storm surge data and topographic maps, extra care should be taken when evaluating options for the current village site and potential relocation areas. For instance, when calculating the amount of fill needed for the current site to raise it above the 100-year storm surge estimate, it is important to consider the storm surge estimate relates to MLLW while elevations on the 1999 community map are above MHW.[14]

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[12] MTL is the arithmetic mean of MHW and mean low water, and it is not identical with MSL.

[13] Tidal range for Kivalina is less than one foot (Mason et al. 1998). While not a great height, a foot can make an important difference when predicting flooding because of the low height of the island.

[14] The 1999 community map indicates that most of the houses are situated 10' above MHW, with some of the houses on the lagoon side of the island located about 7' above MHW. According to notes on the map, MHW is 0.77'Higher than MLLW. Considering the new 100-year flood level is estimated to be 7' above MHW (7.77' MLLW – 0.77'), most if not all of the houses appear to be located above the 100-year flood level estimate.

Storm surge estimates are not always based on consideration of the same technical factors. For example, studies may or may not include technical considerations such as wave setup, wave run-up, sea ice extents, air-sea temperatures, or inverted barometer set-up (U.S. Army Corps of Engineers 2008). Wave run-up occurs when the rush of a wave runs up a slope or structure. Wave setup is an increase in the surface of water near the shoreline due to breaking waves. Wave run-up and wave setup are important considerations for determining the maximum height water could overtop a beach or a revetment, but neither of these factors raise the actual water level of a storm surge.

Storm surges cause more damage when winds create wave run-up, and flooding in Kivalina has been attributed to wave run-up rather than from water levels strictly from storm surges. Sheffner et al. (1998) estimate the maximum wave run-up at Kivalina to be 2 meters (6.56'). The 2008 draft Corps memorandum recommends that a defensible storm surge analysis be completed for low-lying relocation sites that would include consideration of sea level rise, delayed freezing and increased erosion.

An October 2009 U.S. Army Corps of Engineers report provides the most current information about flood estimates in Western Alaska (Chapman et. al 2009). This report developed estimates of storm-generated water levels (i.e., storm surges) for different recurrences (i.e., how often a surge of a specific height is estimated to occur). The 100-year flood level estimate is discussed in the Situation Report because FEMA requires elevation of structures above this level. Stated in another way, the 100-year flood level means that in any given year, there is a one percent chance that a flood at this level will occur.

The October 2009 water level estimates were made by amending a previous computer model called the "ADCIRC long-wave hydrodynamic model" (Chapman et al. 2005).[15] Using historic water level data from Nome and the Red Dog Mine port site for calibration (i.e., to make sure predictions from the model match recorded water levels), the model produces simulations which estimate storm surge levels for various intervals of occurrence between 5 and 100 years. For Kivalina, the model estimates the 100-year storm surge to be 7.77' above MLLW with a standard deviation of 1.08'.[16] In other words, while the 100-year flood estimate is 7.77', the model predicts it could range between 6.69' and 8.85'.[17] The October 2009 report does not indicate whether the U.S. Army Corps of Engineers has replaced the previous flood estimate used for Kivalina in the 2006 *Master Plan* or the current estimate on the agency's webpage with this new

[15] The 2005 study has not been finalized and was not available for review.
[16] The ADCIRC model does not include tidal information, but the flood level estimates in Appendix C of the October 2009 water level study does include consideration of tidal influence on storm surge estimates.
[17] This 100-year flood estimate for Kivalina may be found in the table in Appendix C of Chapman et al. (2009, p. 59). Table 4.1 on page 26 of the report uses meters, but when converted to feet, the figures are different than the table in Appendix C because Table 4-1 is referenced to mean tide level while the table in Appendix C is referenced to MLLW.

flood estimate.[18] Additional site-specific studies may be needed to develop agreement of what estimate should be used for future community planning.

The October 2009 100-year flood estimate for Kivalina (7.77' above MLLW) is 8.53' lower than the estimate used for the 2006 *Master Plan* (16.3' above MLLW). This difference would change the cost estimates for remaining at the current site since less gravel would be needed to raise the community.[19] In addition, the hazards mitigation plan may need to be revised to reflect the new flood estimates.

A 2008 draft memorandum from the U.S. Army Corps of Engineers included a summary of previous water level studies (U.S. Army Corps of Engineers 2008). While this draft memorandum did not include information from the 2009 water level study, it includes a useful discussion of some of the previous studies which is summarized below.

- **1981 State Study:** *Storm Surge Climatology and Forecasting in Alaska (*Wise, Comiskey and Becker 1981). This study states that a November 1976 storm was reported to have flooded 20-30% of the community, and the water level was one foot below the lowest home. The study estimated the 100-year flood to be 8.3' above MLLW.
- **1988 Kivalina Study:** *Development of Water Surface Elevation Frequency-of-Occurrence Relationships for Kivalina, Alaska (*Scheffner and Miller 1988). The study estimated the 100-year flood to be 10.6' above MLLW.
- **1999 Port Site Study:** *Delong Mountain Terminal Project Feasibility Study: Metrocean Condition Report* (Triton 1999). The report found that predicting water levels more than a 15 year return is not accurate, but it estimated the 100-year flood to be 14.6' above MLLW.
- **2003 Kivalina Study:** *Reformulation of Water-Surface Elevation Frequency-of-Occurrence Relationships for Kivalina, Alaska – Draft* (Mark 2003). This study estimated the 100-year flood to be 16.3 feet above MLLW. It was used as the basis for recommendations in the 2006 Master Plan (U.S. Army Corps of Engineers 2006a).
- **2005 West Coast Alaska Study:** *Regional Tide and Storm-Induced Water Level Study for the West Coast of Alaska* (Chapman, Mark and Cialone 2005). The results for the Chukchi Sea-Bering Sea area are considered more representative for Kivalina. A frequency of occurrence for Kivalina was developed in 2007 using this model. The study estimated the 100-year flood to be 8.9' above MLLW. The estimate did not include wave run-up or the effects from sea level rise.

[18] The U.S. Army Corps of Engineers website indicates the 100-year flood estimate to be 10.6' above MLLW (U.S. Army Corps of Engineers 2010b).

[19] The 2006 Master Plan stated that the community would need to be raised to a height of 16.5' because of storm surges.

Water levels at the Singuak Entrance are determined principally by storm surges and to a lesser extent by tides. A 1999 report by Triton Consultants Ltd. found that typical annual surge levels are driven by winds (3') and tides (0.5') (U.S. Army Corps of Engineers 2007a).

The 2008 *Local Hazards Mitigation Plan* includes the following estimates for recurrence of storms: A 4' elevation storm surge can be expected every year, a 6' storm surge can be expected less than every 5 years, and a 16.3' storm surge (above mean sea level) can be expected every 100 years.[20] Prior to 2004, only two storms flooded portions of the village. The estimated water levels in this plan should be reevaluated as a result of the 2009 storm surge estimates by the U.S. Army Corps of Engineers.

Regardless of the 100-year flood estimates, there have only been a few documented instances of flooding in Kivalina. Prior to 2004, only two occurrences of flooding have been reported. The 1970 "storm of record" inundated portions of the community (U.S. Army Corps of Engineers 2006a), and in September 1976 storm resulted in flooding of 20-30% of the community (Wise et al. 1981). In October 2004, waves from a storm overtopped the bank on the ocean side of Kivalina which led to flooding (Kivalina 2009). As mentioned above, flood events in the community are likely a result of wave runup rather than by the height of the storm surge itself.

