REPORT

HAZARD IMPACT ASSESSMENT

Kipnuk, Alaska

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EXECUTIVE SUMMARY

Climate warming trends have put the community of Kipnuk at greater risk for climate change-related hazards. As part of the Alaska Climate Change Impact Mitigation Program (ACCIMP), administered by the Alaska Department of Commerce, Community, and Economic Development (ADEC), a Hazard Impact Assessment (HIA) of the community of Kipnuk was conducted by Duane Miller Associates (DMA) now Golder Associates Inc. (Golder).

The HIA provides a general baseline data collection effort and review of existing data. Onsite data collection included a community-wide survey of historical observations, ground temperature measurements, active layer probe depths, relative elevation and riverbank survey, school pile cap relative survey, and visual observations of typical home and public structure foundations. In addition to on-site data collection, existing climate, hydrology-related erosion, and geotechnical data were compiled.

Threats to the community were identified such as destructive seasonal and storm-related flooding, riverbank erosion, and ground settlement due to thawing of permafrost. During flooding, school access is sometimes restricted, sewage lagoons and the landfill are sometimes overtopped. The entire community is subject to flooding during severe events. Riverbank erosion rates are estimated from 6 to 9 feet per year, though localized erosion rates vary. Residents reported between 15 and 20 feet of riverbank loss near the fuel transfer facility during the summer of 2009. Kipnuk is underlain by marginally frozen, thaw-unstable ground that is subject to thaw-settlement that results in ground surface subsidence, increasing the degree of flooding and potential loss of foundation support for public and private buildings.

Conceptual-level mitigation measures are discussed in the HIA in relation to each of the identified hazards. Additionally, the HIA identifies that additional data is needed to quantify the following:

- Establish mean sea level and normal tidal fluctuation
- Variations in riverbank erosion rates
- Storm and related surge frequency and severity
- Rates of ground and air temperature changes
- Rates of permafrost degradation and ground settlement

These additional data are needed to assist the community of Kipnuk in developing plans for the near and long-term future.

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1.0 INTRODUCTION

This document presents the results of the Hazard Impact Assessment prepared by Golder Associates Inc for the Kipnuk Tribal Council. The project began under DMA, which was acquired by Golder in 2009. The purpose of this project was to identify potential climate change-related hazards for the community of Kipnuk, located on the Kuguklik River in western Alaska. The document will serve as a baseline for future studies and planning.

Our scope of work included field studies (measurement of active layer, relative riverbank location survey, relative elevation survey, general observations of foundation types and performance), community questionnaires, interviews, and town-hall meetings, a written report that includes a summary of newly collected and existing data, descriptions of identified climate change-related hazards, conceptual mitigation measures, potential funding sources, and recommendations for future study.

Climate change-related hazards affecting the community of Kipnuk were identified, including trends and impacts to Kipnuk. Resident's anecdotal observations were documented. Limited quantitative data was developed, using readily available existing data sources. Generalized conclusions regarding conceptual-level mitigation measures were developed to address hazards including riverbank erosion, flooding, and permafrost degradation.

The Hazard Impact Assessment team included Susan Wilson, geologist, Jeremiah Drage, PE and Duane Miller, PE, geotechnical engineers, of Golder, Anne Brooks, PE, public involvement coordinator, of Brooks and Associates, and Doug Jones, PhD, hydrologist, of Coastline Engineering. The project team consulted with Jimmy Paul, Tribal Administrator, and Paul J. Paul, President, of the Kipnik Traditional Council, and Sally Cox and Erik O'Brien of the Alaska Division of Community and Regional Affairs (DCRA).

Existing data was gathered, compiled, and analyzed. Information from residents was collected through interviews and distribution and collection of a questionnaire survey. Baseline 2009 Kipnuk technical data was collected including a relative elevation survey, active layer probe depths, ground temperature measurements, school pile cap relative elevation survey, and general observations of foundation performance during a October 2009 community visit. State and Federal agencies were contacted regarding information related to Kipnuk and ongoing or proposed projects in Kipnuk.

2.0 METHODOLOGY

Data collection consisted of compilation of existing information, resident contributions, and onsite data collection.

