Shaktoolik Planning Project

Final Situation Assessment

February 2012

Prepared by

Glenn Gray and Associates

in association with

Kawerak, Inc.

McKnight and Associates

for

The Community of Shaktoolik

Situation Assessment

Shaktoolik Planning Project

Acknowledgements

Native Village of Shaktoolik
Harvey Sookiayak, Sr., President
Axel Jackson, Council Member
Edna Savetilik, Council Member
Agnes Takak, Council Member
Randall Takak, Council Member
Matilda Hardy, Council Member
Edgar Jackson, Sr., Council Member
Karlene Sagoonick, Administrator
Michael Sookiyak, Sr., Grant Writer
Simon Bekoalok, Jr., Past President

City of Shaktoolik
Eugene Asicksik, Mayor
Edgar Jackson, Sr., Vice Mayor
George Sookiayak, Council Member
Fred Sagoonick, Council Member
Axel Jackson, Council Member
Agnes Takak, Secretary
Edna Savetilik, Treasurer
Rita Auliye, City Clerk

Shaktoolik Native Corporation
Eugene Asicksik, President
Teresa Perry, Vice President
Carol Sookiayak, Secretary
Betty Jackson, Treasurer
Ellen Hunt, Director
George Sookiayak, Director
Tanya Sagoonick, Director
Fred Sagoonick, General Manager

Kawerak, Inc.
Denise Michaels, Director, Kawerak Transportation Program
Steve Ivanoff, Kawerak Transportation Program

McKnight and Associates
Sean McKnight

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Abbreviations

ADCIRC	Coastal Circulation and Storm Surge Model
ANCSA	Alaska Native Claims Settlement Act
ANICA	Alaska Native Industries Cooperative Association, Inc.
ANTHC	Alaska Native Tribal Health Consortium
AVEC	Alaska Village Electric Cooperative
BIA	Bureau of Indian Affairs
CDQ	Community Development Quota
Corps	U.S. Army Corps of Engineers
DGGS	Division of Geological and Geophysical Services, Department of Natural Resources
EPA	Environmental Protection Agency
F	Fahrenheit
FEMA	Federal Emergency Management Agency
GAO	General Accounting Office
IAG	Immediate Action Workgroup of the Governor’s Subcabinet on Climate Change
IGAP	Indian General Assistance Program
IRA	Indian Reorganization Act
IRR	Indian Reservation Roads Program
kW	Kilowatt
kWh	Kilowatt hours
NSEDC	Norton Sound Economic Development Corporation
mph	Miles per hour
MHW	Mean high water
MLLW	Mean lower low water
MSL	Mean sea level
NOAA	National Oceanic and Atmospheric Administration
REAA	Regional Education Attendance Area
SNAP	Scenarios Network for Alaska Planning

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Executive Summary

Introduction: The primary purpose of the *Situation Assessment* is to compile existing information about threats from natural hazards to Shaktoolik to assist the community in future planning. New information about severe flooding and erosion dangers heightens the need for the community to make a decision whether to relocate or remain in place and defend against destructive storms. A secondary purpose of the document is to provide information about changing environmental conditions, including potential impacts from climate change.

A basic premise of the project is that members of the Shaktoolik community know best how to chart their future. The *Situation Assessment* and its companion documents (*Summary of the April 2010 Door-to-Door Survey* and *Annotated Bibliography*) are meant to help the community make informed decisions. The *Final Project Report* documents next steps recommended by the community.

The *Situation Assessment* includes information about natural hazards, evacuation and emergency planning, evacuation road and shelter options, and alternatives for relocation or remaining in place. The Shaktoolik Planning Project was coordinated with a coastal flooding analysis for community completed by U.S. Army Corps of Engineers in October 2011.

Background: Shaktoolik is an Iñupiat Native community on Norton Sound in Northwest Alaska. Located on a sand spit, Shaktoolik faces erosive forces from both the Tagoomenik River and Norton Sound. The community has a tribal government, a city government, and local Native corporation.

Climate change is occurring in Alaska's northern latitudes faster than in other areas. Although there are year-to-year variations, trends indicate the climate is warming. Scientists predict substantial changes will occur in the next 100 years: Warmer temperatures; sea level rise; increasing intensity of storms; melting sea ice; melting permafrost, ocean acidification; changes to fish, wildlife and plant communities; and drier tundra that will be more susceptible to wild fires.

Natural Hazards: Climate-related natural hazards include storms, flooding, erosion, ice hazards, melting permafrost, sea level rise, and ocean acidification. Storm surges and ice hazards have always been a concern for the people of this region. Recent trends of stronger and more frequent fall storms are occurring with later freeze up and earlier break up. Residents are concerned that storms may result in flooding and erosion of the sand spit on which the community sits.

Coastal Processes: Coastal processes are dynamic; while one area erodes, another area accretes (grows). The net movement of sediment along eastern Norton Sound occurs in a northerly direction with most of the sediment source from a 10-mile stretch of eroding bluffs located halfway between Shaktoolik and Unalakleet. Storm-driven sediments provide the second largest contributor of sediments for Shaktoolik, and rivers play a smaller role.

Erosion: A U.S. Army Corps of Engineers report found that analysis of aerial photographs did not reveal any clear trends, but the beach either accreted or stayed the same between 1980 and 1994 and eroded between 1994 and 2004. Assuming the recent rate of erosion will stay the same, the agency predicts about 45 acres will continue to erode in the next 40 years. It should be noted that the lack of long-term aerial photograph coverage reduces the certainty of these predictions.

Flooding: Norton Sound is especially susceptible to storm surges and flooding, and there are many examples of impacts to Nome and other communities over the last 100 years. The U.S. Army Corps of Engineers completed the *Shaktoolik Coastal Flooding Analysis* in October 2011. That analysis predicted grave consequences to the community from extreme storms. In summary, a 15-year storm event would likely push debris into the community, water would reach the beach side of the community in a 25-year event, and the community would be flooded by several feet during 50-year and 100-year storm events. Since the community relocated to its current site in 1974, no storms have resulted in flood levels beyond a 20-year event.

These new predictions provide the community with critical information for its evaluation of future short- and long-term responses to flooding and erosion. It should be emphasized that the *Shaktoolik Coastal Flooding Analysis* is based on historic storms and does not consider potential impacts of climate change such as increased severity of fall storms, reduced ice coverage, or sea level rise.

Permafrost: Permafrost melting has already occurred around Shaktoolik and may be the cause of draining of local lakes and slumping of stream banks.

Responses to Hazards: The community has not yet implemented any significant responses to natural hazards beyond completion of planning and emergency response documents. In 2009, the U.S. Army Corps of Engineers recommended an articulated concrete mat to protect the south tank farm, but this recommendation may merit further consideration. Most states promote “soft” techniques, such as beach nourishment and re-vegetation of beach berms and dunes over “hard” techniques such as rock revetments.

In 2011, the U.S. Army Corps of Engineers recommended additional investigations be completed to address safety issues, including design analysis of structural flood control measures (e.g., a revetment for wave protection or relocation of structures) and flood proofing of buildings (e.g., elevating buildings and mechanical and electric units). A trained coastal engineer should be consulted before deciding on specific control measures for erosion protection on the beach side of the community.

Evacuation and Emergency Planning: The community has completed a *Local Multi-Hazard Mitigation Plan*, *Emergency Operations Plan*, *Evacuation Plan*, and *Continuity of Operations Plan*. The hazard mitigation plan needs to be updated to incorporate new information about flooding and erosion. During the door-to-door survey for this project, many residents expressed a need for training or drills on what to do if an evacuation was necessary.

Evacuation Road and Shelter: Responses during the door-to-door survey show general support for both an evacuation road and shelter. A 2007 scoping report and a 2008 reconnaissance report provide initial information about evacuation road options. The reconnaissance report addresses a route to the Foothills where a gravel source and a potential new village site are located.

Shaktoolik has discussed options for emergency shelters, including the use of cabins along the evacuation route and construction of a shelter in the community. During 2011, USKH Inc. began an engineering and architectural project to facilitate a collaborative decision making process for a multipurpose building within the community that could serve as an emergency shelter. This option could reduce or eliminate the need for an evacuation route.

Options to Relocate or Remain at the Current Site: While the community has not conducted a comprehensive evaluation of options to relocate or remain at the current site, informal discussions have occurred. Information from the 2011 U.S. Army Corps of Engineers flooding study provides important information that merits close consideration by the community.

Some relocation options discussed informally include sites near Norton Bay, Christmas Mountain, Reindeer Mountains (near Cape Denbigh), and the Foothills. During the door-to-door survey, many people mentioned the Foothills site as a potential relocation site, but some people were concerned about the lack of river access and a safe place to store boats.

Now that the flooding study has been completed, the community needs to complete additional investigations to determine if whether remaining at the current site is a viable option or if relocation is necessary. Potential adaptation measures to remain at the current site include erosion protection structures, beach nourishment, raising the natural beach berm, and elevating buildings.

Next Steps: The Shaktoolik Planning Project *Final Report* includes a list of next steps the community needs to take in response to new information about natural hazards. Additional community planning will be needed to implement these next steps. The Immediate Action Workgroup (IAG) of the Governor's Subcabinet on Climate Change recommended at-risk communities convene community planning groups to evaluate options and develop priorities. The IAG recommended the group include representatives from the Tribe, city, school, Shaktoolik Village Corporation, and Kawerak. Because no single agency is responsible for addressing impacts to communities from climate change, it will be important for Shaktoolik to coordinate its efforts with state and federal agencies and other communities. In addition, the IAG recommended a phased and coordinated approach among the communities of Shishmaref, Kivalina, Shaktoolik, and Unalakleet.

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1. Introduction

The purpose of the Shaktoolik Planning Project is to develop information for the community to make informed choices about its future. Shaktoolik faces significant risks from natural hazards, especially coastal flooding and erosion. Unlike the nearby communities of Unalakleet and Koyuk, the flat topography surrounding Shaktoolik provides no opportunities for a quick escape to high ground in response to rising waters from a sudden storm surge. The *Situation Assessment* provides an analysis of existing reports about Shaktoolik and climate-related threats to the region.

The *Situation Assessment* is one aspect of the Shaktoolik Planning Project. Other parts of the project include a door-to-door survey, community meetings, and a community effort to evaluate future options and identify next steps. Companion documents to this report include the *Summary of the April 2010 Door-to-Door Survey*, an *Annotated Bibliography*, and the *Final Project Report*. All aspects of the project depend on local and traditional knowledge in addition to scientific information.

Kawerak, Inc. funded this project in association with a companion project completed by the U.S. Army Corps of Engineers which was funded by the Denali Commission. The U.S. Army Corps of Engineers project included the *Shaktoolik Coastal Flooding Analysis* in October 2011 that included the following tasks.

- **Survey and Mapping:** Completion of a survey to define a tidal benchmark, development of maps of the community and surrounding areas, and completion of beach profiles.
- **Update Model Data:** Updated wind information for the 2005-2009 period for use in computer models that predict storm surges and waves.
- **Hydraulic Study**: Completion of an engineering study of offshore waters to enable better prediction of wave heights at Shaktoolik and flood levels for the 4%, 2% and 1% events (i.e., floods with a 4%, 2% and 1% chances of occurring in any given year).
- **Erosion Study:** Update the initial Shaktoolik erosion study completed by the Corps in 2009 using older aerial photos.

The remaining sections of the *Situation Assessment* summarize information about Shaktoolik according to the following topics.

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

Where additional information may be needed by the community, options for further investigation are outlined in headings titled "information needs and opportunities." Community discussion is encouraged to determine which of these options should be pursued further and to identify actions that should be included in future community planning.

2. Background

Shaktoolik is located on the eastern edge of Norton Sound with a population of 251 people (U.S. Census Bureau 2010). It is located 33 miles north of Unalakleet and 125 miles east of Nome. The homes and other buildings are located in rows on either side of a single street that extends through the village. The road extends north to the airport and south to the landfill toward the former townsite.

The people of Shaktoolik are descended from the Unalit and Malemiut people. The Unalit are Yupik Eskimos who occupied the area during the time of first western contact, and the Malemiut are Iñupiaq Eskimos who migrated to the Norton Sound region from the Kotzebue Sound area.

Located on a sand spit, Shaktoolik faces erosive forces from both the Tagoomenik River and Norton Sound. The Tagoomenik and Shaktoolik rivers converge two miles northwest of the community at the end of the sand spit. All of Shaktoolik is located within the 100-year flood plain (U.S. Army Corps of Engineers 2011).

Shaktoolik is considered to have a subarctic climate with Norton Sound generally ice free between May and October. Typically, the temperature is between 47-62° F during summer months and between -4-11° F during the winter. Extreme temperatures vary between -50°F and 87° F. The average annual precipitation is 14", including 43" of snowfall.

The remainder of Section 2 includes the following subsections: Community background, history, funding, climate change, and vulnerability assessments.

2.1 Community Background

Shaktoolik is located on a sand spit between Norton Sound and the Tagoomenik River. The western portion of the community has a beach ridge with an elevation of 25' above MLLW, but the elevation drops to 14' above MLLW on the other side of the community (R.J. Kinney Associates 2008).

Maps posted on the Alaska Department of Commerce, Community and Economic Development website depict buildings, utilities, subsistence use areas, and flood prone areas (State of Alaska 1980, Kawerak 2004a, 2004b, 2004c, and 1996).[1] The topographic elevations on the 1980 and 2004 maps conflict, but a new topographic map completed by the U.S. Army Corps of Engineers in 2011 is more accurate and are based on a new tidal benchmark established by NOAA.

[1] The 1980 map indicates that most buildings are located at an elevation of 28' to 30' while the 2004 maps indicate most buildings are located at an elevation between 18' and 20'.

Governance: Shaktoolik has both a city government and a tribal government. The City of Shaktoolik incorporated as a 2nd class city in 1967 and is governed by a 7-member council with a "strong mayor" form of government. The mayor provides day-to-day management of city affairs with assistance from the city clerk. The City is in the process of selecting lands for expansion under authority of Section 14(C)(3) of the Alaska Native Claims Settlement Act.

The Native Village of Shaktoolik is a federally-recognized tribe organized under authority of the Indian Reorganization Act (IRA) that is governed by a 7-member IRA council. The Native Village has diverse powers, including authority for the protection of life, property, and the environment threatened by natural disasters (Kawerak 2007).

Economy: The local economy is primarily based on subsistence supplemented by commercial fishing and a limited number of conventional jobs provided by the City of Shaktoolik, the Native Village of Shaktoolik, the Shaktoolik Native Corporation, the Bering Strait School District, and the Shaktoolik Native Store. There were 4 active business licenses in Shaktoolik during December 2011, including the Shaktoolik Native Corporation, Shaktoolik Native Store, a video store, and a bed and breakfast. The two grocery stores are operated by the Shaktoolik Native Corporation and the Alaska Native Industries Cooperative Association, Inc. (ANICA). In 2010, 97 people were employed in the community, the median household income was $32,250 and the mean income was $54,487 (U.S. Census Bureau 2010).