Sea Level Rise: The degree of sea level rise is an important consideration for Kivalina's community planning because projected rates of rise could affect storm surge predictions and desirability of potential relocation sites. Basic strategies to deal with sea live rise include retreating (e.g., moving structures to higher ground), accommodation (e.g., designing structures to withstand higher water levels), or protection (e.g., beach nourishment, dikes or levies) (Intergovernmental Panel on Climate Change 1990). Without specific local data, the U.S. Army Corps of Engineers (2008) uses the global average of 0.6' rise per hundred years for the historic average for Kivalina. In the Kivalina *Master Plan*, a rise of between 1' and 2' over the next 100 years is predicted (U.S. Army Corps of Engineers 2006a). In a draft memorandum about water levels, the U.S. Army Corps of Engineers (2008) used three sea level rise scenarios from the National Research Council to adjust its the recommended new 100-year estimated storm surge level; with sea level rise factored in, the adjusted estimated storm surge would be between 10.5'and 13.7' by the year 2100. According to the U.S. Army Corps of Engineers (2008), an important implication of sea level rise is increased erosion. It would also be logical to assume, however, that increased erosion will also lead to increased deposition of the sediments elsewhere. Another sea level rise concern is that as low-lying areas of ice-rich permafrost melt, substantial subsidence could occur, and the effect of sea level rise could be amplified.

[20] The Local Hazards Mitigation Plan states that modeling indicates a 100-year storm would have a water surface level of 10.5 feet (p. 30) and that the U.S. Army Corps of Engineers calculates the 100-year storm surge at 16.3 feet above mean sea level (p.32).

3.3 Erosion

Kivalina has been included on priority lists for Alaska communities facing impacts of erosion (GAO 2003 and 2009, U.S. Army Corps of Engineers 2009, and Immediate Action Workgroup 2008 and 2009). During 2009, the U.S. Army Corps of Engineers included Kivalina in its designation of Priority Action Communities for the Alaska Baseline Erosion Assessment.

Barrier islands like the one on which Kivalina is located are dynamic systems. Depending on direction of wave action, sediments are either deposited on the beach or eroded away. While one storm may erode the beach, another storm may build the beach back up. Because of this ever changing process, it is important to know what the net effect is of sediment transport. As discussed in the introduction, a site-specific sediment transport analysis has not been completed for the Kivalina area. The U.S. Army Corps of Engineers (2007a) assumes that the net transport of sediments occurs in a southward direction, but a site-specific analysis may be prudent if additional erosion control is planned for the community. While it has been confirmed that the net sediment transport for the Red Dog Mine Port Site occurs in a southward direction, the net sediment transport for Point Thompson reportedly occurs in a northward direction.

Erosion Events: As described in Section 3.1, natural processes erode Kivalina's beaches, and through a process known as longshore transport, beaches are rebuilt. With later freeze up of the Chukchi Sea, however, fall storms have caused extreme erosion. A single storm in 2004 eroded 40' of beach, including the area in front of the principal's residence. A 2005 storm eroded 70' of beach near the school and removed the beach to within 12'of the airport. During 2006, a storm destroyed an emergency erosion control project one day before its dedication. Serious threats of erosion have occurred on all three sides of the community facing the Chukchi Sea, Singuak Entrance and the lagoon. Erosion has posed immediate threats to buildings, fuel tanks, the airstrip, and electric transmission lines.

Erosion is threatening the Kivalina dump site located north of the airport, and continued erosion could result in an environmental catastrophe where waters used for subsistence are contaminated (IAW 2008). The dump is located at an extremely narrow part of the island, and community members indicate that storms have resulted in flooding of this area.

Erosion Control Efforts: Since 1990, a number of erosion control projects have been completed in Kivalina as summarized in Table 2. Little is known about the specific mechanics of erosive forces and longshore transport of sediments at Kivalina, and as a result, efforts in Kivalina to protect against erosion have a history of trial and error. In 1990, sandbags were placed on the lagoon side of the island to protect against the erosive forces of the Kivalina and Wulik rivers (Mason et al. 1997). Reportedly, this effort failed because the sandbags were not placed high enough against the bank. In response to storms in 2004 and 2005, the Northwest Arctic Borough led an effort to install an emergency erosion control structure in 2006. This gabion-like structure used HESCO bags filled with sand from the area in front of the AVEC fuel tanks and placed in a wired structure. This structure did not even last one season, and in 2007 another emergency response involved placement of one cubic yard "super sacks" provided by the U.S. Army Corps of Engineers.

Table 2: Summary of Erosion Control Efforts in Kivalina

Date	Description
1990	Sandbags placed on the lagoon side of island. The erosion control was not successful because the bags were not placed high enough on the bluff (Mason et al. 1997).
2006	The Northwest Arctic Borough led an effort funded by the Denali Commission to construct a $3 million erosion control barrier using HESCO baskets, a collapsible wire mesh container (gabion) lined with a heavy-duty fabric that is filled with sand and gravel.
September 2006	A storm results in minimal damage to the HESCO basket structure that is repaired.
October 11, 2006	A storm results in severe damage to the HESCO basket structure.
August – November 2007	The Northwest Arctic Borough leads an effort to repair the erosion control structure using one cubic yard "super sacks" provided by the Army Corps of Engineers.
Summer 2008	Phase I of the rock revetment project begins with construction of the initial 400 feet.
Summer 2009	An additional 1,200 feet added to the rock revetment on the ocean side of the community (cost for 2008 – 2009 construction was $12.5 million).
Summer 2010	An additional 400' of rock revetment is planned for construction on the ocean side of the island towards the airport at a cost of $3.5 million.

Source: City of Kivalina 2009, Immediate Action Workgroup (2009), Mason et al. (1997).

In 2008, the Corps began a multi-year project that involved placement of a rock revetment around the community, beginning on the Chukchi Sea shoreline. The revetment was designed to a height of 14' to minimize overtopping from wave setup and wave run-up. The Corps estimates the life of the new revetment to be 15 years or longer if it is maintained on a regular basis. A second phase to the Corps project is planned to continue the rock revetment around the lagoon side of the island. Erosion of this side of the island is occurring at a slow but steady rate (U.S. Army Corps of Engineers 2007b).

In addition to the listed projects in Table 2, the Alaska Department of Transportation and Public Facilities (DOTPF) plans to repair eroded areas on the ocean side of airport using funds from FEMA. Due to higher estimates for this work, DOTPF is working with FEMA to secure additional funding (Immediate Action Workgroup 2009). At the time this report was completed, adequate funding for the airport revetment had not been secured.

Coastal engineers generally use hard structures like revetments as a measure of last resort. International design practices for response to natural hazards prioritize actions as follows:

- Retreat or migrate away from the threat,

- Modify structures to avoid damage from high water and storms, and
- Protect using non-intrusive methods such as beach nourishment or as a last resort, "hard structures" such as seawalls or revetments (Intergovernmental Panel on Climate Change 1990).

More information about the coastal processes around Kivalina is needed to help the community plan for future protection from storms. For example, it may be prudent to investigate the effectiveness of beach nourishment and groins (jetties) to ensure the rock revetment is not undermined by future storms. Beach nourishment could be accomplished by dredging materials from offshore areas or possibly using sediments in the lagoon.

Efforts to reestablish beach grass may also impede future erosion. Beach grass stabilizes the ground and may be the major reason the island has not washed away (Alaska Department of Transportation and Public Facilities 1984).

Aerial Photo Analyses: Comparisons of aerial photographs have been used to get a better understanding of how sediments are eroded from or deposited to the beaches on Kivalina's island. While this technique can provide some useful information, it should not be used to predict rates of erosion because beach processes are cyclic and episodic. Aerial photographs record single points in time without providing information about what has occurred during the period between photographs. There appears to be general agreement that storms are increasing in severity due to later freeze up, but there is not a consensus about the long-term patterns of erosion and deposition of sediments. A comparison of aerial photos from 1952 through the early 1990s found that there was not conclusive proof that there was excessive erosion on the Chukchi Sea side of the island, but there was substantial erosion on the lagoon side of the island near Singuak Entrance (DOWL Engineers 1994). A comparison of aerial photos taken in 1954 and 2003 states that accretion patterns "may indicate that this portion of the coast is in the process of normal erosion associated with offshore transport of materials with a net loss of area due to erosion. This may or may not be considered significant erosion from 1952 to 2003" (NOAA 2004, p.2). The comparison by NOAA of aerial photos resulted in the following findings:

- **Net Erosion:** Between the two periods there was a net loss of 19 acres with an average loss of 10-35' on the Chukchi Sea coast (27 acres lost on the Chukchi Sea side, and 8 acres accreted within Kivalina Lagoon).
- **Chukchi Sea Shoreline:** Comparing the 1952 and 2003 aerial photos, 13.8 miles of the Chukchi Sea shoreline eroded while 7.6 miles have accreted. A net area of 27 acres was eroded (76 acres eroded and 49 acres accreted). Maximum erosion at a single location was 200 feet and maximum accretion was 100 feet.
- **Lagoon Shoreline:** There has been a net gain of 11 acres on the Kivalina Lagoon side of the island (11 acres of accretion and 3 acres of erosion).