2.1 Existing Data Collection

Existing information from publicly available sources and previous DMA projects was compiled for Kipnuk. Information sources included DCRA, Alaska Department of Commerce, Community, and Economic Development (ACED), US Army Corps of Engineers (USACE), Alaska Department of Transportation and Public Facilities (AKDOT&PF), Lower Kuskokwim School District (LKSD), Alaska Native Tribal Health Consortium (ANTHC), and DMA's library of previous work in the Kipnuk area.

2.2 Resident Observations

A community survey was conducted, consisting of distribution of a questionnaire related to historical hazards. The goal of the community survey was to determine residents' views and personal accounts of critical infrastructure, historical knowledge of hazard events, and future concerns. Questions included on the community survey were based on compiled available data. The community surveys were distributed prior to and during a Community Workshop. Throughout the site visit, residents of Kipnuk were very helpful and eager to share their knowledge. Many residents discussed their concerns directly with the project team.

The Community Workshop was held on Friday, October 16th, 2009 at the Traditional Council Building. The project team described the project scope and data collection efforts, and asked questions of the group and answered questions from the group. Surveys were available for completion during the meeting, and door prizes were awarded by drawing at the conclusion of the meeting. Resident participation was high. Summaries of survey results and community meeting proceedings are included as Appendices A and B, respectively.

Resident observations included seasonal flooding and flooding impacts –wet floor insulation, uneven foundations, erosion of the stream bank, damage to snow machines, four-wheelers and other personal property and observations of the ground –sinking" and –flattening" around the community when considering ground appearance observations since childhood. Residents indicated equipment was available in the community to assist homeowners relevel their homes when affected by settlement.

2.3 Onsite Data Collection

Ground temperature measurements were collected from existing conduit sources. Ground temperature measurements were attempted in existing PVC conduits installed by DMA in 2007 at two locations near the school and at the proposed bulk fuel facility site. Only one of three PVC pipes was located at the school addition site, north of the school; however the single remaining pipe was inaccessible. Two of three PVC conduits were located at the proposed water tank site, south of the school. The pipes were filled with water; therefore the equipment could only be inserted to a shallow depth, due to frozen water at the permafrost surface. Ground temperatures measured at this site were not representative due to the presence of water and shallow depths of measurements; however, a depth to permafrost surface was attainable. Two PVC conduits at the proposed bulk fuel facility were accessible to depth and ground temperatures were successfully recorded at this site.

The active layer depth, seasonally thawed soil near the ground surface, was probed by manually pushing a 4-foot long, slender fiberglass rod into the soil until refusal was met at the permafrost surface or the limits of the probe length were achieved. The probe refusal on permafrost soils is distinguishable by feel from the probe refusal and experience of the field personnel. Active layer depths and locations of frozen ground encountered were recorded.

A relative ground surface elevation survey was completed at areas of interest within the community. The purpose of the survey was to establish a baseline for future elevation measurements throughout the community and to record the current riverbank location for comparison to existing data. The survey was conducted with a differentially corrected GPS system, including a base station and a rover unit. Horizontal and vertical GPS coordinates were collected at public buildings and along the top and bottom of the exposed Kuguklik riverbank.

A pile cap relative elevation survey was completed at the school to compare movement of the piles in relation to a previous survey completed in 1996 by Arctic Foundations, Inc. Ground temperatures within the foundation were measured using permanently installed instrumentation. Damage observed within the school, reportedly due to foundation movement, was documented and photographed.

Visual observations of structure foundations were conducted throughout the community. The foundation type and general condition and performance was noted for public buildings and resident houses.

3.0 GENERAL CONDITIONS

3.1 Location

The community of Kipnuk is located in the Yukon-Kuskokwim Lowlands, on the Kuguklik River about three miles from the Bering Sea coast. The community is about 100 miles southwest of Bethel. The Kuguklik River is a meandering stream that originates about 30 miles east in a flat tundra and lakes complex area. The community is located on an actively eroding bend of the river. The area around Kipnuk is flat and poorly drained with numerous lakes and small drainages that flow into the Kuguklik River. The Location Map, Plate 1, shows the community of Kipnuk and identifies locations of select buildings and infrastructure.