Shaktoolik residents participate in commercial fisheries for salmon and herring. Commercial fishing provides the main source of cash income for the village in addition to government assistance programs. In the early 1960s, a local market for salmon was created when fish buyers came to the village, and in 1979, a commercial herring fishery began. In 2009, 44 residents had commercial fishing permits. Shaktoolik is strategically located amidst the center of Norton Sound's herring spawning grounds.

Shaktoolik participates in the Community Development Quota (CDQ) through participation in the Norton Sound Economic Development Corporation (NSEDC). The intent of the CDQ program is to give a share of the Bering Sea fisheries to communities to generate sustainable fishery-related economic activities. NSEDC distributes a community benefit share to each of its member communities, and it administers a number of other programs that benefit Shaktoolik and other member communities.

Subsistence: From a subsistence standpoint, the community is ideally located for easy access to Norton Sound and to the Shaktoolik and Tagoomenik rivers. The river side of the community provides access to freshwater fish, upriver caribou and moose and a safe area for storing boats. Close proximity to Norton Sound provides convenient access to marine mammals and fish. Most species are harvested for local consumption except for salmon and herring which are also harvested for the local commercial fisheries. The primary subsistence food resources include crab, moose, beluga whale, caribou, seal, rabbit, geese, cranes, ducks, ptarmigan, berries, greens, and roots.

Subsistence provides the dominant cultural and economic activities for Shaktoolik residents. It provides food, a cultural identity, and a way to express the cultural tradition of sharing. Subsistence "links the harvester to heritage of countless generations of ancestors who harvested the same species, often in the same geographical location" (Thomas 1982, p. 290).

Water: The community obtains its water from a site at the Tagoomenik River, known locally as "First Bend", which is located about 3 miles south of the current town site. The water is pumped from the river during the summer, treated and then stored in an 848,000 gallon insulated tank. A buried water line connects the village to the to the intake site. The City of Shaktoolik operates the water treatment facility and a washeteria. Sixty-one of the 66 estimated homes are directly supplied with running water from the system, and about 75% of the homes have complete plumbing. Erosion of the sand spit near the drinking water source could result in saltwater intrusion to the water supply.

Sewer: Most homes in Shaktoolik are connected to septic systems that serve multiple households. Vertical perforated culverts serve as seepage pits. Septic sludge is disposed of at a designated site which does not meet Alaska Department of Environmental Conservation standards.

Dump: An unpermitted dump site located close to the airport was recently relocated to a site about 1.5 miles south of the village. While refuse was burned at the former site, there is no burn facility at the new site. The Native Village of Shaktoolik operates a program under EPA Indian General Assistance (IGAP) funding for limited management of the dump site.

Power: The Alaska Village Electric Cooperative (AVEC) provides electricity for the community using three separate diesel-powered engine generator sets of 207 kW, 175 kW, and 250 kW capacity (Alaska Village Electric Cooperative 2008). The plant generated 13.80 kWh for each gallon of fuel consumed in 2007. A reliable source of power is needed to keep sewer and water systems in operation.

Bulk Fuel: Two tank farms supply fuel for the community. The AVEC tank farm is located next to the power plant. The second tank farm, located southeast of the community, is owned by the Shaktoolik Native Corporation, the Native Village of Shaktoolik and the Bering Straits School District. None of the tanks meet U.S. Coast Guard standards and are in need of upgrading.[2]

Airport: The Alaska Department of Transportation and Public Facilities maintains a 4,000' by 75' gravel landing strip with regular service from Nome and Unalakleet.

Freight: In addition to air freight, cargo is barged from Nome. Barges land on the beach in locations near the school, the AVEC electric generation site and near the Shaktoolik Native Corporation tank farm.

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[2] The U.S. Coast Guard regulates facilities that receive fuel by barges.

Housing: According to the 2010 census, there are 70 housing units in the community with an estimated 64 occupied and 4 vacant (U.S. Census Bureau). There were 4 more housing units in 2010 than in 2000.

Roads: The City of Shaktoolik is responsible for road maintenance within the municipal boundaries, and the Alaska Department of Transportation and Public Facilities is responsible for maintaining the road to the airport (Rodney J. Kinney Associates 2007). The Shaktoolik IRA will be responsible for maintaining any future roads constructed under the Indian Reservation Roads (IRR) program.

2.2 History

This section begins with a description of early occupation of the Shaktoolik continuing with a summary of major events occurring after Western contact. It ends with a summary of the previous relocations of the village.

2.2.1 Early Occupation

The Shaktoolik area has been occupied for at least an estimated 6,000 – 8,000 years (Giddings 1964, National Park Service 2010).[3] Archaeological excavations conducted at the Iyatayet site, located about 12 miles to the northwest of Shaktoolik on the Denbigh Peninsula, revealed three levels of occupation: Denbigh Flint Complex (6000-4000 BC), the Norton Culture (500 BC-300 AD), and the Nukleet Eskimos (800 AD).

Most people lived in small groups along the coast although there were a few larger settlements in Eastern Norton Sound. These groups moved to different sites on a seasonal basis to take advantage of subsistence food sources. A map drawn by Giddings (1964, p.2) in an archeological study of the area indicates 7 former sites in the area: Iyatayet and Madjujuinuk (located north of Cape Denbigh), Nukleet (located at Cape Denbigh), three sites at the sand spit near the mouth of the Shaktoolik River (one site at the mouth, another at approximately the same location as the current village and one at the site of the 1974 village), and a site called Ditchanhak just south of the First Bend of the Tagoomenik River (Giddings 1964).[4] Ditchanhak was larger than most former settlements with an estimated 99 households. In addition, two settlements were located on Besboro Island.

2.2.2 Post Western Contact

Observations by early Western explorers of people in the area occurred as early as 1778 when Captain Cook made contact with one of several people observed on the shoreline of Cape Denbigh (Ray 1967). During early contacts, the Unalit occupied the coasts of Norton Sound. Sometime after Western contact, the Malemiut people migrated to Norton Sound from Kotzebue Sound, primarily from the Kobuk River and Buckland River areas.[5] In 1839, Shaktoolik was the only Malemiut

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[3] Giddings began field work in 1948 and reports that radiocarbon dating shows the oldest layers of the Iyatayet site to be approximately 3,000 – 4,000 years old. Subsequent research indicates the sites may be much older.
[4] The map labels the Tagoomenik River as the Mukluktoolik River.
[5] Ray (1975) speculates that the migration of the Malemiut had not begun by 1782 because written references to the pronunciation of Shaktoolik used the Unaluk rather than the Malemiut pronunciation.

village in Norton Sound, but by the 1840s some Malemiut people had moved to Unalakleet and St. Michael.

The Russians established their first settlement in the area in 1833 at St. Michael located on the southern shore of Norton Sound. A Russian supply post at the mouth of the Unalakleet River was established in 1838. A smallpox epidemic reached Norton Sound in 1838, but it may not have affected people north of Unalakleet.

Reindeer herding in the region began in 1892 with establishment of the Teller station (Stern et al. 1980). In 1898, Laplanders moved to Unalakleet and later to Eaton Station on the Unalakleet River (Degnan 1999). A reindeer station was established in Shaktoolik in 1907, but by 1980 only one person was involved in the reindeer industry. Reindeer herding ended in Shaktoolik when the herd joined caribou in their seasonal migrations.

Discovery of gold at Nome in 1898 brought miners to Norton Sound in search of other deposits, and miner occasionally employed local residents to assist them. A gold dredge at Ungalik, north of Shaktoolik on the eastern shore of Norton Bay, employed residents during its years of operation (1938-1940 and 1947-1948).

The pattern of a mixture of large and small villages in Norton Sound area changed to one of larger settlements due to several reasons (Ray 1983). First, flu epidemics wiped out residents in some of the smaller settlements. Second, the establishment of schools required families to relocate to villages where schools were located. Third, economic opportunities attracted people to the larger settlements where they could earn cash.

Thomas (1982) conducted extensive discussions with Shaktoolik elders to understand how the community adapted to Western influences. His research found that the first outboard motor arrived in the community in 1935, and the first snow machine in arrived in 1960. Commercial fishing also began in 1960 when buyers began coming to the village. Table 1 summarizes the major historical events since the mid-1800s.

2.2.3 Village Relocations

The location of Shaktoolik has changed a number of times over the last century, often in response to the threat of natural hazards. Sources provide different accounts of village locations and moves, and this summary depends on original sources as much as possible. As mentioned earlier in this section, Giddings (1964) reports 3 archaeological sites near the top of the sand spit and one near First Bend south of the current village site.

Ray (1983, p. 180) reports that Shaktoolik has moved at least three times in the historical period, including at least once because of concerns about riverine erosion. According to Thomas (1982), the earliest site remembered by village elders, Robertvale, was located several miles up the Shaktoolik River where the first school was built. In 1916, the village moved a few miles downriver due to

Table 1: Major Historical Events in the Shaktoolik Region since the Mid-1800s

Date	Event
1839	In 1839, Shaktoolik was the only Malemiut village in Norton Sound.
1840 - 1841	Russian American Company built an outpost in Unalakleet.
Late 1800s	Caribou became scarce around Shaktoolik.
1898	Reindeer herders from Lapland arrive in Unalakleet.
1898	Nome gold rush sparks interest in mining in the area. Norton Sound Eskimos employed by local operations.
1907	A reindeer herding was established at Shaktoolik.
1916	Shaktoolik village moved from a site upriver to an area on the Shaktoolik River closer to the coast.
1918	Influenza epidemic affected people south of Shishmaref and north of St. Michael.
Early 1930s	First planes arrive in region and first outboard motors arrive in Shaktoolik.
1930's	Reindeer herds crash around Shaktoolik.
1932	The Village Council decides to move the village to the coast.
1933	The community moves to the location currently known as "Old Site" approximately 3 miles south of the current village location.
1935	First outboard motor arrives in village.
1936	First store opened in Shaktoolik.
1938–1940 and 1947-48	Shaktoolik residents work at mining dredge operations at Ungalik.
1960s	First snow machines arrive in village.
1961	Commercial fishing begins when first fish buyer arrives in village.
1962	Community applied for a federal townsite.
1968	The process began to consider moving from the former location to the current village site.
1969	Shaktoolik incorporated as a 2nd class city.
1971	Alaska Native Claims Settlement Act (ANCSA) provided authority for the Shaktoolik Native Corporation and its land entitlement of 155,200 acres.
1974 – 1975	Initial buildings constructed at the current village site.
1978	Commercial fishery for herring begins.
1980	By 1980, just one reindeer herder operated in Shaktoolik.
1985	A community owned and operated fish buying station built in Shaktoolik.
1989	Norton Sound Economic Development Corporation established (NSEDC).
1992	The Community Development Quota (CDQ) Program began, and NSEDC restructured to be the regional CDQ organization which includes Shaktoolik and 14 other communities.

Sources: Anderson and Eells 1935, DCCED 2010 Kawerak, Inc. 2007, Kizzia 2008, Ray 1975, Ray 1983, Stern et al. 1980, Thomas 1982, U.S. Army Corps of Engineers 2009a.

difficulty in getting freight to the community from the *Northstar*, the BIA supply ship. In 1931, village leaders considered moving five miles downstream because the river was eroding the community (Anderson and Eells 1935). In 1932, the village council decided to move the village to coast to be more accessible to freight, firewood (driftwood), seal hunting, and the reindeer corral

(Thomas 1982).[6] The village relocated to the coast in 1933, and in 1974 the first buildings were constructed at the current townsite.

2.3 Funding

At least 184 Alaska Native villages have experienced increased erosion or risks of flooding, but there are limited funding programs for these purposes (GAO 2004).[7] Government agencies consider Shaktoolik as to be one of 4 communities in immediate need of relocation (GAO 2009), and the State of Alaska Immediate Action Workgroup included it in the 6 top priority communities referenced in this document as "at-risk communities."[8] A growing number of communities, however, 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 Shaktoolik's chances of receiving future funding.

Shaktoolik, Shishmaref and Kivalina have expressed concerns that discussions about relocating the communities has resulted in a reluctance of some agencies to fund community improvements (GAO 2009). Shaktoolik residents are also concerned about the potential threat to life and property and inadequate funding for community improvements.

Options currently discussed for Shaktoolik include short- and long-term solutions. While many residents believe the community will eventually need to be relocated, they recognize the funding challenges to accomplish this goal (Glenn Gray and Associates 2010a). Interim solutions being discussed by the community and government agencies include erosion protection structures, an evacuation road and a multi-purpose evacuation shelter located in the community.

National budgetary concerns and competition among Alaska communities for limited funds provide significant challenges for Shaktoolik. The Shaktoolik Planning Project and the *Shaktoolik Coastal Flooding Analysis* (U.S. Army Corps of Engineers 2011) provide the community with some of the information it needs to develop a detailed plan of action. An effective planning process will ensure the community evaluates all feasible options before selecting a way forward. Shaktoolik may wish to investigate the process used by Newtok to respond to threats of flooding because it is the only one of the 6 at-risk communities that has made substantial progress to relocate (GAO 2009).

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.[9] Congress replaced this

[6] Thomas (1982) acknowledges that Giddings (1964) provides a slightly different account of the moves: The original village was located at the mouth of Shaktoolik River, it moved few miles up the river, back to mouth again, back upriver, and then to the site near the first bend of the Tagoomenik River.

[7] The General Accounting Office (GAO) is an investigative arm of Congress that requested to study erosion and flooding in Alaska villages.

[8] The Immediate Action Workgroup is a workgroup of the Alaska Governor's Sub-cabinet on Climate Change.

[9] Section 17 was authorized by the 2005 Energy and Water Development Appropriations Act, but Shaktoolik was not one of the villages included in this funding (GAO 2009).

funding authorization in October 2009 with a legislative provision known as Section 116 funding.[10] The 2009 legislation requires 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 and a 35% match (U.S. Army Corps of Engineers 2010a). An in-depth list of potential federal funding sources can be found in Appendix A of *Adapting to Climate Change: A Planning Guide for State Coastal Managers* (NOAA 2010).

2.4 Climate Change in the Arctic and Alaska

Northern Alaska communities, such as Shaktoolik, are experiencing increasing impacts from a changing climate. This section begins with a discussion of science-based observations for the Arctic region followed by a discussion of Alaska-specific scientific and local and traditional knowledge.

2.4.1 Arctic Climate Change

While Shaktoolik is located below the Arctic Circle, the Bering Sea and Norton Sound are considered part of the Arctic by the 8-nation Arctic Council, and many of findings for the Arctic apply to this region. The Intergovernmental Panel on Climate Change (2007) found that all but one year between 1995 and 2006 represented the warmest surface temperatures since 1850. Impacts from climate change have been magnified in the Arctic in a process called Arctic amplification. The 2004 *Arctic Climate Impact Assessment*, prepared by the Arctic Council, found that increased concentrations of greenhouse gases have led to significant changes, including:

- 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 add to sea level rise,
- Permafrost soil 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. [11]

A 2009 update to the *Arctic Climate Impact Assessment* found that climate indicators show “extensive climate changes at rates faster than previously anticipated” (Arctic Monitoring and Assessment Programme 2009). 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. 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.