- **Entrances:** The northern channel near the Kivalina River has migrated about 625 feet to the south. The south lagoon was not connected to the sea in either 1952 or 2003.

A comparison of aerial photos beginning in the 1980s found that there was a loss of beach from the Singuak Entrance to the airport undercutting the vegetative mat on the Chukchi Sea side of the island (U.S. Army Corps of Engineers 2006a).

A 2007 comparison of aerial photographs from 1966, 1997, 2000, and 2007 included the following observations (Combellick 2007).

- Between 1966 and 2000, there was no measurable erosion of the vegetated backshore, but there was evidence of erosion on the older, vegetated crest along the northern one-third of the town and part of the airstrip.
- "The irregular character of the berm in 1966 suggests it has undergone, and possibly still undergoing, thermal erosion of frozen soil." Subsequent aerial photographs show that the beach has accreted and that the berm became vegetated.
- The 2007 aerial photographs showed that portions of the vegetated berm along the southern one-third of town had receded several feet. They also showed erosion has taken place along the southern one-third of town on the lagoon side probably resulting from flow from the Wulik and Kivalina rivers.
- The Singauk Entrance to the lagoon migrates back and forth over time, and it closes periodically. In 1997, it was located considerably further south of where it was located in 2007.
- In 1997, the spit near the entrance extended about 1,200 feet, but by 2000 half of it had eroded, and it completely disappeared by 2007. The beach at the southern end of the island accreted by 200-300 feet by 2007.

Additional erosion analyses may be needed for Kivalina to determine what further responses are needed. Such analyses would be especially needed if the relocation efforts are delayed.

Effects of Human Alterations to the Coast: In addition to natural processes and climate change, any man-made change to the coastal area has the potential to increase erosion or accretion of sediments along the coast. Because the site-specific coastal processes determine how human activities affect beach erosion or accretion, it is important to understand the coastal dynamics of Kivalina. Examples of potential effects of humans in the area around Kivalina are discussed in the following bullets.

- Borrowing of sand from the Kivalina beach has been implicated with causing increased erosion (City of Kivalina 2009). A report by the Alaska Department of Transportation and Public Facilities (1984) warned that mining of beach sand would exacerbate erosion and that no obstructions should be placed on the beach because they would cause scouring from turbulence.

- ATVs, foot traffic and dogs have destabilized some of the beach grass which has resulted in erosion (Alaska Department of Transportation and Public Facilities 1984).
- The sand-filled HESCO baskets constructed in Kivalina during 2006 as an immediate response has been implicated with increasing the severity of erosion because sand and gravel for filling the baskets was taken from the beach in front of the AVEC tanks and from the area in front of the airport (Kivalina 2009). The failure of these baskets is thought to have accelerated erosion (U.S. Army Corps of Engineers 2007a).
- In the environmental assessment for the recently constructed rock revetment along the Kivalina beach, the Corps recognized that potential effects of disruption of longshore drift are poorly understood, and that the project could affect transport of sediments and changes to the morphology (structure and form) of Singuak Entrance (U.S. Army Corps of Engineers 2007a). The report speculates that Singuak Entrance could move towards Kivalina.[21] There would be fewer sediments moving south because of expected "accretion on the up current side of the structure and erosion on the down current side of the structure" (p. 19). Several states discourage or prohibit the use of rock revetments because of the impacts they have to coastal processes.
- The Red Dog Mine port site dock provides a local example of how a manmade structure can affect longshore drift. Sediments are deposited on the north side of the dock to such an extent that the mine operator has secured a permit for periodic movement of the deposits to the south side of the dock (U.S. Army Corps of Engineers 2007a).

3.4 Riverine Flooding

The 2008 *Local Hazards Mitigation Plan* does not describe flooding hazards from the Wulik or Kivalina Rivers (City of Kivalina 2008). A low-lying area on the northeast part of town between housing and the airstrip, however, is subject to periodic flooding. A study found that the risks of flooding to the Igrugaivik and Kiniktuuraq relocation sites would be more influenced from flooding of the lagoon from a storm surge than by flooding from the Wulik River (DOWL Engineers 1994).

3.5 Permafrost Melting

Melting permafrost is a growing concern across the Arctic, and Kivalina residents are experiencing local impacts. Continuous permafrost occurs throughout Northwest Alaska, but in recent years, residents have reported instances of coastal erosion, sink holes, melting ice cellars, and shallow water depths when digging holes. Permafrost melting has implications for Kivalina

[21] During May 2010, the entrance was located directly against the southern part of the town, and the banks directly below one of the houses were failing.

because it may affect coastal erosion, drinking water quality, subsistence access in the rivers, the ability to store food in ice cellars, and the feasibility of relocating to some proposed sites.

Melting permafrost on Kivalina's island has been occurring to some degree for many decades. A 2007 investigation of aerial photographs found that "[t]he irregular character of the berm in 1966 suggests it has undergone, and possibly still undergoing, thermal erosion of frozen soil" (Combellick 2007). One potential positive effect of permafrost melting in Northwest Alaska may be an increase in the availability of sediment that may be deposited on beaches as the result of long distance transport of sediments from eroding bluffs and stream banks (Smith 2009, personal communication).

Interviews with Kivalina residents for this project revealed that melting permafrost has resulted in eroding stream banks and slumping up the Wulik River. Residents are concerned that increased levels of silt could affect the drinking water supply or block access to upriver subsistence uses. During the January 2010 workshop associated with this project, residents said melting permafrost has resulted in a higher water table that presents problems at the cemetery located north of the airport. Although it uses a different system to obtain drinking water, warming water temperatures may be the cause of increased maintenance costs for Point Hope's lake-based water system due to a substantial increase in algae (Brubaker et al. 2009).

During the interviews, community members indicated that ice cellars across Singuak Channel have shown signs of melting and in some cases are filled with water. Because Kivalina is a whaling community, reduced capacity of ice cellars could lead to spoilage of meat when a bowhead whale is harvested. Brubaker et al. (2009) reported similar melting of ice cellars in Point Hope.

In regard to community relocation, melting permafrost has been a major factor when evaluating options. Concerns about future permafrost melting have been raised for many of the proposed relocation sites because of ice-rich permafrost soils. Findings from the 2006 *Master Plan* recommended against further consideration of a number of sites because of the potential for these soils to collapse when melted. The plan proposed a 9' gravel fill for some of the sites to insulate the permafrost (U.S. Army Corps of Engineers 2006a). A recent study, however, modeled permafrost dynamics at the proposed Kiniktuuraq relocation site and found that gravel fill would not prevent permafrost melting (University of Alaska 2008). The model involved simulations for 3 different thicknesses of gravel pads (6, 9 and 12 feet) as well as a scenario for a one-foot gravel cap placed on fine-grained fill. Based on the soil characterization from a 2002 report by R&M Consultants, the study evaluated two climate scenarios where mean annual air temperatures increased 4° C by the end of the century (1st scenario) and by 2°C by the end of the century (2nd scenario). The author makes a number of conclusions using information from the simulations of the model.

- Surface subsidence will occur when permafrost melts down to the ice-bearing horizon which is located 0.4-1.0 meter deep.
- Without any fill, the model predicts thawing up to 1.5 meters by 2030 under the 1st scenario (4°C rise) but the thawing would not penetrate the ice-bearing permafrost layer under the 2nd scenario (2°C rise). [22]
- Different thicknesses of gravel fill may delay but would not stop thawing of the ice-rich permafrost layer. Under a rapid increase of air temperature (1st scenario), the ice-rich permafrost layer would melt completely. Under a more moderate increase of air temperature (2nd scenario), the thickness of the gravel pad would likely affect whether the ice-rich permafrost layer thawed completely or partially by 2050.
- Removal of significant snow accumulations from the gravel fills would help delay melting of the permafrost soils.
- Soil subsidence would occur when permafrost melts down to the ice-bearing horizon.