Kipnuk is a traditional Yup'ik Eskimo community, maintaining a subsistence lifestyle, and approximately 98 percent of community residents are Alaska Native. Commercial fishing is an important income source. Based on census reports, the population of Kipnuk grew from 470 in 1990 to 644 in 2000. The 2010 census listed the population at 639. The first recorded census population for Kipnuk, in 1940, listed a community of 144. There are 153 occupied housing units in Kipnuk. Over 95% of these housing units lack complete plumbing.

3.2 Geologic Setting

The U.S. Geologic Survey (USGS) maps Kipnuk in an area of undifferentiated surface deposits consisting of marine, river and deltaic sediments. Area soils consist of peat over organic silt and inorganic silt grading to silty fine grained sand and sand with depth. Permafrost conditions vary widely in the community. The permafrost soils in Kipnuk are relatively warm and contain dissolved salts within the pore water, which depresses the freezing point temperature of the soil.

3.3 Climate

The climate at Kipnuk is predominantly subarctic marine, with influence of inland continental weather. Kipnuk has relatively cool summers and moderately cold winters. Average winter temperatures range from 6 to 24 degrees Fahrenheit (° F) and average summer temperatures range from 41 and 57° F. The area receives an average annual precipitation of 22 inches, with 42 inches of snow, State of Alaska, 2011.

Design climate data including average thawing and freezing indices are presented in Table 3-1 for the Kipnuk area. The indices are calculated from data available by the University of Alaska Fairbanks (UAF) Scenarios Network for Alaska Planning (SNAP). Design indices are based on the three coldest winters (freezing index) or warmest summers (thawing index) observed during the analysis period. Included in Table 3-1 is projected climate data for year 2031 to 2040 based on the UAF SNAP data.

Table 3-1: Engineering Climate Indices for Kipnuk, AK

	1948-1978	1979-2009	2010-2040 (estimated)
Average Air Temperature	28.9 ºF	30.7 ºF	33.1 ºF
Average Freezing Index	3,366 ºF-days	2,959 ºF-days	2,268 ºF-days
Average Thawing Index	2,238 ºF-days	2,481 ºF-days	2,668 ºF-days
Design Freezing Index	4,143 ºF-days	3,729 ºF-days	3,334 ºF-days
Design Thawing Index	2,574 ºF-days	2,859 ºF-days	3,367 ºF-days

Projected by UAF SNAP, Global Climate Model ECHAM5, Emission scenario A1B

SNAP data was prepared by Rupp et al. (2009) and is distributed as two separate products. Historical records were calculated using the PRISM model by combining climate data from multiple meteorological records across the state of Alaska from 1901 to 2009, and modeled across the state in a manner that accounts for ~~“~~variations in slope, aspect, elevation, and coastal proximity” (PRISM Climate Group, 2004). Forward-looking projections were prepared from 2009 to 2099 utilizing multiple global climate models, and several carbon emission scenarios.

This report utilized the ECHAM5 global climate model results, which was found by the SNAP group to have the highest accuracy for Alaska, and the A1B carbon emission scenario was considered (mid-range future emissions).

Climate trends show that air temperatures in Alaska are rising. As indicated by the reviewed data, the average air temperature from 1979 to 2009 is 1.8°F higher than the prior 30-year period. As a result of increasing air temperatures, the near surface permafrost in the area is expected to warm and possibly thaw.

4.0 HAZARDS

Potential climate change related hazards include permafrost degradation, which could impact riverbank erosion rates and increased flooding extents due to thaw settlement of the ground surface. Structures potentially impacted include homes, commercial and public buildings, and infrastructure such as power generation facilities and distribution systems, bulk fuel storage, transportation boardwalks, and communication facilities and networks.

4.1 Erosion and Coastal Hazards

Kipnuk has a history of riverbank erosion and flooding. The Alaska District Corps of Engineers (USACE) recently completed a Community Erosion Assessment of the Kuguklik River at Kipnuk. Three primary areas of erosion were identified as part of the USACE study with calculated erosion rates between 6 and 9 feet per year. The majority of erosion is reported to occur in the fall, during coastal storm surge events. The reported fall erosion timing correlates with the deepest extent of active layer thaw, which occurs at the end of summer. The reported erosion rates are consistent with estimates DMA developed in 1984 as part of the Dry Dock Feasibility Study. Residents report that flooding affects Kipnuk on a regular basis, occurring mainly in the spring and fall. Residents indicated that the severity of the floods depended upon whether flooding was storm driven and concurrent with high tides. Concerns were raised by residents that more homes are being affected over time as foundations shift, resulting in lower floor elevation and wet floor insulation.