[10] 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.
[11] While Shaktoolik is located below the Arctic Circle, this region is considered to be within the Arctic region by some organizations, including the Arctic Council.

The web-based *Arctic Report Card* by the National Oceanic and Atmospheric Administration (NOAA) provides annual climate change updates beginning in 2009. The 2009, 2010 and 2011 updates include the following conclusions:

- In 2011, changes to Arctic winter wind patterns resulted in higher than normal Arctic temperatures, with record ice sheet mass loss, shorter lake ice duration, and unusually lower temperatures and snow storms in some low latitude regions,
- A shift in Arctic Ocean ice since 2006 demonstrates a persistent decline in the thickness and summer extent of ice cover and a warmer upper ocean; the 2009 summer sea ice extent was the third lowest on record, and the September 2011 sea ice the second lowest on record,[12]
- An unprecedented amount of fresh water on the surface of Arctic sea ice contributes to warming air temperatures in the fall,
- Biologic productivity at the base of the marine food chain increased by about 20% between 1998 and 2009 while habitat for ice-dependent marine mammals has continued to diminish,
- Warming ocean temperatures lead to summer sea ice loss that in turn affects air temperatures and Arctic atmospheric circulation,
- A new record low spring snow cover duration occurred in the Arctic during 2010,
- Greening tundra vegetation and increased permafrost temperatures are linked to warmer land temperatures in coastal regions,
- The normal east-to-west jet stream patterns reversed in December 2009 and February 2010,[13]
- 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 manmade causes of climate changes such as a reduction in greenhouse gas emissions. Adaptation involves measures to respond to effects of a changing climate such as changing subsistence use practices or community relocation.

2.4.2 Implications for Climate Change in Alaska

Alaska temperatures have increased at twice the rate as the rest of the country, and climate change models indicate there will be both a rise in temperature and precipitation for Alaska through the end of the century (SNAP 2010).[14] Since the 1950s, average temperatures rose 4° F, and they are

[12] The sea ice coverage in September 2007 represented the lowest coverage since measurements began in 1979 (Wang and Walsh 2010). Arctic sea ice is generally at its lowest extent in September and its maximum annual extent in March (Perovich et al. 2010).

[13] This change in wind patterns has happened only three times previously in the last 160 years.

[14] The models show monthly predictions for the following time periods 2001-2010, 2031-2040, 2061-2070, and 2091-2100. These predictions are displayed on a monthly basis using scenarios for low, medium and high greenhouse gas emissions.

projected to rise 1.5-5° F by 2030 and by 5-18° F by 2100 (Parson et al. 2009). Precipitation is expected to increase 20-25% in north and northwest Alaska by the end of the century.

While long-term measurements show a warming trend, short-term fluctuations can occur from year-to-year. For example, during 2009, the warming trends in the Arctic slowed down while in the first half of 2010 the global mean air temperature reached a record high (Wang and Walsh 2010). On a local level, a resident from Unalakleet reported that during the winter of 2009-2010, residents were able to travel further out on the ice than he could remember (Ivanoff 2010, personal communication).

Throughout Alaska, climate change has been attributed to the most severe stresses to the environment (Parson et al. 2009). Other climate-related impacts in Alaska are summarized in the bullets below.

- **Sea Level Rise:** Sea level rise is a long-term concern for Shaktoolik because of the community's low elevation. It occurs from an increase of fresh water into the ocean from melting sea ice and glaciers and from expansion of water molecules from warming temperatures. During the past 50 years, the sea has risen 8" or more in some areas of the U.S. coast (NOAA 2010). Sea level rise will increase flood levels, especially during storm surges and may increase erosion. The Intergovernmental Panel on Climate Change (2007) reports that models indicate that by the end of the century, global sea level could rise between 0.18-0.59 meters (7.08"-23.2" or 0.6' to 1.9'). More recent evidence suggests the sea level could rise between 3'-4' by 2100 (NOAA 2010). While melting glaciers in Alaska have contributed to sea level rise, frozen ice in Greenland and Antarctica have the greatest potential to affect future sea level rise. Neither state nor federal agencies have established official estimates of sea level change in Alaska.
- **Ocean Acidification:** Ocean acidification is a growing concern, especially in the Arctic, and it is believed to be more severe and occurring more rapidly in Alaska waters than in tropical waters (University of Alaska 2009). It occurs as a result of increasing concentrations of carbon dioxide in the atmosphere which are absorbed by the ocean. Ocean acidification is expected to affect the ability of corals and mollusks to make shells and skeletons (NOAA 2006) and may affect populations of species low on the food chain such as krill. Increased acidification could affect commercial crab fisheries and have an indirect effect on other species. For example, a 10% decrease in the population of pteropods (species used by pink salmon) could result in a 20% decrease in body weight of adult pink salmon (ScienceDaily 2009). As a result of ocean acidification and an increase of melt water in the Canada Basin, calcifying organisms have experienced corrosion (Proshutinsky et al. 2010). As a result, certain types of plankton have increased while others have decreased. Acidification may also indirectly affect fish and marine mammals through a reduced availability of some food sources. A set of mooring buoys deployed in Alaska waters in 2011 will provide more information about ocean acidification.
- **Plankton:** Earlier melting of sea ice will have implications to the timing and location of phytoplankton blooms that occur when the ice retreats (Simpkins 2010). This annual bloom is a major source of productivity in northern waters, and changes to it could affect the entire food web.

- **Changing Plant and Animal Communities:** Models developed by scientists predict drastic changes in the major biomes (plant and animal communities) in Alaska (Murphy et al. 2010). About 60% of Alaska's biomes are expected to change by the end of the century, and the western tundra biome is expected to decrease by 54%. The Western Alaska tundra community is the most vulnerable and least resistant to climate change.
- **Fisheries:** Warming sea temperatures in the Bering Sea between 2000 and 2005 resulted in lower numbers of species that require sea ice (Overland 2010). Unusually cold ocean conditions since 2005, however, have resulted in an increase in Arctic cod and a decrease is pollock. According to Overland (2010), recent ocean trends in the Bering Sea may be the result of natural variability, but by 2020 a trend of prolonged warm temperatures is expected.
- **Marine Mammals:** Reductions in marine mammal populations in the Bering Sea have been attributed to climate change (Adaptation Advisory Group 2010). A warming climate has implications for marine mammals that are dependent on sea ice, including bowhead and beluga whales, ringed and bearded seals, walrus, and polar bears. These mammals are at the top of the food chain so changes to them can be important indicators of climate change (Simpkins 2010). Behavioral changes have been observed for both polar bears and walrus. During 2007, 2010 and 2011, walrus hauled out in large numbers in new locations, and this unusual behavior can result in trampling and increased pressure to nearshore benthic species. In addition, a continued warming trend could lead to early collapse of ringed seal lairs.
- **Birds:** Significant reductions in seabirds in the Bering Sea have been attributed to climate change (Adaptation Advisory Group 2010). The Arctic and Subarctic regions are important breeding grounds for birds; over half of the world's shorebirds and 80% of its geese breed in these regions (Gill 2010). Research reveals that some species of murres have shown negative population trends in response to changes in surface sea temperature (Gaston and Gilchrist 2010). In general, geese populations have increased since the 1970s along with a greater range in northern areas (Loonen et al. 2010). This situation has resulted in impacts to tundra vegetation and a greater supply of eggs for predators. Several Arctic goose populations, however, are declining.
- **Invasive and Non-native Species:** Changing climatic conditions are expected to result in the displacement of native species in Alaska. Later freeze up, earlier break up and warming air and water temperatures may be contributing to sightings of new species in the region and changes to the numbers and distribution of native species. Combined with other changes, climate changes can increase the vulnerability of native species to impacts from invasive species (NOAA 2010). Climate change has the potential to change conditions that would be more favorable to new and invasive species that compete with native species. An increase in insect infestations has been associated with a warming climate, including the largest outbreak of spruce beetles in the world which occurred in Southcentral Alaska (Parson et al. 2009). The degree of impact of new species to the region will depend on the adaptability of new and existing species to climate changes. Software has been developed to determine the vulnerability of species to climate change (NatureServe 2010).
- **Vegetation:** Climate change is expected to result in new vegetation patterns in Alaska. A research project found that the abundance of vascular plants in the Toolik Lake tundra

increased by 16% while nonvascular plants decreased by 18% (Walker et al. 2010). While some northern areas have not shown much change in the geographic range of certain plants, sudden shifts are expected in the future once tipping points are reached (Doak and Morris 2010). A comparison of oblique aerial photographs on the North Slope of Alaska over the last 50 years found an increase in shrubs in tundra areas, including alder, willow and dwarf birch (Tape et al. 2006).

- **Drying Tundra:** Despite an increase in precipitation, soils are expected to become drier, especially during the growing season. Increased air temperatures will result in more evaporation, and an increase in the number of shrubs will result in more transpiration (O'Brien and Loya 2009, Parson et al. 2009, SNAP 2010).
- **Wildfires:** An increase in wildfires has been attributed to climate change in Alaska (Parson et al. 2009). Alaska wildfires are expected to double by the middle of the century and triple by the end of the century. As tundra soils dry, they are more vulnerable to fires.
- **Lakes:** Climate change has been attributed to declining lakes in Alaska due to greater evaporation and melting permafrost (U.S. Global Change Research Program 2009). Shaktoolik residents believe permafrost melt has resulted in the draining of several large lakes near the community.[15]
- **Permafrost:** Permafrost is another indicator of climate change. Romanovsky et al. (2010) found that permafrost warming that began 20-30 years ago is continuing and that colder soils are warming at higher rates than permafrost soils closer to the melting point (i.e., 0° C). While there was substantial warming of soils during the 1980s and 1990s, during the past 9 years permafrost levels on the North Slope have been relatively stable). Coastal areas in Alaska, however, have shown continuous warming. Over the next 100 years, up to 30' of discontinuous permafrost is expected to melt (Parson et al. 2009).
- **Health and Safety:** Climate change may result in risks to human health. A decrease in use of subsistence foods from climate change-related impacts could lead to health problems including an increase in hunger, malnutrition and disease (ANTHC 2010). Displacement of food resources may result in the need to travel further thereby increasing risks of accidents. Also, increased intensity of storms will increase risks to commercial fishermen and subsistence users. Section 3 provides more information about natural hazards.

2.5 Vulnerability Assessments and Adaptation Plans

Completion of a vulnerability assessment is an important step when preparing for impacts from climate change, including the development of adaptation plans (NOAA 2010, Ford et al. 2009, Downing et al. 2002). Vulnerability assessments can help communities adapt to climate change-related impacts to resource harvesting, food systems, transportation, and community infrastructure (Ford et al. 2009). An understanding of the vulnerability of environmental, social and economic systems to climate change and who and what are vulnerable to climate change is necessary before solutions can be adequately evaluated. Information from a vulnerability assessment can be used to ensure a community's adaptation plan reflects local needs and risks. The federal government

[15] During the door-to-door survey for this project, 5 residents mentioned lakes close to the village have been draining, and they thought the cause was melting permafrost. The residents did not indicate the name of the lakes.

recognizes that an adaptation plan driven by local needs will be most effective, and the agency promotes an ecosystem approach when developing adaptation plans (Council on Environmental Quality 2010).

When assessing vulnerability, it is important to consider a number of factors (Council on Environmental Quality 2010). Certain populations may be more sensitive to climate change than others, such as people dependent on subsistence resources, those with low cash incomes or those living in housing that is not retrofitted to withstand natural hazards. Likewise, certain plants and animals and their habitats may be more sensitive than others to climate-related changes (e.g., changing air or water temperatures, sea ice retreat, or salt water flooding). A community's resiliency, that is, its ability to prepare for and respond to a changing climate, is another important consideration.

While development of a complete assessment is beyond the scope of this project, this section outlines some factors that would be included in a vulnerability assessment for Shaktoolik. In addition to scientific information, the incorporation of local and traditional knowledge into a vulnerability assessment is necessary if it is to be useful the community.

Shaktoolik residents are keenly aware of their surroundings, and they have noticed changes in climatic trends for some time. Thomas (1982) reported that village residents noticed warming trends in the early 1980s, including a reduction in the extent of sea ice. Residents reported that by the late 1970s, ice rarely formed out to Besboro Island which is located 15 miles southwest of Shaktoolik, and that shorefast ice extended only a mile from shore. While Thomas found some residents believed the change in sea ice resulted from a change in winds, others believed winters were becoming milder, starting later and ending earlier.

In meetings and interviews associated with the Shaktoolik Planning Project, residents reported climate-related trends, including increased severity of storms, unusual flooding in the flats, later and milder winters, earlier springs, lakes drying up, and melting permafrost. Some residents observed changes in species distribution and numbers, timing of migrations and new species never seen before.

Habitat and Fish and Wildlife Resources: Climate change has the potential to affect the numbers, kinds and distribution of fish, wildlife and plants. Arctic habitats are considered to be especially vulnerable to climate change impacts (Council on Environmental Quality 2010). Climate change impacts to species and their habitats can be amplified by other factors such as pollution, over harvesting and habitat destruction.

The Bering Sea has a wide diversity of species, including 25 species of marine mammals; 450 species of fish, crustaceans and mollusks; and 66 species of seabirds (Parson et al. 2009). In the early 1980s, Shaktoolik residents noted that murres were laying eggs a month earlier than they did 30 or more years ago (Thomas 1982).

Climate change-related habitat changes, including warming waters, increased air temperatures, later freeze-up, and earlier break up have already resulted in variations to the migration of fish and wildlife. In general, waterfowl have shown trends for northern range shifts as a result of a warming climate (Krcmar et al. 2010). The loss of sea ice in northern Alaska is affecting migration of walrus and polar bears. An unusual event occurred in September 2010 when over 10,000 walrus hauled out onshore near Point Lay, likely a result of diminished sea ice (Hopkins 2010). Changes in polar bear behavior have been attributed to reductions in sea ice. Closer to Shaktoolik, warmer water temperatures are affecting the Bering Sea ecosystem by impacting fish, marine mammals and birds (SNAP 2010). Climate change has also been attributed to a possible cause for the 2009 late migration of caribou in Northwest Alaska 2010 (Brubaker 2010).

Shaktoolik residents report new species observed in the region during recent years, including killer whales, “green bugs” in the ocean, blowfish, and a new kind of beetle (Glenn Gray and Associates 2010a). During the fall of 2010, a skate was found on a Kivalina beach (Barber 2010).

Residents report a number of changes to fish, wildlife and plants and their habitat that may be related to climate change (Glenn Gray and Associates 2010b).

- Residents have expressed concerns about disappearing lakes and potential impacts from saltwater flooding in the flats adjacent to the community.
- Increased erosion of riverbanks has resulted in shallower water with increased aquatic plants. Residents are concerned that this change may adversely impact salmon spawning habitat.
- The numbers of certain species have been reduced, including ling cod and Sheefish.
- Populations of other species have increased significantly, including beavers.