While the potential for permafrost melting is a concern in most of the potential relocation sites, it is less of a problem at the Kivalina townsite. Melting permafrost has not been identified as a much of a concern in Kivalina. The barrier island where the community is located is composed of mostly sand with a low moisture content which does not settle much when the permafrost melts. A 1984 report on the proposed realignment of the airport stated that core samples under the project area encountered permafrost, but the report found that settling due to melting permafrost would be minor "because it was present in sand with relatively low moisture content . . ." (Alaska Department of Transportation and Public Facilities 1984).

The depth of permafrost in Kivalina may vary depending on the specific location, and it appears to have changed over time. ASCG (2005) reports that permafrost begins 4'to 18' below the surface and continues to a depth of 600 feet. A well drilled near the school encountered permafrost from 6'-167' (Golder Associates 1997). Some of the residents interviewed for the Kivalina Consensus Building Project said there used to be shallow permafrost under the community, but that now salt water is found when digging holes. Several people interviewed believe the roads in the community are sinking because of melting permafrost, and one person noted that some areas of the school building are settling because of thawing soils.

3.6 Ice hazards

Ice hazards facing Kivalina include sea ice run up onshore (ice override), ice break up in the lagoon, and changing ice conditions that are affecting subsistence use patterns. The Hazard *Mitigation Plan* (City of Kivalina 2005) does not specifically mention ice hazards for Kivalina, but the community profile (Alaska Division of Community and Regional Affairs (2009) cites severe wind-driven ice damage and erosion as primary reasons for relocating the community.

[22] The ice-bearing permafrost layer in the soil at Kiniktuuraq is located between a depth of 1.3' and 3.28'. The models predict the natural peat layer would provide better insulation than gravel fill.

Mason et al. (1997) also mention ice hazard risks for Kivalina including breakup of the ice cover in the lagoon. Ice override hazards were briefly mentioned for the Kiniktuuraq site (U.S. Army Corps of Engineers 2006a).

During an ice override event, also known as an ivu to the Iñupiaq people, ice is pushed onshore from offshore winds. While there here have been no recent occurrences of ivus in Kivalina, elders contacted during this project indicated that there have been ivus in front of the community in the past and large ivus just south of the community on the other side of Singuak Entrance. Generally, ice ridges form offshore of Kivalina rather than coming ashore. According to traditional knowledge on the North Slope, ivus can occur without warning at any time ice is present (North Slope Borough 2007). Ivus have occurred in Northern and Northwest Alaska over the years. In Nome, a 1974 ivu reached a height of 30 – 40 feet, and a 1980 event reached a height of 20 – 25 feet (Michaels 2006). A 1989 ivu in Barrow advanced 100 feet onshore causing $500,000 in damage, and in 2006, two 20' high ivus occurred two miles apart in Barrow (North Slope Borough 2007). Additional scientific research and local and traditional knowledge is needed to determine the risk from ivus for Kivalina.

In addition to ocean ice hazards, ice break up in the lagoon may also occur when storm surges raise the level of the lagoon and break up the ice (Mason et al. 1997). In the past, this kind of hazard has affected the ability for residents to access the mainland which could be important if an emergency evacuation was necessary.

Changing ice conditions provide new challenges for Kivalina residents. Community interviews conducted by Braund and Associates (2005) documented impacts to subsistence use as well as increased hazards from thinning sea ice:

- A shorter season for hunting Ugruk (bearded seals) as they migrate north with the sea ice,
- Earlier arrival of bowhead and beluga whales,
- Subsistence users must travel further to obtain resources because the ice is not thick enough near the village,
- Dangerous ice conditions inhibit subsistence use south of the community and impede access to open leads,
- Fewer walrus migrate near the community than in the past, and
- Ice conditions and a greater number of leads affect the availability of marine mammals (e.g., bowhead whales are migrating further from shore).

While subsistence users must travel further to obtain some subsistence species, open leads closer to the community provide new opportunities for hunting nachiq (ringed seals). During January 2010, an unusually early lead opened up in front of the community allowing subsistence users to hunt for natchiq in front of the community earlier than usual.

Ice can also be a dampening force for the impacts from storm surges on the community. While solid ice can reduce the effects of storm surges, Unalakleet residents attributed slush conditions to a reduction in wave damage from a 2009 fall storm (Anchorage Daily News 2009).

3.7 Other Potential Impacts from Climate Change

Other potential long-term impacts from climate change to Kivalina include sea level rise and ocean acidification. Sea level rise is a long-term concern for Kivalina because the highest point in the community is 12 feet above MHW. The Intergovernmental Panel on Climate Change (2007) reports that models indicate that by the end of the century, global sea level could rise will rise between 0.18-0.59 meters (7.08"-23.2"). Sea level rise occurs from warming temperatures which results in melting of ice and expansion of water molecules in the ocean. While melting glaciers in Alaska have contributed to sea level rise, melting ice in Greenland and Antarctica have the greatest potential to affect future sea level rise.

Ocean acidification is another growing concern in the Arctic. Ocean acidification occurs as a result of increasing concentrations of carbon dioxide in the atmosphere which are absorbed by the ocean. Acidification of the ocean is expected to affect the ability of corals and mollusks to make shells and skeletons (NOAA 2006). Acidification may also have an indirect effect on fish and marine mammals through a reduced availability of some foods. Ocean acidification in Alaska waters is thought to be more severe and occurring more rapidly than in tropical waters (University of Alaska 2009).

3.8 Information Needs and Opportunities

While there is a lot of information about natural hazards and climate change in Western Alaska, Kivalina may need additional information before it finalizes a plan of action for its next steps. The community may wish to take a strategic approach to identify what information it needs and who would be best suited to provide that information. The remainder of this section Provides some ideas the community may wish to consider.

- **Traditional Knowledge:** A community inquiry about local and traditional knowledge would provide more information about natural hazards and local ocean processes. This information could be used to validate assumptions related to relocation decisions.
- **Coastal Engineering Study:** A site-specific study about sediment transport processes around Kivalina and other potential relocation sites may be useful when making future decisions. A "sediment budget" would identify the source of sediments that rebuild beaches. Current assumptions that the net sediment transport occurs in a southward direction need to be confirmed. This study should be completed by a coastal engineer with experience in Alaska.
- **Future Alternatives:** Coastal engineers generally prefer "soft" erosion control techniques such as beach nourishment, using revetments as a last measure. It may be

prudent to investigate the feasibility of beach nourishment projects and groins (jetties) that would complement the rock revetment. Restoration of grasses along the beach north of the revetments may also be a low-cost option to reduce coastal erosion.

- **Local Hazard Mitigation Plan:** When updating the *Local Hazards Mitigation Plan*, information should be added about the reduction of risks from the rock revetment and the new 100-year storm surge estimate.
- **Geohazard Evaluation:** The 2009 State of Alaska *Coastal Impact Assistance Plan* includes funding for a project called Geohazard Evaluation and Geologic Mapping for Coastal Communities (State of Alaska 2009). The project is expected to begin in Kivalina during the summer of 2010 and may be expanded to other communities. According to the Immediate Action Workgroup (2009), this project will identify areas acceptable for an evacuation road and for community relocation. Kivalina may wish to work closely with the Division of Geological and Geophysical Surveys to ensure the project meets community needs.
- **LIDAR:** During 2008, NOAA prepared a detailed survey of the area using LIDAR technology. LIDAR is a remote sensing technique that characterizes land surfaces. This data may be useful in evaluating future relocation efforts.
- **Health Impact Analysis:** The Alaska Native Tribal Health Consortium is completing a health impact assessment that will evaluate climate change-related impacts.
- **Dump Site:** In response to environmental threats from erosion and flooding, Kivalina may wish to investigate funding sources for managing the current dump site. Management measures may include purchase of a burn box, compaction, containment of refuse, hiring staff to oversee operations, implementation of a collection system, and options for containing human wastes at the disposal site. A survey of other coastal communities in Western Alaska would indicate what practices have been successful.
- **New Landfill:** The current dump site appears to have reached its capacity, and Kivalina may wish to begin planning for its replacement. Future studies on evacuation roads or relocation sites could include investigations into alternatives for disposal of solid waste and human waste.
- **Third-Party Review:** The community has requested a third-party review of Corps studies. The State of Alaska Immediate Action Workgroup included a recommendation for such a review in its April 2008 final report to the Governor’s Subcabinet on Climate Change. If this review is not undertaken by the state, the City of Kivalina may wish to seek funding for such a review.
- **Science Advisory Committee:** The community may wish to pursue establishment of a Science Advisory Committee to review reports on an as-needed basis. Many organizations, including the North Slope Borough, use such committees to review findings of studies and reports.

4. Evacuation and Emergency Planning

This section addresses evacuation planning which includes development of plans for evacuating the community in the event of a storm or other disaster. It summarizes efforts by Kivalina for emergency planning and evacuation. It concludes with a section outlining information needs and opportunities.

The Immediate Action Workgroup (IAW) of the Governor's Climate Change Subcabinet identified immediate needs for Kivalina for emergency planning including an update to the Community Evacuation Plan and completion of an Emergency Operations Plan and Training (IAW 2008, 2009). The City of Kivalina is working with the Alaska Division of Homeland Security and Emergency Management and a private consultant. Although drafts of these plans were not available for incorporation into this report, the plans are expected to be finalized in 2010.

The current evacuation plan, completed in 2005, directs residents to assemble in the school during an emergency, but there is concern that this facility could sustain damage from a large storm surge (ASCG 2005).

The experience of the 2007 evacuation of the community will be useful when completing these plans. On September 12, 2007, the Northwest Arctic Borough initiated a voluntary evacuation of Kivalina as a result of a severe storm predicted by the National Weather Service (Kivalina 2009). A house-to-house visit was completed to alert residents about the voluntary evacuation. Ninety people were flown to Kotzebue, 131 people were transported to the Red Dog Mine Port Site and 86 remained in the village. The evacuation to the port site involved use of boats to transport ATVs across Singuak Entrance channel and then transport of residents, including women and children by ATV to the Port Site. The residents returned to Kivalina two days later. While no one was hurt during the evacuation, there were potential threats to human safety, including transport of people and ATVs across the Singuak Entrance. According to the GAO (2009), villagers reported that the evacuation was so dangerous that it should never be attempted again.

4.1 Information Needs

In addition to the two emergency planning documents currently being completed (Community Evacuation Plan and Emergency Operations Plan), an update to the 2008 *Hazards Mitigation Plan* approved is needed. As discussed earlier in this document, an update to the *Hazards Mitigation Plan* could provide useful information for evacuation planning, including an analysis of how risks from natural hazards may be affected by the lower 100-year flood estimate and construction of the rock revetment.

5. Evacuation Road and Shelter

The lack of progress in relocating the community has led to an increased interest in exploring options for an evacuation road and shelter. Table 3 summarizes efforts to evaluate the feasibility of constructing an evacuation road including two reports that were completed in 2005 and 2008. The most recent report estimated costs for the evacuation routes to be between $20.3 and $38.9 million, and it recommended the project not be pursed further until a significant portion of the funding is obtained.

Table 3: Summary of Efforts to Design and Construct an Evacuation Road

Date	Description
August 2005	On August 23, the Northwest Arctic Borough Assembly passed Resolution 05-51 that authorizes ASCG, Inc. to complete a feasibility study for an evacuation road.
October 2005	ASCG Inc. submitted an evacuation road feasibility study to the Northwest Arctic Borough that considered 8 alternatives
June 2007	Agreement reached between the Denali Commission and Western Federal Lands Highway Division to complete preliminary engineering for an evacuation road.
February 2008	Western Federal Lands Highway Division completes a feasibility study on two routes: One across the lagoon and the other across Singuak Entrance towards Kiniktuuraq. It recommends no further work on these routes until a significant portion of the funding is obtained.

Source: ASCG Inc. 2005, Western Federal Lands Highway Division 2008

Almost all of the community residents interviewed during the door-to-door survey for this project recommended construction of an evacuation route (Gray 2009). Most people recommended a route across the lagoon, some preferred a route across Singuak Channel and some recommended a bridge across Singuak Entrance. Many people didn't express a preference for a specific route as long as it led to a safe place. Some of those who preferred a route across the lagoon thought other routes along the coast would be dangerous during a storm. Some of the people who supported a route across the lagoon supported this option because it was the most direct route inland. Problems that occurred during the 2007 community evacuation highlight the need for more reliable options for future evacuations that may be needed in response to major storms. In addition to providing an escape route, an evacuation route could provide access to a new dump facility, a corridor for water lines and possibly, a route to a new community site.

The remainder of this section describes options for an evacuation route and shelter and needs for additional information.

5.1 Evacuation Routes

The two studies on evacuation road options are discussed below. The most recent study, completed in 2008, recommended that future efforts to construct an evacuation route be put on hold until substantial funding for the entire project is secured. This study estimated costs for a route across the lagoon to be $20.3 million and a road south through Kiniktuuraq to be $38.9 million.

ASCG Inc. 2005 Report: The Northwest Arctic Borough contracted with ASCG Inc. in 2005 to produce a feasibility study for an evacuation road. ASCG evaluated eight alternatives using the following criteria: Routes must lead to an elevation of 25', potential other uses for the route, maintenance requirements, land ownership, and environmental concerns. The report recommended construction of a 24' wide gravel road using national and state design standards for a road that could support a semi-trailer for use in relocating the village.

Of the eight alternatives evaluated, ASCG selected Alternative 6 as the preferred option. This route begins in the center of Kivalina and crosses the lagoon using a 0.5-mile earthen causeway and a 60' long bridge. It would continue across the tundra 3.6 miles terminating at the Simik village relocation site. The cost for this route in 2005 dollars was estimated to be $21.3 million. The environmental analysis in the document states that a causeway will be less expensive than a long bridge, but there may be concerns raised about damage to fish habitat and effects to sediment transport.

Western Highways 2008 Report: This project resulted from an agreement between the Denali Commission and the Western Federal Lands Highway Division for preparation of preliminary engineering for an evacuation road from Kivalina. This study considered the two most supported routes that were studied by ASGC Inc. in 2005: A Kiniktuuraq alignment ($38,881,000) and the Simiq alignment ($20,265,000). The Division recommended that the project not be pursed further until a significant portion of the funding is obtained. Further, it warns that Title 23 funds would have to be repaid if a project was started but not finished.

The Kiniktuuraq alignment would involve a bridge across Singuak Entrance with a road through Kiniktuuraq with termination of the road 3 miles south. The Simik alignment would involve a causeway across the lagoon with a road terminating at Simik 3.5 miles to the east.

Both options included a road to a potential material source (rock) at Kisimiguktuk Hill. Cost estimates were made for both a 24' and 14' roadway width with additional criteria. Both routes terminated at an elevation of 25', incorporated rock armoring in the coastal areas to protect against erosion and recommended use of deep foundations for bridges to withstand scour, high winds and waves.

Additional Benefits of an Evacuation Road: In addition to providing a means of escape from a hazardous storm, an evacuation route has a number of other potential benefits.

- An evacuation shelter could be built in association with the road.

- A route across the Lagoon or towards Kiniktuuraq would provide access to a new dump or land fill.
- A route across the lagoon would provide a route for running waterlines from the Wulik River.
- A route across the lagoon would provide access to Wulik River sandbars which could provide a low-cost source of fill. This fill could be used to expand the village by constructing an island adjacent to the causeway or to provide beach nourishment on the ocean side of Kivalina.