The drying tundra will result in different plant species and a related increase in wild fires which will affect the habitat. Plant species will also likely change with some tundra areas being replaced by shrubs and a potential expansion of forests westward towards the Seward Peninsula.

As mentioned earlier in this report, ocean acidification is expected to impact shellfish and potentially impact the food chain if the increased acidity decreases the number of krill.

Subsistence Uses: Climate change will likely have negative and positive impacts to subsistence uses. Researchers predict climate change will result in additional stress to the subsistence way of life (Adaptation Advisory Group 2010). According to Parson et al. (2009), “climate change already poses drastic threats to subsistence livelihoods . . . as many populations of marine mammals, fish, and seabirds have been reduced or displaced due to retreat and thinning of sea ice and other changes” (p. 285). These changes are expected to increase, and there is some speculation that changes in plant species could be detrimental to caribou, especially for lactation and winter nutrition. Ecosystem shifts will likely affect subsistence uses and species by changing the numbers and distribution of fish, wildlife and plants. New species to the region and invasive species will complete with native species used for subsistence. In addition, relocation of the community could impact subsistence uses if a new location reduces access to species in freshwater, saltwater and inland areas where game is plentiful. Shaktoolik's *Local Economic Development Plan* recognizes that climate change may negatively affect the subsistence way of life (Kawerak 2007). The late migration of caribou in Northwest Alaska during recent years, a possible result of climate change, increased the costs per pound for caribou for one Kiana hunter to $1.75 per pound (Brubaker 2010). Low cash incomes and poverty can increase vulnerability by increasing risks a person might take to get subsistence resources during hazardous conditions (Ford et al. 2009). The change in distribution, numbers and timing of some species may benefit subsistence users. For example, researchers have found that waterfowl populations generally move north in response to a warming climate (Krcmar et al. 2010). This trend is expected to continue in the future and benefit subsistence users in Northwest Canada.

Health and Safety: Climate change poses significant health and safety concerns. The Adaptation Advisory Group to the Governor's Subcabinet on Climate Change (2010) recommended continued evaluation of climate change impacts on communities and development of adaptation and mitigation options. While a large storm could lead to direct loss of property and life, other more subtle impacts could occur.

- Increased flooding and erosion may spread pollutants from garbage dumps, fuel tank farms and other areas where hazardous materials are stored or have been spilled.
- Changes to the distribution of subsistence resources could result in increased safety risks as subsistence users travel greater distances.
- Unpredictable sea ice conditions and increased severity of fall storms pose safety hazards.
- If access to subsistence resources is reduced, a greater dependence on western foods could result in increased heart disease, diabetes and vitamin deficiencies (ANTHC 2010).
- Concerns about flooding and erosion may adversely impact a community's mental health.

Cultural Resources: In addition to impacts to subsistence, increased erosion threatens archaeological sites along the rivers and shoreline of Norton Sound.

Economic Impacts: Since all of Shaktoolik would be flooded in 100-year event, future storm surges and continued erosion is expected to affect the economy of the village through flooding, erosion and damage to infrastructure. Commercial fishing provides the most important employment sector for the community. A move to another location could impact commercial fishing if access to Norton Sound is inhibited or if a suitable harbor is not available for the fishing fleet. Changing climatic conditions may also result in new distribution of commercial fish and the potential for introduction of species that compete with them.

Infrastructure Impacts: Community infrastructure has been affected by fall storms and later freeze up of sea ice. Past storms have resulted in erosion along the shoreline, the former airstrip south of town, and on either side of the sand spit south of town, including the road which provides access out of town. In addition, storms have damaged buildings and fuel lines. Storms in recent years have deposited a line of driftwood close to buildings and other infrastructure. Residents have expressed concern that future storms could lead to flooding, erosion and damage from driftwood battering. Facilities and buildings of immediate concern include the southern fuel tank farm, sewage systems, the airport, and the school. The *Multi-Hazard Mitigation Plan* identifies the community's critical facilities, essential facilities and critical infrastructure (WHPacific 2009). Some of the newer homes have been built on pilings which will reduce potential damage from flooding.

Impacts to Water Supply: Changing climatic trends have raised concern about the possibility of saltwater intruding to the current water supply if a channel is eroded to the current water supply at the First Bend of the Tagoomenik River. Concerns have also been raised about possible impacts to berries growing in the flats near the community from more frequent salt water flooding.

The 2007 *Local Economic Development Plan* identifies a number of buildings and infrastructure that need improvement. Priority 2 addresses the need for an evacuation road, priority 3 addresses the need for erosion control, priority 4 addresses a multi-purpose building, and priority 6 would replace the bulk fuel tanks.

3. Natural Hazards

Communities routinely consider natural hazards in their planning efforts, but for Shaktoolik, the risks from flooding and erosion pose significant threats to the safety and well being of its residents. In summary, a 15-year storm event would likely push debris into the community, water would run across the sand spit in a 25-year event, and the community would be flooded by several feet during 50-year and 100-year storm events.

The remainder of this section on natural hazards begins with a historical perspective of natural hazards followed by a discussion of specific hazards, including flooding, erosion, permafrost melting, ice hazards, and wildfires. This section concludes with a discussion of responses to the threats of natural hazards, opportunities and information needs.

3.1 Historical Perspective

The people of Norton Sound have always faced danger from natural hazards, but threats to human safety, property and the environment have increased for Shaktoolik. Since relocation of the community to the coast in 1933, residents have faced increased danger from fall storms. In the long term, climate change will increase the effects of fall storms because of later freeze up of Norton Sound, and drying trends will increase risks of tundra fires.

Stories passed down through generations recognize the threats from natural hazards. One Shaktoolik resident relayed a story told by his grandmother about an orphan girl in a village south of Shaktoolik who was hungry and no one would feed her (Thomas 1982). As the story goes, she walked out on the ice, and a strong wind from the south destroyed the entire village. Another story reported by Thomas described destruction of a village at the mouth of the Shaktoolik River. As result of strong south/southeast winds, ice came ashore pushing sod homes onto the flats, and people drowned in the water that accompanied the ice flow.

Accounts from elders also mention damage from flooding and tsunamis to villages in the region. While the threat of a tsunami to Shaktoolik is considered low (WHPacific 2009), tsunamis have occurred in the past (Mason et al. 1997, Ray 1983). A tsunami reported to have occurred in the 1830s affected at least 4 villages in Western Alaska, including Shaktoolik (Ray 1983, p. 195).[16] An 1899 seismic wave destroyed a site near Golovin from the force of ice. In addition, accounts of elders report that a tidal bore destroyed an entire village on the Diomede islands, likely sometime in the 1800s (Hawkes 1913).[17]

Shaktoolik residents recognize the significance of fall storms and ice hazards (Thomas 1982). They know that winds from the south or southwest generate high water (storm surges), and in one instance they report a storm caused a 15’ rise in sea level that brought salt water into the rivers. Several of the relocations of the community of Shaktoolik occurred at least in part due to coastal or riverine flooding and erosion.

The debris lines and coastal berms provide evidence of past floods in Norton Sound. The tundra inland of Shaktoolik flooded during the 1974 storm as evidenced by a line of driftwood debris, and residents report increasing instances when the flats inland of the village floods.

3.2 Coastal Storms and Flooding

Coastal storms and associated flooding and beach erosion pose significant risks to Shaktoolik residents. Although no flooding has been documented at the current village site, the entire townsite is located within the 100-year flood plain (U.S. Army Corps of Engineers 2011).[18] Damage to the old townsite several miles south of the current site occurred in 1960, 1965 and 1974, and some beach erosion and other damaged occurred at the current site in 2003, 2004, and 2005.[19] The September 1974 storm flooded the former community site and several storms have washed debris up on the beach ridge of the current site (R.J. Kinney Associates 2008). There has not been a storm at the current village site that has resulted in flood levels beyond a 20-year event (U.S. Army Corps of Engineers 2011).

In addition to damage documented during historic storms, there is speculation that climate change has increased the risk of storms and flooding in Alaska. As a result of later ocean freeze up, there is a longer period where fall storms will affect Shaktoolik, and higher-energy waves will impact the shoreline (U.S. Army Corps of Engineers 2009c).

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[16] Ray (1983) reports that a seismic sea wave in about 1830 washed out hundreds of buried skeletons from a site adjacent to Safety Sound, about 15 miles east of Nome.

[17] Annual fall storm surges of 20’ or more have been reported for the Diomede Islands in the early 1900s (Hawkes 1913). These surges may be influenced by the narrowness of the Bering Straits where water flows between the Bering and Chukchi seas.

[18] For flood insurance purposes, the entire community would be classified as “V Zone” where National Flood Insurance Program regulations require that buildings to be anchored to resist wind and water, protected from impacts of waves and erosion and elevated above the base flood elevation. Shaktoolik does not participate in the National Flood Insurance Program, but if it did, it would be required to meet these standards.

[19] The maximum ground height at old site 25’ while the maximum ground height at current site 24.7’ near the public safety building (U.S. Army Corps of Engineers 2011).

This section on coastal storms and flooding begins with definition of important terms used throughout the analysis. It continues with a short discussion of impacts from riverine flooding followed by a more detailed analysis of flooding risks from the marine waters of Norton Sound. Although directly related to coastal storms, erosion is discussed separately in Section 3.3.

3.2.1 Definitions

A number of terms used in this report and other documents about coastal flooding in Shaktoolik and Norton Sound relate to the elevation of water. While land elevations on topographic maps are usually measured from a global reference plane called "mean sea level" (MSL), nautical charts usually reference a local plane called "mean lower low water" (MLLW). The U.S. Army Corps of Engineers referenced flood levels to MLLW in its 2011*Shaktoolik Coastal Flooding Analysis*. A monument buried in the ground references the location of MLLW. Unfortunately, the original monument for Shaktoolik was lost to erosion, so the National Oceanic and Atmospheric Administration (NOAA) installed a new monument in association with the 2011 flooding analysis. Table 2 defines common tidal terms, and Table 3 defines other terms used to describe flood levels.

Table 2: Definition of Common Tidal Terms

Acronym	Term	Definition	How Term Is Used
MLLW	Mean Lower Low Water	Average of the lower low water elevations of each tidal day.	Elevation from which most flood levels are measured in the *Shaktoolik Coastal Flooding Analysis*. MLLW is also the reference point for below water measurements on nautical charts.
MLW	Mean Low Water	Average of all low water heights of each tidal day.	Used to determine mean tide level.
MSL	Mean Sea Level	Average height of the ocean's surface usually determined using hourly height readings (such as the halfway point between mean high tide and mean low tide).	MSL is used in 2 ways: 1) A global MSL is used as a reference plane used in topographic maps to measure onshore elevations throughout the country (NAVD88) 2) MSL also refers to a local measurement derived from a tide gauge. In Shaktoolik, the local MSL is 1.3 meters higher than the NAVD88 MSL.
MTL	Mean Tide Level	Average of MHW and MLW.	This term is used in the *Shaktoolik Coastal Flooding Analysis* with respect to the definition of "storm water level."
MHW	Mean High Water	Average of all high water heights. Also called mean high tide.	Shoreline on nautical charts and upper limit of state-owned submerged lands and tidelands in Alaska.
MHHW	Mean Higher High Water	Average of higher high water elevations of each tidal day.	Used on some older nautical charts.

Table 3: Definition of Terms Referenced in Flooding Analyses

Term	Definition	How Term is Used
Astronomical Tide	The rise and fall of seawater due to the gravitational effects of the sun and moon.	Tide levels are included in predicted flood levels.
Recurrence Intervals	The periods for which a certain storm event can be expected occur (often expressed as the 5-, 10-, 15-, 20-, 25-, 50-, and 100-year events).	Used in this report and in the *Shaktoolik Coastal Flooding Analysis* to express the risk of a storm event occurring in any given year.
Storm Surge	Rise in water levels due to extreme low pressure systems and high winds over long distances of open water (fetch).	Storm surges are a major factor in coastal flooding risks.
Storm Water Level	Level of water from astronomical tides plus storm surge and wave setup.	This term is often used in flood level estimates. It does not include wave heights, wave runup, or sea level rise.
Wave Height	The difference between the crest of a wave and its neighboring trough.	The wave height raise the level of water in community buildings, especially during 50- and 100-year events.
Wave Runup	The rush of water up a beach or structure caused by the momentum of a wave.	Wave runup is an important consideration because it can cause water to reach much higher levels than the storm surge level.
Wave Setup	Increase in water level due to waves breaking at the seashore.	Wave setup is one factor that determines the "storm water level."

3.2.2 Riverine Flooding

While flooding from the Tagoomenik River would affect Shaktoolik during extreme events, most of the flooding danger to the community is associated with storm surges in Norton Sound. Under a 50 year event, however, the river would rise to 19' above MLLW, and a 100-year storm would result in the river rising above the finished floor level of most buildings on the east side of the community (U.S. Army Corps of Engineers 2011).

Other than the 2011 *Shaktoolik Coastal Flooding Analysis* prepared by the U.S. Army Corps of Engineers, little information exists about riverine flood hazards. The 2009 *Local Multi-Hazard Mitigation Plan* does not describe flood hazards from either the Shaktoolik or Tagoomenik rivers (WHPacific 2009). Rodney J. Kinney Associates (2007), however, indicates that stream overflow has occurred in the past.

3.2.3 Coastal Storm History

Coastal storms in the Norton Sound region are documented in articles, government publications and research papers. Because of a scarcity of information for historical storms, a review of newspaper articles provided a technique to understand previous storm patterns. An analysis of newspaper accounts in the *Nome Nugget* revealed there were 60 storms in a 95-year period with big storms occurring every 10-11 years and smaller storms occurring every 3-7 years (Mason et al. 1997). Table 4 identifies storms in Norton Sound and Nome. It should be noted that effects of storms in Nome, including storm surge levels, could be quite different than in Shaktoolik.

Table 4: Summary of Reported Storms in Norton Sound and Nome

Date	Interval[20]	Description
October 5-6, 1913	Unknown (likely greater than a 100-year event)	Storm winds estimated to be up to 75 miles per hour in Nome with a 20' storm surge. $1 million in damages occurred leaving 500 people homeless. A 900-pound safe and a schoolhouse were carried 1/4th mile, and a schooner landed on top of a cabin. Impacts incurred included oil spills from broken oil tanks, a bridge collapse, road damage, destroyed buildings, and fires. The town of Solomon was completely swept away.
October 1945	Unknown	Martial law declared for Nome and storm damage included collapse of several wooden bulkheads, eroded roadways, building damage, and flooded basements. Unalakleet was reported to be in danger of being completely wiped out. $500,000 in damages (1945 dollars).
October 1946	Unknown	Storm winds up to 56 mph in Nome; flooding higher than previously recorded with water crossing a road in the east end of town; buildings collapsed; fuel tanks damaged, and water flooded basements.
October 1960	70 Years	Worst storm experienced at the former village site with a storm surge of 16.24' above MLLW. A reported 3' of water washed logs and debris over former airport just north of the Old Site and seawater entered the river.
November 1965	11 Years	Storm surge of 10.63' above MLLW. Loss of several outhouses and one dwelling in Shaktoolik.
November 1966	25 Years	Storm surge of 12.47' above MLLW in Shaktoolik.
November 1970	26 Years	Storm surge of 12.70' above MLLW in Shaktoolik.
November 1974	48 Years	Storm surge of 14.44' above MLLW'. $20,000 damage in Shaktoolik. In Nome, peak wind velocity reached 69 mph, roads and basements flooded (River Street under 5' of water), the seawall sank 2', and sewage pollution threatened drinking water. The highest levels of storm surge were located just north of Shaktoolik in Norton Bay (Brower et al. 1988).
November 1975	15 years	Details of storm not available.

[20] These recurrence intervals were initially calculated for the years 1954-2004 and extended to 2009 for the 2011 Shaktoolik Coastal Flooding Analysis prepared by the U.S. Army Corps of Engineers. Recurrence intervals have been rounded and reflect approximate values based on information available at the time of the analyses.

Date	Interval[20]	Description
1974 – 1975	n/a	Initial few houses built at the current village site.
August 1975	15 Years	Storm surge of 11.16' above MLLW in Shaktoolik.
November 1978	20 Years	Storm surge of 12.07' above MLLW in Shaktoolik.
October 1991	7 Years	Storm surge of 7.22' above MSL (9.17' above MLLW).
October 5-6, 1992	—	Basements flooded in Nome and damage to roads, fish camps, and buildings in Golovin and St. Michael occurred. Damage to roads in Nome, Golovin, Elim and the Nome-Council road. Governor Hickel declared an emergency for area. While reported in one source to be worst storm since 1974, this storm was not included in the top 10 storm surges listed in the *Shaktoolik Coastal Flooding Analysis*.
August 20, 1993	—	A storm resulted in a brief storm surge of 3.9' at Nome. The Shaktoolik fish buying station received damage to the overhead rail, dock, and shoreline. This storm was not included in the top 10 storm surges for Shaktoolik identified by the Corps.
October 1996	10 Years	Storm surge of 10.6' MLLW.
November 7-9, 2003	—	Considerable beach erosion in Shaktoolik resulted from this storm, and damage was incurred. In Nome, winds peaked at 41 mph.
October 18-20, 2004	15 Years	Shaktoolik was declared a state flood disaster area. Storm surge of 11.12' above MLLW. Considerable beach erosion resulted from storm, power lines damaged, 2,800' of fuel lines damaged, and parts of the spit flooded. Peak wind velocity was 52 mph in Unalakleet, and parts of east Front Street in Nome flooded.
September 22-24, 2005	11 years	Storm surge of 10.76' above MLLW. Shaktoolik was declared a state flood disaster area. The road south of the village flooded, thereby cutting off land access out of the village. Wave runup damaged several fences and washed gravel from under the stairwell at the Corporation building. Debris pushed up near the fuel tank farm.
November 11, 2009	Not included in Corps analysis	Storm surge of 6.4' above MLLW. Elders were moved to the school, runup deposited driftwood on the current runway, and several fences damaged from woody debris. Many residents, attributed the slushy nearshore waters as saving the community from damage because the freezing saltwater dampened wave energy.
November 8-9, 2011	Not included in Corps analysis	Slush approximately a mile offshore dampened the effects of waves. On December 5, 2001, Governor Parnell declared a disaster emergency for Western Alaska, including the Bering Strait REAA.

Sources: Blier et al. 1997; Chapman et al. 2009; General Accounting Office 2009; GenDisasters 2010; Haecker 2005; Hopkins 2009; National Climate Data Center 2010; Nome Daily Nugget 1913; Nome Nugget 1945(a), 1945(b), 1946, 1974, 1992(a), 1992(b), 2003, 2004(a), 2004(b); R.J. Kinney Associates 2008; Shaw 2011 (personal communication); Stehle 1999; U.S. Army Corps of Engineers 2011, 2009(a), 2009(c); Wise et al. 1981, Young and Lewis 1996.

Recurrence intervals include estimates of the probability that a certain storm event will occur in any given year. As an example, a flood with a 100-year recurrence interval means that in any given year, there is a one percent chance that a flood at this level will occur. It should be noted that these storm events are estimates of the probability of a storm occurring in a year. While a 100-year storm event has only a one percent chance of occurring in a single year, it is possible (although not probable) that a 100-year storm event could occur two years in a row.

3.2.4 Flooding Information

A number of factors determine whether a coastal storm will flood Shaktoolik and surrounding areas. Extreme low pressure systems can combine with wind to cause storm surges in Norton Sound. With the addition of tide and wave setup (storm water level) and wave runup, waters rise above the base level of a storm surge. During the 50- and 100-year events in Shaktoolik, the height of the waves and wave runup against buildings will cause water to rise above the storm water level.

Computer Models: When actual data are not available, computer mathematical models are used to predict flood levels and wave heights. Models are tested through a "hindcast" process that uses known storm information for past events to test the accuracy of a model. In other words, information from actual storms is used to make sure the models will correctly predict future storm events.

The 2011 U.S. Army Corps of Engineers *Shaktoolik Coastal Flooding Analysis* relies on several models to predict wave height, storm surges and wave runup. Table 5 summarizes how these models are used for the flooding analysis for the 56-year period between 1954 and 2009.

Table 5: Models Predicting Flood Levels and Runup 1954-2009

Model Name	Description
Wave Model (WAM)	Estimates wave height, wave period and wave direction for historic storms for 56-year period.
Advanced Circulation Model (ADCIRC)	Predicts storm surge water levels and currents for 56-year period.
SBEACH	Provides information about breaking waves and sediment transport and estimates of wave runup for 5- and 10-year events.

Source: U.S. Army Corps of Engineers 2011

The 2011 *Shaktoolik Coastal Flooding Analysis* adds to the storm surge estimates from an October 2009 study (U.S. Army Corps of Engineers 2009b) which in turn amended the "ADCIRC long-wave hydrodynamic model" (Chapman et al. 2005). The 2011 analysis expands coverage to include storms between 2005 and 2009.

Storm Surges: Norton Sound is especially susceptible to storm surges because of its relatively shallow depth, gently sloping seafloor and west facing opening (Blier et al. 1997, Brower et al. 1988). Surges occur when winds combine with low barometric pressures from a low pressure system (Bureau of Land Management 1980). The bathymetry of the ocean floor and the shape of the shoreline affect the level of the storm surge (Blier et al. 1997). Surges most often occur during late summer and fall when winds come from a southwesterly direction, and in general, these surges raise surface waters between 1 and 3 meters (3.3' – 9.8') above normal levels. The gradual seabed slope and the long distance over open water (fetch) that winds develop contribute to storm surges in Shaktoolik. Table 6 provides surge and wind information for the top storms between 1954 and 2009.

Table 6: Estimated Storm Surge and Wave Heights for Top 10 Storms 1954-2009

Rank	Date of Storm	Maximum Surge Above MLLW	Peak Water Elevation	Maximum Wind Direction	Return Period in years[21]
1	October 1960	16.24'	18.13'	SW	58.2
2	November 1974	14.44'	16.33'	SSE	48.1
3	November 1970	12.70'	14.58'	SW	26.2
4	November 1966	12.47'	14.36'	SSE	24.8
5	November 1978	12.07'	13.97'	SSE	20.1
6	August 1975	11.16'	13.07'	SSW	14.8
7	October 2004	11.12'	13.01'	SSW	14.7
8	September 2005	10.76'	12.67'	SSW	11.4
9	November 1965	10.64'	12.52'	S	10.6
10	October 1996	10.60'	12.48'	S	10.1

Source: U.S. Army Corps of Engineers 2011

During high storm surges, wave energy is not dissipated as it would be during normal water levels so the waves are higher (Kamphuis 2010). Wave heights are an important consideration for Shaktoolik for the 50- and 100-year storm water events because the entire community would be flooded. During those events, the waves would deposit water in buildings above the storm water level.

High tides increase the impact of storm surges, but the small difference between extreme high and low tides in Norton Sound diminishes the importance of tidal influence in this region. Considering the low elevation of Shaktoolik, however, even a small increase in water levels can be important. The tide range for Shaktoolik is estimated to be 1.95' (Chapman et al. 2011).[22]

Debris lines and beach berms provide an indication of the height of previous storm surges (Mason et al. 1997). The debris line results from storm surges combined with wave run-up and the tide. Sallenger (1983) observed a single debris line for most locations in northern and eastern Norton Sound indicating the 1974 storm likely pushed previous debris lines higher than the previous highest storm. The highest debris line of 5 meters (16.4') was located in Eastern Norton Sound, while a

[21] This column represents the recurrence interval for wave heights. A given storm may have a different recurrence interval for wave heights than for storm water level.

[22] There is an average 1.6' difference between the highest high tide and the lowest low tide in Nome during a given year and a maximum of 2.4'. In St. Michael, located approximately 110 air miles southwest of Shaktoolik, the average tidal range is 3.9' (Mason et al. 1997).

lower debris line was located in Norton Bay, north of Shaktoolik.[23] A subsequent investigation of debris lines in the region found two debris lines in many areas but only one debris line in some areas which may indicate the 1992 storm resulted in higher water lines in some areas of Northern Norton Sound than the 1974 storm (Blier et al. 1997).

Wave Runup: Flooding in the community can occur even when the storm surge level is below the top of the beach. Wave runup occurs when waves rush up the slope of the beach (or structures) depositing water higher that the level of the storm surge. In addition to damage from flooding, a high storm surge could cause damage to village structures from driftwood battering (U.S. Army Corps of Engineers 2011, 2009c and WHPacific 2009).

The SBEACH model provides estimates of wave runup for the 5- and 10-year events. Since the 10-year event produces wave runup that almost reaches the crest of the beach, the model does not predict runup for 20-year and greater storm events. It should be noted, however, wave runup can cause waves to rise above the beach when they rush against driftwood or structures.

Predicted Impacts from Flooding: The 2011*Shaktoolik Coastal Flooding Analysis* provides the most current estimate of impacts of flooding, including flooding from Norton Sound and the Tagoomenik River. That analysis supplements previous estimates by the U.S. Corps of Engineers including the October 2009 flood estimates for Western Alaska (2009b). Also, the analysis supersedes information in a 1980 map of flooding in the community (State of Alaska 1980).

The results of the 2011 flooding analysis are sobering as detailed in Table 7 and summarized below.

- **15-year Storm Event:** Waves would likely push debris into the community with a potential for damage to coastal buildings from wave-driven driftwood.
- **25-Year Storm Event:** Waves would overtop the sand spit, seawater would likely inundate the coastal side of the community, and wave-driven driftwood would damage structures.
- **50-Year Storm Event:** The entire village would be flooded, seawater would rise above the floor level of many buildings, and the river would rise to 19’ above MLLW.
- **100-Year Storm Event:** The entire village would be flooded, seawater would rise above the floor level of all buildings, and the river would rise above the floor level of most buildings on the river side of the community.

Damages from storms could be greater than implied in the above bullets because the 2011 flooding analysis did not consider the force of wave runup against buildings or potential beach erosion from storms. Also, it should be noted that water level estimates assume mean high tide, so the levels would be slightly higher during high tide. Lastly, the analysis did not consider the effects of climate change, including sea level rise and the potential for increased severity of storms.

[23] This finding appears to conflict with a 1988 report that states the highest levels of storm surge occurred in Norton Bay (Brower et al. 1988)

It may be tempting for some community members to dismiss the findings of the 2011 flooding analysis because the community has not experienced a severe storm since it relocated to the current site in 1974. According to the recent flood analysis, however, the community has not experienced more than a 20-year event at its current location, and the majority of most severe storms occurred during the 1960s and 1970s (U.S. Army Corps of Engineers 2011).

Table 7: Flooding Danger in Shaktoolik by Probability of Occurrence

Event	Probability	Water Height[24]	Flooding and Wave Runup Danger
5-Year	20%	14 feet	No flooding in village. Wave runup would reach an average of 18.4' above MLLW.
10-Year	10%	17 feet	No flooding in village. Wave runup would reach an average of 22.1' above MLLW (almost to top of the beach).
15-Year	7%	19 feet	Waves would overtop beach, but it is unknown how far inland seawater and debris would flow. Potential for damage from driftwood and debris battering buildings.
20-Year	5%	20 feet	Waves would overtop the sand spit and seawater would likely inundate the coastal side of the community but not overtop the road. Potential for damage from driftwood and debris battering.
25-Year	4%	21 feet	Waves would overtop the sand spit and seawater would likely inundate the coastal side of the community but not overtop the road. Potential for damage from driftwood and debris battering.
50-Year	2%	24 feet	The total water level at the school would be 3' above the highest point of the beach (1.7' surge plus 1.3' wave height). Seawater would be above many of the finished floor level of many of the community's buildings. The river would rise to 19', but it is not expected to rise above finished floor elevations.
100-Year	1%	27 feet	The total water level at the school would be 8.2' above the highest point of the beach (4.6' surge plus 3.6' wave height). The storm water level would be above the finished floor level of all buildings in the community. The river is expected to rise above the finished floor elevations of most buildings adjacent to the river.

Source: U.S. Army Corps of Engineers (2011), Shaw (personal communication 2011)

3.3 Coastal Processes and Erosion

This section begins with a discussion of coastal processes in Norton Sound and continues with a summary of erosion threats in the area around Shaktoolik.

[24] The water height represents the number of feet above mean lower low water (MLLW) for the storm water level (mean high tide, storm surge and wave set up). These figures do not include wave heights which would deposit additional water into buildings during the 50- and 100-year events. In addition to wave height, seawater would runup even higher as the waves run up against structures.

3.3.1 Coastal 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 to (accreted) or removed (eroded) from the coast. Typically, most erosion takes place during episodic events that often occur during a single fall storm where considerable erosion can occur. Waves cause more damage than floods (Mason et al. 1997). As a result of storms, beaches become steeper and narrower.

Beaches rebuild gradually during periods of low wave action, usually during the spring and summer. Exceptions to this general rule occur such as an October 2010 event in Kivalina where 200’ of new beach accreted in one week (Fant 2010, personal communication). During periods of accretion beaches become wider with a gentler slope. In addition to annual cycles, accretion and beach erosion patterns vary over longer periods. For these reasons, it is difficult to predict future occurrences of erosion and accretion without long-term measurements of the shoreline.

Unless physical conditions change significantly, coastlines maintain at equilibrium over the long term; when one area erodes, another area accretes. This equilibrium can be upset by changes in water levels, changes in predominant waves or changes in the source of sediments. Also, short-term erosion patterns can change, so they may not be an accurate predictor for long-term changes. For example, a pattern of beach erosion may be short lived if the sediments eroded from a beach are deposited on a sandbar offshore. As a result of the sand bars, the waves will begin to break further offshore and the beach will grow again during periods between storms (U.S. Army Corps of Engineers 2009a, Mason et al. 1997).

The mass movement of sediments from shallow water to deeper, known as sheet flow, commonly occurs in Norton Sound (Bureau of Land Management 1980). Sheet flow occurring along the seafloor is often a result of storm surges.