5.2 Evacuation Shelter

Neither of the two evacuation road studies addressed construction of an evacuation shelter. The door-to-door survey conducted in association with the Kivalina Consensus Building Project revealed a high degree of consensus for an evacuation road and varying opinions regarding construction of an evacuation shelter (Gray 2009). Some people thought an evacuation road to higher ground where tents could be erected would be sufficient. Others said that not everyone in the community has camping gear, and a shelter would be especially needed for elders and young people. Residents interviewed offered the following suggestions.

- A large shelter should be constructed that would house everyone in the village.
- Army-style Quonset huts would be sufficient.
- The shelter could be combined with a museum.
- A Conex with provisions should be provided at the evacuation site.

5.3 Information Needs

Depending on the direction Kivalina wish to take, one or more of the following options for future investigations may be taken.

- **Materials Cost:** In November 2009, NANA Development Corp. received concurrence for its coastal management consistency certification a quarry located miles 12 miles northwest of Kivalina. An inquiry may be useful to determine if this local source of materials would reduce the cost estimates in the 2006 *Master Plan*.
- **Bearing Capacity of Lagoon Soils:** If Kivalina wishes to consider the possibility of an evacuation route across the lagoon, additional field investigations will be needed to confirm the bearing capacity of the soils below the lagoon.
- **Circulation Patterns:** Construction of a causeway across the lagoon or a bridge toward Kiniktuuraq could affect circulation patterns of the water. If these concerns are raised, it may be necessary to develop a water circulation model to predict effects.
- **Evacuation Shelter:** Neither of the two studies on evacuation roads analyzed alternatives for construction of an evacuation shelter.

- **Evacuation Shelter in Kivalina:** If there is a possibility Kivalina will remain in the current location for an extended period, it may be advisable to investigate the feasibility of building an emergency shelter in the community. A shelter could be combined with a new school or a multi-purpose community building.
- **Evacuation Road Assumptions:** The most recent estimates for evacuation routes are $20.3 million for a route across the lagoon and $38.9 million for a route across Singuak Entrance (Western Federal Lands Highway Division 2008). The Western Federal Lands Highway Division recommended that project not be pursed further until a significant portion of the funding is obtained. It may be advisable to investigate if other evacuation options would reduce costs, such as a causeway and bridge across the lagoon with an ATV trail to higher ground or a bridge across Singuak Entrance with an ATV trail to a shelter at higher ground.

6. Options to Relocate or Remain at the Current Site

Concerns about natural hazards have troubled Kivalina since its inception. During the 1950s, the community again discussed options for relocation, and a renewed interest in relocation was discussed during the 1990s. Government agencies have produced many studies that investigated options for remaining at the current site or moving to 12 other potential relocation sites. Agencies conducted major studies for potential relocation sites in 1994, 1998 and 2006. Table 4 summarizes the findings of these studies.

Residents of Kivalina have responded to the threats or erosion by considering relocation of the community as early as 1911, 6 years after the community was founded (Replogle 1911). Since then, the community has held 5 elections about relocation options (City of Kivalina 2009).

- **1953 Election:** The community was split with half the community wanting to move and half wanting to remain.
- **1992 Election:** Sixty-five of 72 voters in a 1992 election chose to move the community.
- **1998 Election:** A majority of voters selected Igrugaivik, a site southeast of Kivalina on the Wulik River.[23]
- **2000 Election:** As a result of studies by the Corps that found Igrugaivik unsuitable for a townsite because of large quantities of ice in the soils, a special election was held during April 2000 where a majority of voters selected Kiniktuuraq, a coastal site located just south of the current community.[24]
- **2001 Election:** Another special election was held in November 2001 where the community chose a layout for the new community.[25] The 2006 *Master Plan* for the

[23] The 1998 election resulted in 85 votes to move to Igrugaivik, 25 votes to move to Imnaaquq on the Kivalina River, and 19 votes to remain at the current location.
[24] The 2000 election resulted in 53 votes for Kiniktuuraq, 32 votes for Imnaaquq, 8 votes for Igrugaivik, and 6 votes to remain at the current site.
[25] The 2001 election resulted in 47 votes for the selected layout and 32 votes for an alternative layout.

Kivalina relocation, however, found that the Kiniktuuraq site was unsuitable because of risks from natural hazards (U.S. Army Corps of Engineers 2006a).

The lack of progress towards relocation has taken a toll on the community, and many people have expressed a sense of hopelessness.

The remainder of this section begins with an overview of the relocation studies followed by a more detailed discussion of the proposed Kiniktuuraq site and options for remaining at the current site. This section concludes with a discussion of information needs and opportunities.

6.1 General Overview of Studies

There are many studies and reports about options to remain in the community or move to a new location. DOWL Engineers completed the first major study for the community 1994. The U.S. Army Corps of Engineers completed two other studies in 1998 and 2006. Table 4 summarizes the major findings of these three reports. In addition to these major studies, many additional reports have been completed about natural hazards, storm surge estimates, water source investigations, and geotechnical investigations.

1994 Study: DOWL Engineers evaluated 11 future options for the community including two options for remaining in the community, a bridge across Singuak Entrance, and an investigation into the feasibility of 8 potential relocation sites selected by the community. Kuugruaq received the highest score, but during a 1993 flood, half the site was flooded. A Native allotment presented land ownership problems at the site and with access to a gravel site. Igrugaivik received the second highest ranking. Other findings from the DOWL study are summarized below.

- Many of the community's structures could be moved, but major infrastructure buildings could not be moved.
- The size of the new community should be at least 60 acres.
- The existing townsite would remain in current ownership, but some reclamation of the site would be necessary. The sewage disposal site, dump site and fuel storage areas would need further evaluation before abandonment. The dump site could be reclaimed by covering it with soil after confirming no hazardous materials are present.

1998 Study: This Corps study evaluated 2 potential relocation sites and the option of remaining at the current site. Options for remaining at the current site are discussed in Section 6.3. The appendices include a groundwater source investigation, Wulik River flood risk analysis, water supply alternatives at the relocation sites, wastewater options at the sites, community layout alternatives, an implementation plan, and a summary of a model Native village in Quebec.

Table 4: Results of Studies Evaluating Options for Kivalina's Future

Site	1994 DOWL Study	1998 ACOE Report	2006 Master Plan
Kivalina	Two options considered: Move airport and fill lagoon. Good subsistence access. Storm surge risk. Economical option. Middle range score.	Investigated option of expanding the community to part of the airstrip and filling a small part of the lagoon adjacent to the community. The airstrip would be moved 607' north.	Recommended no further consideration because of high risks of erosion. This option would require gravel fill to a level of 15.5' and other improvements. Cost: $196.2 million.
Kiniktuuraq	Build bridge to south. Storm surge risk. Good subsistence access. Above average for funding sources. Middle range score.	Not studied	Recommended no further consideration – subject to flooding, erosion and melting permafrost. Good subsistence access. Community-preferred relocation site. Cost: $248.2 million.
Tachim Isua	Not studied	Not studied	Recommended further investigation. Out of flood plain. Some problems with subsistence access. Limited fill needed for low areas. Cost: $154.9 million.
Imnakuk Bluff	Not studied	Poor subsistence access. Residents reported that winter winds made this site undesirable. Report discusses options for transportation and utilities.	Recommended further investigation because of no known flooding or erosion. Severe winds reported. Poor subsistence access. 9' pad needed. Cost: $248.7 million.
Simiq	Not studied	Not studied	Recommended against further consideration because of unstable ice-rich permafrost soils. Gravel fill would need to be placed to a height of 9'. Cost: $251.5 million.
Igrugaivik	Some risk of storm surge flooding. Good subsistence access. Poor soils. High cost. 2nd highest score.	Recommended this site - confirmed by a community vote. New information showed substantial part of site above 100-year flood. Ice-rich permafrost soils.	Recommended against further consideration because of ice-rich permafrost. A 9' gravel pad would be needed. Cost: $246.1 million.
Kuugruaq	Low storm surge risk. Good soil. Land ownership problems. Good	Not studied	Recommended against further consideration because of ice-rich permafrost and flooding.