The net movement of sediment along Shaktoolik’s coast occurs in a northerly direction. Most of the sediment comes from a 10-mile stretch of eroding bluffs located halfway between Shaktoolik and Unalakleet (Smith 2010, personal communication). Additional sediments are moved onto the beach from offshore bars during summer months and back offshore during fall storms. The contribution of river sediments to the Shaktoolik shoreline is insignificant.

Coarse materials are deposited on the upper areas of beaches while finer sands move offshore during fall storms and onshore during the spring and summer. Wave action plays a greater role in transporting sediments than ocean currents. While there is a predominantly northern flow of sediments, occasionally waves from a different direction transport sediments in the opposite direction.

Natural coastal processes can be altered by human actions. Borrow sites from beaches and sand berms can upset the natural balance and lead to further erosion. As discussed more in the next section, construction of coastal erosion control structures often change local shore dynamics and result in increased erosion elsewhere.

While natural processes continually change the coast, there is evidence that climate change has exacerbated coastal erosion and increased the intensity of storms. For example, 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 (U.S. Army Corps of Engineers 2006a). With later freeze-up, fall storms have led to higher storm surges, a longer fetch (area where waves are formed) 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).

Regarding Shaktoolik, residents have noticed a number of physical changes to the coastline and ocean: The shoreline banks used to be steeper, the banks currently are slumping even during times between storms, the beaches used to be more gradually sloped, and currents are getting swifter in front of the village (Glenn Gray and Associates 2010a, 2010b). In addition, residents report that the water in front of the old site is deeper while the waters in front of the new site are shallower and sandbars are growing.[25]

3.3.2 Erosion

Coastal erosion occurs from wave action and from flooding. Shaktoolik is included on priority lists for Alaska communities facing impacts of erosion (GAO 2009, U.S. Army Corps of Engineers 2009, and Immediate Action Workgroup 2008 and 2009). In its 2009 *Alaska Baseline Erosion Assessment*, the U.S. Army Corps of Engineers designated Shaktoolik as one of 26 Alaska "Priority Action Communities." This designation indicates an immediate need for action which includes either an evaluation of potential solutions or continuing efforts to manage erosion. Priority Action Communities have reported serious erosion that threatens community viability.

The 2007 *Shaktoolik Economic Development Plan* identifies erosion control as the community's third top priority. The plan mentions both a breakwater and a seawall as potential erosion control measures. In the past, limited efforts have been implemented to control erosion along beach, including erosion control methods near the former fish processing plant and 55-gallon drums that were reportedly placed on the ocean side of the spit near First Bend but washed out.[26]

Areas at Risk: Most occasions of erosion around Shaktoolik involve the beaches with some limited areas of upland erosion. The following bullets summarize areas subject to past erosion and areas of concern for future erosion.

- A 1993 storm damaged the diking and embankment of the fish buying station (Young 1996).
- The active beach zone has encroached on the state airport just north of the village.

[25] Bathymetric measurements by the Alaska Division of Geological and Geophysical Surveys confirm that the water is deeper offshore of the old site, and the wave energy is greater because less energy is dissipated before it reaches the shore (Kinsman 2011, personal communication).
[26] Also, 55-gallon drums were used to control erosion from road runoff near the location of the part of the road at First Bend.

- The former village site and areas about halfway in between the current townsite and the old village site have experienced some erosion.
- Erosion may potentially affect the Shaktoolik Native Corporation building.
- The school's septic system has the potential for future erosion (U.S. Army Corps of Engineers 2009c).[27]
- Home sewer lines could be subject to erosion (U.S. Army Corps of Engineers 2009c).
- The southern and northern fuel tank farms may experience damage from an extreme storm, and as a result, erosion could release hazardous substances (U.S. Army Corps of Engineers 2009c). The U.S. Army Corps of Engineers estimates the southern tank farm will be destroyed by erosion within 10 years (U.S. Army Corps of Engineers 2009a)
- The most substantial impact from river erosion has occurred at the Tagoomenik River at First Bend (Army Corps of Engineers 2011, 2009a). The community has expressed concern that coastal erosion could breach the sand spit which would make the community an island and bring saltwater to its water supply (U.S. Army Corps of Engineers 2009c).
- Residents have noticed that local riverbanks are also eroding, and the sediments are making the rivers shallower (Glenn Gray and Associates 2010b).
- While residents report areas of accretion at the north end of the sand spit above the community in recent years, approximately 800' of the spit has eroded since 1965 (Glenn Gray and Associates 2010b).

Since the general direction of sediment drift comes from the south, erosion of areas south of the community provide materials for natural beach nourishment to the beach in front of Shaktoolik. Areas of erosion include the old village site and the bluffs located about 15 miles south of the current village site. The northern end of the spit near the outlet of the Shaktoolik and Tagoomenik rivers has accreted several hundred feet in recent years.

Aerial Photo Analyses: An analysis of aerial photos can give some idea of erosion patterns, but because the photos are just snapshots in time, this technique has some limitations. Sediment transport is a dynamic and cyclical process, and comparison of a limited number of photographs does not provide information about erosion and accretion patterns that occurred during the periods between the photographs. In addition, the timing of the aerial photo series can make a big difference if the comparisons are used to predict future rates of erosion, especially if the photo was taken after a large storm (U.S. Army Corps of Engineers 2009a). In addition, seasonal and storm-induced changes can result in "noise" that can reduce the accuracy of predicting future erosion rates.

The length of time of observations and the time span of photographs affect the ability to predict future erosion. According to the National Research Council (1990),

> erosion trend rates can only be established accurately in those areas where long-term shoreline positions are available or where the trend rates are large. Where beach erosion rates

[27] The school leach field may have been constructed with materials from the shoreline berm. Reestablishment of the berm and re-vegetating it with native plants would reduce threats to the leach field (Smith 2010, personal communication).

are calculated to be in the low range (1 foot or less per year), it must be realized that the reliability of this measurement is probably low owing to natural fluctuations in beach width (p 126).

Because there are no long-term scientific data available for accretion and erosion around Shaktoolik, the U.S. Army Corps of Engineers completed an analysis of aerial photos taken in 1980, 1994 and 2004 to estimate erosion rates (U.S. Army Corps of Engineers 2009c).[28] The analysis included measurements at 10 locations in front of the community (5,000' to the north and 9,000' to the south). While the analysis did not reveal any clear trends, comparing the photographs between 1980 and 1994 revealed that the beach either accreted or stayed the same. Between 1994 and 2004, the beaches eroded. While it is unknown whether the beaches will begin to accrete in the future, for the purpose of predicting future erosion, the U.S. Army Corps of Engineers assumed the recent erosion rate will continue. Table 8 indicates the predicted rates of erosion for three sections of the beach.

Table 8: Erosion Rates and Projected Land Loss along Shaktoolik Coast

Section	Erosion Rate	Projected Loss of Land in Next 50 years
Section 1: 9,600' on Norton Sound side of current community site	2' per year	23.42 acres
Section 2: Next 3,900' immediately south of Section 1.	1.5' per year[29]	3.86 acres
Section 3: Next 4,700' immediately south of Section 2.	3' per year[30]	17.56 acres
Total		44.84 acres

Source: U.S. Army Corps of Engineers 2011, 2009a, 2009c

The 2009 U.S. Army Corps of Engineers aerial photo analysis compared changes to the vegetation line at the crest of the beach. This analysis was updated in 2011 to include information about changes to the vegetation line at 4 new beach profiles. New information from the 2011 analysis led to a new estimate for the erosion rate for Section 2 from 1.0' per year to 1.5' per year. While the 2009 and 2011 analyses did not estimate volume of materials eroded or accreted from the sections, beach profiles completed in 2011 will allow future analysis of the volume of materials lost or gained for the 4 areas where the beach profiles were completed by the U.S. Army Corps of Engineers. In addition, the Alaska Division of Geological and Geophysical Surveys completed 37 additional beach profiles in the region during the summer of 2011, and these profiles will also allow future volumetric calculations of erosion and accretion (Kinsman 2011, personal communication).

[28] The aerial photos were orthorectified (corrected) so that the scale of the photographs can be measured like a map and compared during different time periods. There are also 3 aerial photographs taken around Shaktoolik in 1974 that were not used in the Corps' analysis (Alaska Department of Environmental Conservation 1974).
[29] The 2009 aerial photograph analysis estimated the erosion rate for Section 2 as 1.0' per year.
[30] Since the aerial photographs did not cover the area south of Section 3 adjacent to First Bend (Tagoomenik River), the U.S. Army Corps of Engineers used the 3' per year estimated rate of erosion for Section 3, the closest area for which aerial photographs are available.

Effects of Human Alterations to the Coast: In addition to natural processes and climate change, any man-made change to the coast has the potential to increase erosion or accretion of sediments along the coast. Examples of human actions that can accelerate erosion are discussed in the following bullets.

- Borrowing of sand from beaches can contribute to erosion as has been the case in Barrow and Kivalina (Mason et al. 1997). A report by the Alaska Department of Transportation and Public Facilities (1984) warned that mining of beach sand at Kivalina would exacerbate erosion and that no obstructions should be placed on the beach because they would cause scouring from turbulence. In Shaktoolik, residents report that borrowing of materials from the beach and barge landings have contributed to erosion (Glenn Gray and Associates 2010b). The removal of the natural berm near the Shaktoolik school's septic system makes this area vulnerable to future erosion (Smith 2010, personal communication).
- ATV traffic over natural beach vegetation can destabilize the beach grass as has occurred in Kivalina (Alaska Department of Transportation and Public Facilities 1984).
- An emergency erosion response that involved placement of sand-filled HESCO baskets at Kivalina during 2006 accelerated erosion (U.S. Army Corps of Engineers 2007a).
- Seawalls and rock revetments often result in erosion of adjacent beaches and may have other unanticipated results.

3.4 Permafrost Melting

Melting permafrost is a growing concern in many areas of northern Alaska. In recent years, residents of Northwest Alaska have reported instances of coastal erosion, sink holes, melting ice cellars, and encountering water when digging holes. Sink holes have been observed up the Wulik and Selawik rivers in the Northwest Arctic Borough.[31] Areas of the shoreline with melting permafrost are subject to increased erosion, especially when associated with wave action.

Permafrost melting has implications for Shaktoolik because it may cause erosion, affect drinking water quality, and reduce subsistence access in the rivers. Shaktoolik is located in an area classified as discontinuous permafrost; in other words, certain soils are not frozen while other soils have permafrost that thaws near the surface during the summer. By the end of the century, the top 30' of permafrost is expected to thaw in Alaska's discontinuous permafrost areas (Parson et al. 2009). Thawing permafrost will result in subsidence in areas where permafrost has a high ice content.

Shaktoolik is located on a well drained sand spit that is mostly free of permafrost (Rodney J. Kinney Associates 2007). Melting permafrost along the coast has the potential to affect erosion and accretion in the Norton Sound region. One potential positive effect of permafrost melting would be

[31] Shaktoolik residents did not indicate any sink holes near the community, but several people indicated during the door-to-door survey for this project that the banks of the local rivers are slumping and filling up with sediment, likely as a result of permafrost melting.

an increase in the availability of sediment that may be deposited on beaches from long distance transport of sediments from eroding bluffs and stream banks.[32]

Melting permafrost could accelerate climate change through the release of methane from hydrates in frozen soils. Methane is at least 20 times more effective in trapping heat in the atmosphere than carbon dioxide, so massive releases of methane could have significant effects.

3.5 Ice hazards

Ice hazards identified for Shaktoolik include ice override and beach erosion from large chunks of ice. The *Local Multi-Hazard Mitigation Plan* briefly mentions that ice hazards in Shaktoolik could cause beach erosion, but it does not provide details of how or when this hazard has occurred in the past (WHPacific 2009). The U.S. Army Corps of Engineers also suspects sea ice may contribute to erosion (Army Corps of Engineers 2009c).

During an ice override event, also known as an ivu to the Iñupiaq people, ice is pushed onshore from offshore winds. In Nome, a 1974 ivu reached a height of 30–40', and the 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 2 miles apart (North Slope Borough 2007). During a November 2011 storm, an ivu damaged cabins at the Golovin fish camp in Northern Norton Sound.

According to Thomas (1982), Shaktoolik elders recount ice damage from south and southeast winds. One story describes destruction of a village at the mouth of the Shaktoolik River. During that event, the sea ice was about 2' thick. When it broke up, the ivu pushed up over the tundra bulldozing sod homes a "considerable distance over the flats," and people died in the high water (pp. 22-23).[33] Thomas (1982) also mentions an ice override event 70-80 years ago at a site several miles south of village. During this event, 1.5–2' thick ice broke loose from the shore fast ice and moved on top of the beach to a point near the tundra line. Thomas said a Shaktoolik elder reported that ice has a lot of force during years when the ocean is frozen out to Besboro Island. More recently, Shaktoolik residents report there was a 24' high ice pile up near the corporation office in the spring of 2009 (Glenn Gray and Associates 2010b).

Sea ice can either dampen or increase the effects of a storm surge (Blier et al. 1997). When stable shore-fast ice is formed, it protects the shoreline from erosive forces. During the 1978 storm, shore-fast ice broke up and likely dampened the effects of waves. Slush can also be a dampening force for the impacts from storm surges on the community. Many of the participants in the door-to-door survey for this project said they believed the slushy waters during the October 2009 storm saved the community by dampening the force of the high waves (Glenn Gray and Associates 2010a). Unalakleet residents reported similar effects during the same storm (Anchorage Daily News 2009).

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[32] The contribution of this sediment that would contribute to available beach materials may be low due to the grain size of permafrost failures in the region (Kinsman 2011, personal communication).
[33] Thomas (1980) does not indicate when this ice event took place.

During the November 2011 storm, the Shaktoolik mayor reported a one-mile wide area of slush formed during the end of the storm that reduced storm damage (Asicksik 2011).

An example of when ice can be a hazard occurred during the 1974 storm when large chunks of ice damaged Nome (Mason et al. 1997, Fathauer 1978, Blier et al. 1996). When combined with a storm surge, ice can cause more damage than water alone (Bureau of Land Management 1980). In addition to damage, it should be noted that ice chunks can be beneficial by pushing sediments onshore.

3.6 Wildfires

While the Shaktoolik *Multi-Hazard Mitigation Plan* found there is a low risk for wildfires, an increase in wildfires and has been attributed to climate change (Parson et al. 2009). Alaska wildfires are expected to double by the middle of the century and triple by the end of the century. Tundra fires are predicted to increase along with increasing air temperatures (Walker et al. 2010). As a result of increased evaporation and transpiration from plants, tundra soils will become drier. A 2007 fire near the Anaktuvuk River is the largest known fire in Northern Alaska. Since 1943, 10 wildfires burned an estimated 20,765 acres within a 25-mile radius of Shaktoolik (WHPacific 2009).

3.7 Responses to Threats of Natural Hazards

Responses to climate change include both mitigation and adaptation. Mitigation refers to efforts to reduce impacts by man that affect climate such as a reduction in release of greenhouse gases. Adaptation involves actions to avoid or minimize impacts from climate change, such as developing local zoning and building codes, constructing shoreline protection structures or relocating a community. This report focuses on options for adaptation rather than mitigation.

This section begins with a general discussion of actions a community can take in response to flooding and erosion. It continues with a discussion of actions already taken by the community and ends with recommendations made by Shaktoolik residents, consultants and government agencies.

3.7.1 Potential Responses to Increased Erosion and Flooding

Communities may adapt to climate change-related impacts through a number of responses. A community may choose to raise, anchor or move buildings; construct shoreline protection structures (e.g., rock revetments, sand bag structures); replace eroded materials (i.e., beach nourishment); collocate community members in an existing community; or relocate the community to a new site.

Erosion response actions involve either “hard stabilization” or “soft stabilization” approaches. Hard stabilization techniques protect onshore structures, but they can accelerate beach erosion. Hard stabilization includes structures that are located onshore parallel to the shoreline (seawalls, revetments and bulkheads), offshore structures parallel to the shore (breakwaters), and structures perpendicular to the shore (groins and jetties). In most situations, structures such as seawalls or rock revetments will eventually cause the beach in front of the structure to disappear and may require future expansion on either side (Bush et al. 1996). Jetties and groins are used to encourage accretion by trapping sediments on one side, however, they can cause erosion on the other side.

Some states restrict use of hard stabilization techniques (NOAA 2010). The California Coastal Act allows hard shoreline protection measures only when there is a threat to a structure and there are no other feasible solutions. North Carolina prohibits permanent coastal erosion control structures, although in 2011, the General Assembly allowed construction of terminal groins in some circumstances.[34] In Rhode Island, the Coastal Resources Management Council prohibits hard erosion control measures along the ocean, such as bulkheads, seawalls, breakwaters, and jetties. New Jersey has a policy that encourages beach nourishment rather than hard structures.

Soft stabilization includes re-vegetation of dunes and beach nourishment. Sometimes called beach replenishment, this technique usually involves pumping of sand from offshore areas to the shoreline to extend the beach, although sometimes materials are deposited on the beach using dump trucks from an onshore source. Beach nourishment is not a permanent solution, and it must be repeated as the beach continues to erode. While there is little experience using this technique in Alaska, experience on the East Coast shows that beaches must be replenished every 2-9 years depending on site-specific conditions (Bush et al. 1996). An understanding of coastal processes is necessary when determining where to obtain the materials for replenishment to avoid unintended consequences. For example, mining sand from a beach can lead to accelerated erosion at that site. Also, use of materials from an offshore area could reduce the amount of sediments that would be naturally deposited and create channels in offshore sandbars that would magnify impacts of a storm (Mason et al. 1997).

Dune management can also protect upland areas from erosion, but natural processes should be assessed before creating new dunes. Dunes can be created by placing new materials along the coast and vegetating them with native plant materials. In some cases, fences can be used to trap sand, but this technique may not be applicable to Shaktoolik because of the grain size of sand in the vicinity of the community.

The U.S. Army Corps of Engineers (2009a) identifies categories of engineering responses to coastal erosion: 1) Armor the shoreline ("draw the line"), 2) slow the loss through shoreline restoration (e.g., beach nourishment), 3) adapt ("live with it"), or 4) do nothing and abandon the area. Regarding shoreline protection efforts, the report identifies factors that should be considered: Strength (ability to withstand wave force), flexibility (ability to settle without failing), and protection from undermining of materials in front of the structure (toe protection) and along the sides of the structure. In most circumstances, structures with gentle slopes and high porosity (drainage) will receive less toe scour.

Appendix H of the Alaska Baseline Erosion Assessment discusses 3 expedient coastal protection measures appropriate for Alaska considering locally available materials and the ability for a locally mobilized work force (U.S. Army Corps of Engineers 2009a).

- Geotextile sandbags, composed of either polyester or polypropylene, are filled with sand or gravel. These bags are placed on top of a filter fabric, overlapped and extended below

[34] The 2011 legislation, Session Law 2011-387, received opposition because of potential erosion caused by groins.

MLLW. This alternative requires annual maintenance and may not be suitable to areas subject to ice damage.

- Beach nourishment involves replacement of sediments eroded from a beach with material at least as coarse as the eroded materials. Materials can be placed from onshore sources or dredged from offshore sources. Wider beaches reduce damage from storm damage, and erosion of the new materials to areas offshore will reduce the amount of large waves from reaching shore. Beach nourishment efforts will need to be continued periodically depending on the rate of the new material. Gravel will last longer than sand and may be an economical option for Alaska (Mason et al. 1997).
- Modified geotextile wrap-around revetments involve filling large sheets of fabric and wrapping them around an enclosed structure. The layers are sewn together. While this technique has not been used in Alaska, it has had success in other areas.

In a report on the effects of climate change on Point Hope, the Alaska Native Tribal Health Consortium (ANTHC) recommends increasing the local capacity for monitoring and managing climate change-related impacts (ANTHC 2010). The report recommends increasing the dialog among Arctic communities about adapting to climate change. Table 9 lists guidelines for climate change adaptation recommended by ANTHC.

Table 9: Ten Principles for Integrating Climate Change into Local Decision Making

1	Protection of human life and health is a top priority.
2	Traditional values should guide local and regional decision making.
3	Development should follow the principles of sustainability.
4	Community adaptation plans should identify valued local resources, such as subsistence areas, cultural sites, and critical water sources and develop plans to protect them.
5	Critical ecological systems, wetlands and subsistence resource areas should be protected where possible.
6	Consideration for climate impacts on erosion, flooding, subsistence, water availability, and transportation should be incorporated into planning and infrastructure design and siting.
7	Cost-benefit analyses should be applied to evaluate the social and environmental costs of building and maintaining coastal protection structures.
8	Phased abandonment of at risk areas should be considered.
9	Coastal emergencies are inevitable and disaster response and recovery capacity, including evacuation routes, emergency response plans, drills, and shelters should be reviewed and kept current.
10	Building capacity to participate in monitoring, research and advocacy is critical to facilitate development of effective adaptation strategies.

Source: ANTHC 2010

Mason et al. (1997) provide some general rules for construction of seawalls.

- Use filter cloth beneath seawalls. A seawall in Shishmaref failed because sand behind it washed out (Mason et al. 1997). Similarly, a concrete revetment in Kotzebue failed in some areas due to gravel washing away. The use of filter cloth will allow water to pass through the fabric while trapping sediments.
- Use footings that are deep and well anchored.
- Use anchors to tie the wall back into the land.
- Revetments will reduce beaches and result in steeper slopes underwater.
- Hard stabilization of any kind will reduce transport of sediments and lead to beach reduction on the downdrift side (and sometimes in the updrift side).
- Ask for examples of what has worked in other similar situations.
- "A few dump truck loads of coarse gravel each year will help preserve an important community asset for future generations. A revetment will destroy it" (p. 110).
- The Nome beach was destroyed after completion of the 1951 seawall.

Seawalls may also redirect driftwood out to sea (Mason et al. 1997). This is an important consideration for communities like Shaktoolik that depend on driftwood for fuel and other uses.

When evaluating erosion control alternatives, it is important to consult with a coastal engineer for all shoreline protection projects, including emergency responses (U.S. Army Corps of Engineers 2009a). This consultation is important because dynamics of coastal erosion and accretion of sediments is different than for rivers. Construction of coastal erosion protection structures often has unanticipated results and in some cases can make the problem worse. For example, construction of a shoreline protection effort in Northwest Alaska "failed shortly after construction and potentially increased local beach erosion in front of the structure" (U.S. Army Corps of Engineers 2009a, p. H-4).

3.7.2 Previous Actions Taken

As discussed in Section 2.2.3, Shaktoolik has relocated the community several times in the past because of threats of erosion and flooding. In addition, the infrastructure at the current townsite received damage from several storms, including the storms of 1992, 2004, 2005, and 2011 when the Governor declared the area a disaster.

In addition to repair of buildings and other infrastructure, there have been some efforts to respond to erosion. In 1993, repairs to the fish buying plant from storm damage included repair work to the adjacent embankment (Young and Lewis 1996). As a response to 2005 flooding, the State of Alaska funded repairs for the safety area and navigational aids at the airport (Immediate Action Workgroup 2009). Previously, oil drums filled with sand and gravel were placed on either side of the sand spit near the First Bend of the Tagoomenik River to protect the road surface from erosion, but they do not protect erosion from the river at the toe of the bank (U.S. Army Corps of Engineers 2009c). Drums placed on the ocean side of the sand spit have washed out.

3.7.3 Recommended Flooding and Erosion Responses for Shaktoolik

Specific recommendations have been made regarding actions Shaktoolik should take in response to increased threats from flooding and erosion, including recommendations in the *Local Multi-Hazard Mitigation Plan*, the U.S. Army Corps of Engineers documents, evacuation road documents, and in plans for constructing an emergency shelter.

Additional Investigations: The U.S. Army Corps of Engineers (2011) recommended additional investigations be completed to address safety issues, including design analysis of structural flood control measures (e.g., a revetment for wave protection or relocation of structures) and flood proofing of buildings (e.g., elevating buildings and mechanical and electric units).

Local Hazard Mitigation Plan: The *Local Multi-Hazard Mitigation Plan* recommends 4 actions:

- Complete shoreline protection measures to protect critical infrastructure,
- Construct an evacuation road,
- Construct erosion protection at First Bend to protect water source from saltwater intrusion or move the water intake to another location, and
- Mark navigable waterways in the rivers to aid evacuation efforts (WHPacific 2009).

Articulated Concrete Mat: A 2009 evaluation of erosion control measures for Shaktoolik considered a number of alternatives including a rock revetment, articulated concrete mat, groin fields, beach nourishment, and relocation of structures (U.S. Army Corps of Engineers 2009c).[35] Table 10 compares the costs for these alternatives. After analyzing options, the U.S. Army Corps of Engineers recommended an articulated concrete mat which involves connecting concrete blocks with metal cables. The plan would involve construction of 260' of mat in front of the south tank farm. The sides and bottom of the mat would be placed on the natural slope and embedded into the beach. The cables connecting the concrete blocks will eventually rust, but it would have an estimated life of 15 years. The cost was estimated to be about $3.3 million as opposed to $6 million for a rock revetment. A feasibility study may need to be completed to determine if this option is still viable.

Table 10: Possible Solutions to Abate Erosion in Shaktoolik

Proposed Action	Cost
Revetment at Community: Construct 4,500' revetment in front of community.	$29.2 million
Revetment at First Bend: Construct 3,350' revetment to protect water supply from saltwater intrusion.	$18.6 million
Groin: Construct a groin field in front of the community to trap sand migrating parallel to the shore which will cause deposition of sand on beach.	$30.8 million
Beach Nourishment: Add sand to beach.	$36.5 million

Source: U.S. Army Corps of Engineers 2009a

[35] Section 103 of the 1962 Rivers and Harbors Act authorizes federal funding for protection from storm damage.

Tank Farm Relocation: It should be noted that the community is also pursuing funding to move the south tank farm with AVEC and the Denali Commission. Moving the tank farms to an upland location was included as Priority #6 in the 2007 community economic development plan, although no specific site was mentioned.

First Bend: Construction of erosion protection to protect the first bend of the Tagoomenik River from saltwater intrusion from potential erosion of the sand spit has been considered. The U.S. Army Corps of Engineers found, however, "that the current water intake structure can be relocated by others to a location safe from the threat of breaching at a substantial savings compared with structurally protecting the potential breach area" (U.S. Army Corps of Engineers 2009c, p. 8).

Airport: The Alaska Department of Transportation and Public Facilities is responsible for the airport and the road from the airport to the community.

Evacuation Road: Section 5 addresses investigations about the feasibility of an evacuation road.

3.8 Opportunities and Information Needs for Natural Hazards

This section provides an initial list of opportunities and information needs related to coastal hazards. The purpose of this list is to provide the community with options it may wish to pursue.

- **Community Plans:** When updating future community plans and establishing community priorities, the City, Tribe and corporation may wish to consider new information about natural hazards when updating the priorities.
- **Driftwood:** Residents have expressed concerns that driftwood could act as "battering rams" during a high flood event. Driftwood also dampens waves in many situations, so removal of the driftwood barrier should only be done after consultation with a coastal engineer. Two possible solutions to this concern may merit additional investigation.
    - During the door-to-door survey for this project, one resident suggested partially burying driftwood to provide a temporary solution to reduce the risks of driftwood battering the tanks during a storm surge while at the same time protecting the beach from further erosion.
    - Another potential solution would be to install steel posts to provide a barrier to driftwood movement or to install a heavy duty 4' chain link fence directly in front of buildings adjacent to the beach (Smith 2010, personal communication). This barrier would trap floating debris and sand eventually creating a berm.
- **"Soft" Erosion Control Techniques:** Shaktoolik may wish to investigate the feasibility soft erosion control techniques. Many states encourage "soft" erosion control techniques as a first line of defense and approve "hard" responses, such as rock revetments or groins, as a last resort.
    - **Beach nourishment:** The beach in front of the community could be nourished by placing materials of the same or larger grain size as existing material. Material could be dredged from offshore areas or trucked from area accreting on the north end of the spit near the mouth of the Shaktoolik River.

- **Berm:** One possible solution to erosion in front of the community would be to raise the berm and plant it with native beach rye. Planting native species along other parts of the eroding coast may also be feasible. A demonstration project could be initiated at the school septic system site since it appears that the current vulnerability to erosion was caused by previous destruction of the natural berm.
- **Beach Grass:** Efforts to reestablish beach grass may also impede future erosion. For Kivalina, the Alaska Department of Transportation and Public Facilities (1984) found that beach grass may be the major reason the island has not washed away.

- **"Hard" Techniques:** If "soft" techniques are not feasible, the community may wish to investigate other alternatives such as rock revetments, articulated concrete structures or low cost groins (jetties) that would trap sediments. The community has discussed construction of a formerly planned road adjacent to the beach to provide erosion and flood protection.
- **Channel Markers:** Placement of channel markers will assist evacuation during periods of high water when the flats are flooded (Okleasik 2003). Without channel markers, boats may become stranded in shallow water.
- **Flood Level Marker:** Placement of a marker calibrated to MLLW would allow real-time monitoring of flood levels.
- **Local Monitoring:** Shaktoolik may wish to pursue grants for community monitoring of erosion and flooding. Community residents voluntarily keep track of the rate of water rise during storms with improved markers. A more formal observation program would be useful to gain a better understanding of flooding danger.
- **Local Hazard Mitigation Plan:** When updating this plan, new information should be incorporated, including information from the 2011 U.S. Army Corps of Engineers study.
- **Geohazard Evaluation:** The Department of Natural Resources Division of Geological and Geophysical Surveys (DGGS) is conducting a Geohazard Evaluation and Geologic Mapping project for Shaktoolik (State of Alaska 2009). This effort will result in maps that delineate natural hazards and improve the quantification of natural hazards in and around Shaktoolik.[36]
- **IGAP Program:** The EPA provides funding to the Native Village of Shaktoolik to participate in the Indian General Assistance Program (IGAP) which provides funding for environmental programs. The IGAP program may provide an opportunity to address some of the issues raised in this document.
- **Grant Opportunity:** Shaktoolik has supported submission of a grant application by the University of Alaska Seagrant Program to continue community planning and development of an adaptation plan.