Site	1994 DOWL Study	1998 ACOE Report	2006 Master Plan
	subsistence access. Average cost. Highest score and community's preferred option. In 1993, ½ of site was flooded.		9' gravel pad needed. Land ownership issues would need to be resolved. Cost: $245.6 million.
Imnaaqquaq	No risk of storm surge. Poor subsistence access. Expensive option. Middle range score	Not studied	Not studied
Sivutchiaq	No risk of storm surge. Poor subsistence access. Expensive option. 3rd lowest score.	Not studied	Not studied
Ikpikrauq	Storm surge risk. Good subsistence access. Expensive option. Lowest score.	Not studied	Not studied
Sivu	No storm surge risk. Poor subsistence access. Costly option. 4th lowest score.	Not studied	Not studied
Kirjiktuuraq	Storm surge risk. Good subsistence access. Higher than average cost. Middle range score.	Not studied	Not studied
Ushaq	Some storm surge risk. Poor soil. Higher than average cost. 2nd lowest score.	Not studied	Not studied

Sources: DOWL 1994, U.S. Army Corps of Engineers 2006a and 1998

The Imnakuk site is located 8 miles north of the current village on the Kivalina River. The report discusses community layout, water supply, wastewater disposal, and a road to the coast. A short road would be constructed to the Kivalina River which would provide boat access upriver. Residents reported that winter winds from the north make this site undesirable.

The Igrugaivik site is located east of the existing townsite on the Wulik River. The report discusses risks of flood and erosion, water supply, waste disposal, community layout, and a road to the coast. The community selected this site as their preferred option in a 1998 election. Surveys for this project helped create more accurate topographic maps that were not available for the 1994 DOWL Engineering report, and it was concluded that a substantial portion of the site would be above the 100-year flood. The report found that the 100 year storm surge in the lagoon would have a greater effect on the site than flooding from the Wulik River flooding. The study recommended buildings be set back at least 100' from the river due to erosion concerns, and it notes that silty ice-rich permafrost lies below a shallow layer of peat.

2006 Master Plan: This document provides preliminary facility designs, costs, a schedule and a decision matrix for the relocation of Kivalina. It compares 8 alternatives including the no action alternative, remaining at the existing site and relocation to 6 different sites. The *Master Plan* found that all sites would be technically feasible, but it recommends against further consideration of all options other than Tachim Isua and Imnakuk Bluffs. The appendices include detailed information about relocation costs, proposed schedules, geotechnical reports, a site development plan, and a community layout design selected by Kivalina in 2001.

The *Master Plan* involved evaluation of potential relocation sites using 31 siting criteria. These criteria included risks from natural hazards, suitability of soils, and access to subsistence resources. The cost estimates for moving the community were based on a number of assumptions including the need for gravel pads, use of gravel roads rather than boardwalks, community wide distribution systems for water, and community-wide sewer systems.

The sites recommended by the *Master Plan* for further consideration are not supported by the community. These sites are undesirable to the community because they are too far from the coast, would disrupt subsistence activities and make supply delivery difficult (GAO 2009).

Due to challenges with all of the options considered in this study, the *Master Plan* states that it may be appropriate to consider additional sites, including a higher rocky area behind the Simik site and a location that could access both the Wulik River and the Red Dog road system.

2006 Revised Cost Estimates: The Alaska Village Erosion Technical Assistance Program estimated the cost of relocating Kivalina to be $95 - $125 million, the cost of future erosion protection to be $15 million and that the community has 10-15 years left at its current site (U.S. Army Corps of Engineers 2006b, p.25). This cost estimate for relocation is significantly less than the $154.9 - $251.5 million estimates in the 2006 *Master Plan*.

New Information: Since completion of the 2006 *Master Plan*, the Corps began construction of a rock revetment around the community. The GAO (2009) found this erosion control project could slow the progress toward relocation because of a false sense of security.

Opportunities: Relocation to a new community would provide new opportunities to make improvements to housing and energy, water, sewer, and solid waste systems. Relocating the community to a new location would provide an opportunity to take advantage of alternative energy sources (Issacs et al. 2007). Alternative energy sources may be appropriate for Kivalina include waste heat recovery and wind energy. New houses would likely be better insulated and energy efficient.

New technology for building in the Arctic may be feasible for Kivalina. The Cold Climate Housing Research Center (2009) constructed a home in Anaktuvuk Pass using a steel frame, soy-based polyurethane R-60 insulation, a sod roof, and earth banking. This energy-efficient home cost under $150,000, including shipping. Volunteers from Illisagvik College in Barrow built the house during a 4-week period in 2009. The center is designing homes for other communities including Metarvik, Newtok's relocation site, and Point Lay.

6.2 Kiniktuuraq

Kiniktuuraq is discussed separately in this report because a majority of voters in a 2000 election chose it as the community's preferred relocation site. The 2006 *Master Plan* (U.S. Army Corps of Engineers 2006a) recommended against further consideration of this site because it is subject to coastal erosion and flooding, and the ice-rich permafrost soils are not suitable for construction. The analysis in the *Master Plan* indicates that a minimum of 9' of gravel would be needed to insulate the soil. New information should be considered in any further evaluation of this site including new models about permafrost melting, costs for a road across Singuak Entrance and the 2009 100-year flood level estimate.

Kiniktuuraq is located on the coast about one-mile south of the existing townsite. This site would have similar access to subsistence resources as the current site, and boats could be moored in the lagoon. The remainder of this section presents findings from relevant reports.

1994 Study: While this study did not specifically evaluate the Kiniktuuraq site, it did evaluate the option of building a bridge across Singuak Entrance that would allow access to the site. The report indicated there would be a risk of storm surge for this option, and that its costs would be above average. This option received a middle range score when evaluated against the evaluation criteria.

2006 Master Plan: This report summarizes the risks of flooding, erosion and melting permafrost. The report states that the current village site was flooded by storm-driven waves in 2004, that it would need to be raised from its current elevation of 10' to 16.5' for flood protection, and a total of 9' of gravel would need to be added to eliminate permafrost degradation. The report states that along the coast, threats of both thermal degradation and mechanical erosion exist. The site is "swampy underlain by unstable, ice-rich, fine-grained soils, and subject to destruction of the existing thermal regime without the addition of a minimum of 9' of gravel . . ." (p. 77). Prior studies found that addition of gravel would be needed to maintain the integrity of the permafrost, and this report recommends the addition of 9' of gravel.

“Mechanical stabilization” would be necessary along the coast. In addition, the report states that this site would be subject to ice override hazards.

A water system similar to that of Kivalina would be needed due to the lack of nearby surface water or groundwater sources. An underground distribution system would be infeasible due to ice wedges in the soil.

The ice-rich soils also pose challenges for wastewater disposal. A vacuum collection system, an above ground utilidor and a sewage lagoon could be constructed. A solid waste disposal site could be located along the 3.5-mile road to the airport. The dump site would need to be raised with a minimum of 9’ of gravel.

2008 Permafrost Study: A model for long-term permafrost dynamics at the proposed Kiniktuuraq relocation site included a number of scenarios including two scenarios for warming air temperatures and simulations for three different thicknesses of gravel pads (6, 9 and 12’) (University of Alaska 2008). The report concludes that surface subsidence will occur when permafrost melts down to the ice-bearing horizon which is located 0.4-1.0 m deep. Application of the model found that different thicknesses of gravel fill could delay thawing of the ice-rich permafrost layer, but would not stop the thawing of the permafrost. This study is discussed in more detail under Section 3.5.

New Flood Estimates: As discussed in Section 3.2, a 2009 water level study by U.S. Army Corps of Engineers estimates the 100-year flood estimate to be 7.77’ above MLLW (Chapman et al. 2009). The estimate, however, does not include wave setup, wave run-up or sea level rise. A draft memorandum prepared by the Corps recommends that a defensible storm surge analysis should be completed for low-lying relocation sites that would include consideration of sea level rise, delayed freezing and increased erosion (U.S. Army Corps of Engineers 2008). It also states that the 100-year water level estimate for Kiniktuuraq is more of a factor of storm surge levels in the lagoon than high water discharges from the Wulik River.

New information that has become available since the 2006 Master Plan could affect the feasibility of Kiniktuuraq as a relocation site. The community may wish to contact the author of the 2008 permafrost study to determine whether the proposed 9’ of gravel recommended in the 2006 *Master Plan* would eliminate permafrost melting and if other alternatives could make the site feasible, such as buildings placed on pilings with elevated board walks. In addition, the new flood level estimate would likely affect the cost and design of erosion control measures.

6.3 Remain at the Present Site

Options for remaining at the present site were investigated in each of the 3 major studies discussed below. All of these studies recommended other options besides remaining at the current site. Considering that it may take many years to move the community, new investigations may be warranted regarding the feasibility for improvements to the current site. Further, there are many uncertainties that could be addressed by additional studies, including new research about coastal processes adjacent to Kivalina and site-specific storm surge data.

1994 Study: DOWL Engineers (1994) considered 2 options for remaining at the current site. The first option involved moving the airport north and using part of the southern end of the airstrip for community expansion. The second option involved filling in a part of the lagoon for community expansion. This option received a middle range score when assessed against the evaluation criteria, and it was found to be an economical option.

1998 Study: This study investigated an option for remaining at the current site (U.S. Army Corps of Engineers 1998). This option involved using part of the land owned by the State of Alaska for the airport and filling in part of the lagoon. This proposal would involve extending the runway by 185 meters (607'). The community did not select this option, but instead, residents selected relocation to Igrugaivik on the Wulik River as their preferred option in a February 1998 election.

2006 Study: The *Master Plan* found it would be technically feasible to remain at the current location, but it recommended no further investigation of this option because of threats from erosion (U.S. Army Corps of Engineers 2006a). Improvements to the site would cost $196.2 million and would include placement of gravel fill to a height of 16.5', moving and raising structurally-sound buildings, replacement of other structures, installation of 4,285' of armor around the village, construction of an infiltration system for year-round water, and development of a wastewater treatment system and a buried drain field. The power system would need to be upgraded in 8 years. The discussion in the *Master Plan* for remaining at the current site included filling part of the lagoon adjacent to the community for the addition of 24 new homes, and presumably the $196.2 million cost estimate includes this work.

Current Situation: Due to information that was not available in 2006, a new look at three issues may be merited. First, the Alaska Village Erosion Technical Assistance Program estimated the community had 10-15 years left at its current site, but this estimate did not consider the rock revetment that has been constructed since then (U.S. Army Corps of Engineers 2006b, p.25). The Army Corps of Engineer's estimated 15-year life for the new revetment assumes no maintenance work will be completed. If maintenance is completed, the revetment could last much longer.

Second, the 2009 water level study reduced the estimated 100-year flood level for Kivalina from 16.3' to 7.7' above MLLW. As indicated in footnote 14, most of the homes in Kivalina appear to be sited at least 10' above MHW. If this is confirmed, the $196 million cost estimate from the

2006 Master Plan could be greatly reduced. The 2006 estimate included $163.4 million for site work, moving buildings and construction of new buildings.

Third, other assumptions in the 2006 cost estimate merit a second look. The estimate for remaining at the current site included erosion protection, but the estimate was made before the rock revetment was constructed. In addition, another analysis of material sources could lead to reduced costs. There are potential sources of gravel in berms of the Kivalina River, but concerns about environmental and subsistence impacts from removing these materials would need to be addressed (ASCG 2005). Sources of silt, sand and gravel may be suitable from the bottom of Kivalina lagoon and could be obtained by suction dredge in the summer.[26] In addition, NANA received approval for the coastal management review of a proposed rock quarry located 12 miles northeast of Kivalina in 2009.

6.4 Information Needs and Opportunities

This section outlines information needs and opportunities the community may wish to pursue depending on the next steps it chooses during the community planning process.

- **Third-Party Assessment:** An important priority of the City of Kivalina has been to have a third-party assessment of the 2006 *Master Plan* prepared by the Corps (GAO 2009). The state's Immediate Action Workgroup identified the availability of $12,000 for this purpose in its 2008 report to the Governor's Subcabinet on Climate Change noting that the outcome of this review is critical to progress on the relocation efforts. This project was not included in the Workgroup's 2009 report, however.
- **Kiniktuuraq:** The 2006 *Master Plan* determined that no further investigation of Kiniktuuraq should occur due to threats of erosion and melting of ice-rich permafrost soils (U.S. Army Corps of Engineers 2006a). Subsequent information about accretion rates at Kiniktuuraq and new flood estimates warrant reconsideration of conclusions in the *Master Plan* about Kiniktuuraq. Also, a survey of the site would be useful to document topography.
- **Feasibility for Relocation:** A new look at the cost of relocation may be merited. As mentioned earlier in this report, the Alaska Village Erosion Technical Assistance Program estimated the cost of relocating Kivalina to be $95 - $125 million (U.S. Army Corps of Engineers 2006b, p.25). This cost estimate for relocation is significantly less than the $154.9 - $251.5 million relocation estimates in the 2006 Master Plan.
- **Investigate Other Coastal Sites:** The Denali Commission has proposed to initiate a transportation system analysis related to relocation of the community closer to the Red

[26] According to the U.S. Army Corps of Engineers (2007a) bore samples from the lagoon indicated that materials may be too variable in composition to be used on the rock revetment project. It is possible that this material would be suitable for community expansion. Additional geotechnical evaluations would be necessary to evaluate the suitability of this material for fill as well the amount of settlement that would occur in the filled area.

Dog Mine port. The commission would likely pursue this option if it was supported by Kivalina.

- **Current Site Feasibility:** The greatly reduced 100-year flood estimate may affect the 2006 *Master Plan* finding regarding feasibility of remaining at the current site. It appears that most houses are located above the new flood level estimate, so the costs for gravel fill would be less, and it may not be necessary to move current structures.
- **Bearing Capacity of Lagoon Soils:** If Kivalina wishes to consider the possibility of expanding the community by filling the lagoon, additional field investigations will be needed to confirm the bearing capacity of the soils below the lagoon. Geotechnical engineers from the Alaska Department of Transportation and Public Facilities have an initial estimate that fill in the lagoon would settle about 4' (Smith 2009, personal communication).
- **Assumptions:** Determine if any of the relocation estimates should be reevaluated using different assumptions that would save costs (e.g., leaving the vegetative mat, use pile foundations and boardwalks and use different options for water, sewer and utilities).
- **Material Costs:** Determine if new local sources of materials would lower relocation estimates.
- **Arctic Technology:** Kivalina may wish to meet with staff from the Cold Climate Research Center in Fairbanks to determine how new low-cost energy efficient housing can be incorporated into future community planning.
- **Connection to the Red Dog Mine Road:** Options to connect the community or a new community to the Red Dog Mine road could be explored.
- **Winter Trail System:** A winter trail system could be developed to move freight and fuel to Kivalina. The Denali Commission is considering investigation of such a system that would involve minimal modification of terrain and installation of light bridges.
- **Funding Availability:** Confirm willingness of agencies to fund infrastructure if relocation efforts are stalled further or if the community decides to remain in place.
- **Future Erosion Protection:** Investigate possible techniques that could extend the life of the new rock revetment including beach nourishment and construction of a groin at the south end of town leading into the ocean that could result in accretion of sediments along the beach.
- **Local Planning Committee:** The Immediate Action Workgroup (2008) recommended the City, Tribe, Borough, and NANA form a local planning committee. The Workgroup recommended development of a "how to" guide to assist local planning committees in developing relocation plans. The Northwest Arctic Borough encourages communities to create local planning committees, and such a committee could be used for future community planning.
- **Community Planning Grant:** Kivalina is eligible for a $120,000 community planning grant to implement recommendations in the Immediate Action Workgroup's 2008 report to the Governors Subcabinet on Climate Change.

The *Situation Assessment* contains information for the community of Kivalina to consider when evaluating its future options. New information about relocation costs, flood level estimates, the potential for permafrost melting, and new material sources may merit a reevaluation of the findings in the 2006 Master Plan. A companion document to *Situation Assessment*, the *Final Report* for the Kivalina Consensus Building Project, provides additional information about meetings held for this project and next steps the community may wish to take.

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