4. Evacuation and Emergency Planning

This section addresses evacuation and emergency planning efforts for the community of Shaktoolik. These efforts include completion of the *Local Multi-Hazard Mitigation Plan* and a suite of 3 plans

[36] These maps may be useful when considering potential relocation sites because natural hazards in the area will be mapped.

that address emergency planning and response: *Emergency Operations Plan*, *Evacuation Plan* and *Continuity of Operations Plan*.

The *Local Multi-Hazard Mitigation Plan* identifies actions Shaktoolik can take to reduce the loss of life and property from natural hazards (WHPacific 2009). This plan characterizes risks of hazards to the community and recommends mitigation efforts to reduce or eliminate long-term risk from hazards. The plan includes a community overview, a capability assessment, a risk assessment, and a mitigation strategy. Hazards present in the community include flooding (high), erosion (medium), severe weather (high), wildfire (low), and earthquakes (medium). The plan includes a mitigation strategy with actions Shaktoolik should consider. Specific findings of this plan are discussed above under the natural hazards section. According to the mitigation plan the community was forced to evacuate on at least one occasion.

The *Emergency Operations Plan* describes how the city, IRA and Shaktoolik Native Corporation will cooperate to mange emergencies, including their participation in the incident command system. The plan describes procedures for mitigation and prevention, preparedness, response and recovery. It outlines responsibilities of local, state and federal agencies and organizations. Specific hazards that may result in an emergency include fires, adverse ice conditions, flooding and erosion, extreme weather, earthquakes, tsunamis, hazardous material releases, and terrorism. The plan specifies training that is needed for members of the incident command system and exercises the community should complete, including "tabletop" and full-scale exercises. Appendices to the plan include a memorandum of understanding to implement the plan, forms and guides.

The *Evacuation Plan* outlines procedures for community evacuations, including an incident command system that involves the City of Shaktoolik, the Native Village of Shaktoolik, the Shaktoolik Native Corporation and the Village Public Safety Officers. The plan specifies that elderly, small children with at least one parent, and individuals with medical needs will be given priority for evacuation. Evacuation orders may be given for residents to remain at home (shelter-in-place), convene at a location within the community or evacuate to areas outside of Shaktoolik. Evacuations may apply to certain parts of the community or the entire village. Evacuation locations include the school (for elderly, families with small children and people with special needs), the Youth Camp (for youth located outside the community accessible by boat), and the National Guard Armory (for others). Evacuation orders will be given on the VHF radio, by telephone, through door-to-door notifications and through television and radio announcements.

The *Continuity of Operations Plan* addresses how the community will provide essential services to Shaktoolik residents during responses to severe weather, natural or manmade hazards or malevolent attack. This plan covers all facilities, vehicles and buildings operated by the city, tribe and the Shaktoolik Native Corporation. The plan lists essential functions, responsible persons and actions that will be taken to maintain these functions. Three scenarios are covered by the plan: A single building, a catastrophic event that affects the entire community and a pandemic influenza outbreak.

The youth camp, located 8 miles across the Tagoomenik River, has been designated as an alternate facility with 5 permanent structures that could be used for shelter.

No evacuations have occurred at the present community site, although an evacuation occurred at the prior community site about 1964 (Bekoalok 2010, personal communication). During a fall 2009 storm, elders were moved to the school. The high water levels during recent storms, however, have resulted in concerns by the community about a potential need for evacuation. The door-to-door survey conducted for this project in April 2010 revealed that many community residents are unsure of what to do if an emergency occurred (Glenn Gray and Associates 2010a).

Emergency planning will strengthen a community's resiliency. Resiliency is the "capability to anticipate, prepare for, respond to, and recover from significant multi-hazards threats with minimum damage too social well-being, the economy, and the environment" (Council on Environmental Quality 2010. P. 15). Emphasis on resiliency planning for climate change-related impacts may be especially suited for Shaktoolik because it provides the ability to incorporate Inupiaq and Yupik values. Resiliency planning incorporates social, cultural, economic, ecologic, and physical factors in response to natural hazards (Coastal States Organization 2010).

4.1 Opportunities and Information Needs

In response to new information in the three emergency planning documents discussed above in the *Shaktoolik Coastal Flooding Analysis*, changes to the 2008 *Local Multi-Hazard Mitigation Plan* are needed. In addition, an update to the plan could provide useful information for evacuation planning, including an analysis of how risks from natural hazards may be affected by construction of erosion protection and flood proofing of infrastructure.

5. Evacuation Road and Shelter

The community has expressed interest in both an evacuation route leading to higher ground and an emergency shelter that would be located in the community. Details about the planning for the evacuation road and emergency shelter are discussed below.

5.1 Evacuation Road

Construction of an evacuation road is the second priority in the community's economic development plan (Kawerak 2007). Many community residents support construction of an evacuation road (Glenn Gray and Associates 2010a).

The Alaska Department of Transportation and Public Facilities, the regional nonprofit corporation Kawerak and others are collaborating to assist the village in determining the feasibility of building an evacuation road from the existing village to a potential relocation site. The potential site needs to be assessed to determine if it is safe and suitable for village relocation, and whether a land exchange may be necessary if some, or all, of the site includes federal lands.

Transportation Plan: The Shaktoolik Long Range Transportation Plan identifies 9 priority projects, and 3 of these priorities address evacuation or relocation (Rodney P. Kinney Associates 2007). The 3rd priority in the plan addresses a road to the Foothills for material access, subsistence access and for evacuation purposes ($64 million). The 4th priority project is to construct roads within the new townsite ($40 million). The 5th priority is to rehabilitate the existing 23 miles of the Foothills route immediately south of the community ($26 million). The City of Shaktoolik only has authority for lands within its boundaries, so roads outside of city limits must be approved by the federal, state or private landowner. The Shaktoolik IRA will be responsible for maintaining any future roads constructed under the Indian Reservation Roads (IRR) program.

2007 Scoping Report: Appendix E of the *Shaktoolik Long Range Transportation Plan* includes a *Scoping Report* for an evacuation road. The report evaluates two alignments for an evacuation road. Both alignments include an initial 1.5 mile segment that begins south of the existing village and would involve two bridges across the Tagoomenik River. Alternative A would continue 11.7 miles due east to the Nulato Hills, and Alternative B would involve a 3.5 mile segment due north to a 350' hill. The 14'-wide single lane road would have turnouts. The initial estimated costs for the evacuation road are between $20.7 million (Alternative B) and $37.9 million (Alternative A).

Reconnaissance Report: The Denali Commission, Bureau of Indian Affairs (BIA) Indian IRR Program and Kawerak, Inc. provided funds for completion of the 2008 *Shaktoolik Evacuation Road Project: Road Reconnaissance Report* (Rodney P. Kinney Associates 2008). The evacuation road would extend from the village south to the Foothills at an estimated cost of $33,398,822. The road would be 14' wide with turnouts, and either the City of Shaktoolik or the Native Village of Shaktoolik would be responsible for maintaining it.

As a result of meetings with the IRA, the new proposed route differs from the routes evaluated in the 2007 Scoping Report. The reconnaissance report splits the road into the following segments.

- **Segment 1 (4.2 miles):** This segment begins north of the school and ends to the south of the former village site where the Tagoomenik River is close to Norton Sound. Work would include raising the first 4.1 miles of the road, straightening its alignment, installing culverts, repairing washed out sections, resurfacing with crushed aggregate, installing 2,000' of armoring, and applying dust treatment.
- **Segment 2 (5.7 miles):** This segment begins at the south end of segment 1 and continues southeast for 2.7 miles and then south along Beeson Slough for another 3 miles. Culverts will need to be placed in this section.
- **Segment 3 (4.7 miles):** From segment 2, segment 3 follows higher ground along Beeson Slough for 3.3 miles where it travels westerly to end at an existing gravel source at Norton Sound. Culverts will need to be installed in this section.

Right of way easements would be needed for all 3 segments other than the in-town portion of Segment 1. Shaktoolik's spit is composed of course granular sand and gravel, and its elevation ranges from sea level to about 30' above sea level.

Additional investigations will be needed to determine if there are areas of permafrost, what sections will need to be armored, wetlands delineations, archeological field investigations, an environmental site assessment, investigation to the extent of the material source, and where culverts need to be placed. None of the segments are anticipated to have high environmental impacts, and the costs for constructing each segment are assumed to be equal.

Other Benefits: While the main purpose of the road would be to provide an escape route during a hazardous storm or other emergency, it would also be used for access to a gravel source, subsistence hunting and fishing resources and cabins that could be used for emergency shelter.

5.2 Community Emergency Shelter

The community has considered 2 different alternatives for emergency shelters in recent years. Previously, the community considered construction of cabins along the evacuation route for emergency use (Immediate Action Workgroup 2009). Currently, the Native Village of Shaktoolik is investigating the feasibility of constructing a multipurpose building in the community that could serve as an emergency shelter. With a $150,000 planning grant from the State of Alaska Climate Change Impact Mitigation Program, the community is working with USKH to provide engineering and architectural background and to facilitate a collaborative decision making process. The project involved holding a design “charette” which involved a process to gain input for the design of the facility. The site of the shelter has tentatively been identified as the location of the current tribal office.

The 2007 economic development plan identifies a multi-purpose building as the 4th highest priority (Kawerak 2007). The building would replace the inadequate current buildings for the City, tribe and community hall. Since the plan was completed, the proposed multi-purpose building would be combined with and emergency shelter.

5.3 Opportunities and Information Needs for an Evacuation Road and Shelter

This section identifies opportunities Shaktoolik may wish to pursue and areas where more information is needed. As mentioned in the previous section, a current project is underway to design a multi-purpose building that will provide needed upgrades to current offices while providing a safe place for the community to assemble during storms. Should fill material be needed to raise the building above the 100-year flood level, the community may wish to investigate the feasibility of obtaining materials from an area near the river that could be used as a boat harbor.

In addition, the construction of a shelter within the community could reduce or eliminate the need to build an evacuation road, and this issue should be addressed in future community planning.

6. Options to Relocate or Remain at the Current Site

Natural hazards have always been a concern for Shaktoolik. As described in section 2.2.3, Shaktoolik has moved a number of times over the past 100 years as a result, in part, of coastal hazards and erosion threats to river banks.

The community has discussed potential relocation sites, although no formal process has been initiated to complete a thorough evaluation of potential sites. The lack of progress towards relocation frustrates some community members while others do not believe relocation is necessary at this time (Glenn Gray and Associates 2010a).

In 2009, the General Accounting Office (GAO), the research branch of Congress, found that other than for the village of Newtok, little progress has been made to relocate Alaska villages that are at risk from natural hazards. The 2009 report 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 listed Shaktoolik as one of its Priority Action Communities.

The remainder of this section begins with a discussion of relocation sites identified by the community and ends with a discussion of potential options to remain at the current site.

6.1 Relocation Alternatives Discussed by the Community

According to village residents, Shaktoolik elders requested the community investigate options for relocation (Glenn Gray and Associates 2010b). No comprehensive study has been conducted, however, to evaluate potential relocation sites.

In 2009, the GAO found that Shaktoolik was one of 4 Alaska villages in immediate need of relocation. Shaktoolik has not identified a preferred relocation site that state and federal agencies and village officials agree on, and the U.S. Army Corps of Engineers has not estimated the costs of relocation.[37]

Shaktoolik has informally discussed potential relocation sites during meetings. Sites located adjacent to Norton Bay north of Norton Sound have been discussed, but these sites have been opposed because the shorefast ice does not melt as quickly in the spring as other potential sites. A site at the

[37] Shaktoolik was not included in the 2006 *Alaska Village Erosion Technical Assistance Program* report prepared by the U.S. Army Corps of Engineers that included costs for relocation for 7 Alaska communities.

Reindeer Mountains near Cape Denbigh has been discussed because of potential natural gas resources in that area (Bekoalok 2010, personal communication). The GAO (2009) reports the community considered a potential relocation site near Christmas Mountain which is about 8.5 miles northeast of the current community. The most popular area for relocation appears to be a site near the Foothills located about 14 miles southeast of the current site (Glenn Gray and Associates 2010a). The evacuation road reconnaissance report provided an initial investigation into a road that would lead to this site (Rodney P. Kinney Associates 2008).

Some of the attributes important to community members for a relocation site include a reliable source for potable water and a location that is protected from erosion and flooding with easy access to subsistence resources located in the ocean, rivers and on land. Early spring melt of ocean ice is also an important consideration. In addition, coastal locations may be more feasible than inland locations because of the added costs involved with transporting fuels and supplies upriver.

At least 4 Alaska communities have relatively recent experience relocating in response to natural hazards. Point Lay and Point Hope, in the North Slope Borough, relocated in response to coastal erosion issues, and Valdez relocated in response to earthquake damage. Newtok is currently in the process of moving to a new site called Mertarvik, and its experience might be useful to Shaktoolik if the community pursues relocation.

6.2 Options to Remain at the Present Site

No comprehensive study has been completed to determine the feasibility of remaining at the current site, although the 2011 flooding analysis provides detailed information about flooding risks. Opportunities and information needs are discussed in this section.

6.3 Opportunities and Information Needs

The following bullets outline information needs and opportunities the community may wish to pursue depending on the next steps it chooses during the community planning process.

- **New Information:** The *Shaktoolik Coastal Flooding Analysis* provides new information about flooding and erosion hazards, and the DGGS Geohazard Evaluation and Geologic Mapping Project will provide additional information about hazards.
- **Funding Availability:** Shaktoolik may wish to explore opportunities to investigate the future alternatives in response to natural hazards including relocation or remaining at the current site.
- **Future Erosion Protection:** The community may wish to investigate possible techniques for temporary or permanents responses to flooding and erosion.
- **Local Planning Committee:** Shaktoolik may wish to create a local planning committee to evaluate future options. This committee would be a useful forum to address recommendations that result from the Shaktoolik Planning Project.

7. Next Steps

The *Final Project Report* for the Shaktoolik Planning Project outlines priorities and next steps identified by the community to respond to threats from flooding and erosion. Once the project is completed, the community may wish to convene a community planning group as recommended by the Immediate Action Workgroup (IAG) of the Governor's Subcabinet on Climate Change. This group could evaluate options and develop priorities. The IAG recommended the group include representatives from the Tribe, city, school, Shaktoolik Village Corporation, and Kawerak. Because no single agency is responsible for addressing impacts to communities from climate change, it will be important for Shaktoolik to coordinate its efforts with state and federal agencies and other communities. In addition, the IAG recommended a phased and coordinated approach among the communities of Shishmaref, Kivalina, Shaktoolik, and Unalakleet.

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