4.2 Permafrost Degradation

If current warming trends continue, thawing ground may result in settlement of the near surface fine-grained soil. As the permafrost thaws, the ground subsides due to the reduction in volume from ice crystal to pore water within the soil, followed by ground settlement as the pore water dissipates and the soil settles to fill the void. Additional settlement can occur due to soil consolidation as the soil strength properties change from frozen to an unfrozen state. The lower ground elevation is then subject to increased flooding potential. Long-time residents indicated that the area seems to be lower than they remember from the past— an anecdotal observation of the potential consolidation of area soils due to warming ground temperatures.

The thawing of permafrost can also result in a loss of foundation support. Foundations designed for permafrost conditions may not necessarily perform as designed under degraded permafrost conditions, resulting in foundation settlement as both uniform and differential settlement. An example of this is the elevation of boardwalks in the community. Another example relates to the residential structures. RuralCAP assisted community members by providing support for residents to ―re-level" their homes. At several locations throughout the community, team members observed housing foundations with gaps between timber support blocking and the structure.

Thawing of permafrost due to increasing surface temperatures could also contribute to changes in river discharges and dynamics. River channel dynamics can be altered due to a reduction in soil strength properties of adjacent riverbank soils when compared to permafrost soil strength properties, thus, erosion rates could increase.

4.3 Other Hazards

Other hazards may include health, biological or ecological changes. Climatic changes may alter the ecosystem, possibly resulting in changes to vegetation and animal populations. These potential impacts are not addressed under the scope for this project.

5.0 ANALYSIS OF TRENDS AND POTENTIAL IMPACTS

5.1 Erosion and Coastal Hazards

5.1.1 Riverbank Erosion

As discussed in Doug Jones' report, erosion is caused by friction of river water against the riverbank as the water flows downstream, causing undercutting of the bank. Over time, this undercutting can cause the overhanging soil and organic mat to cave into the river. Storms are also an effective way to remove this material. The majority of erosion reportedly occurs during the fall storm season. Waves cause erosion. Waves generated during times of high water can also increase erosion. As the river level rises due to high tide, increased runoff, or storm surge; the river bar becomes submerged, effectively widening the river channel and extending the wave fetch, area of water exposed to wind. Waves develop along the fairly straight channel upstream of the village. These waves contact the shoreline primarily within the area near the fuel dispensary. Generally, the larger storms and related storm surges occur in the fall, when the depth of thaw within the active layer is at its thickest, a thermal state that may contribute to the erosion process. The thawed soil is more easily eroded away.

Previous studies by USACE have determined erosion rates at Kipnuk. In USACE's 2009 *Community Erosion Assessment*, three areas of riverbank erosion were identified as Reaches 1 through 3. These areas are illustrated on Plates 2.1 through 2.4. Reach 1 includes 1,000 feet of riverbank downstream of the barge landing. Reach 2 includes 1,500 feet of riverbank upstream of the barge landing, and Reach 3 includes 1,700 feet of riverbank upstream from the slough. Reported erosion rates were 7 feet/year, 6 feet/year, and 9 feet/year for Reaches 1 through 3, respectively. USACE used existing aerial photography from 1963 through 2004 to calculate the erosion rates. USACE used the calculated rate to project damages over a period of 50 years.

In addition to review of aerial photography from 1954 through 2004, field measurements by Golder recorded in the fall of 2009, were used to establish the relative location of the riverbank in October 2009. This data was superimposed on previous shorelines provided by USACE, in order to calculate updated rates of erosion. The map series is illustrated on Plates 2.1 through 2.4. Incremental erosion rates were also calculated to identify variations in erosion rates over time. Results of erosion calculations are shown in Table 5-1. Rates of erosion vary depending on specific location along the riverbank. The rates shown in Table 5-1 represent the highest and lowest rates for each area and time period. For example, in Reach 3, near the fuel tanks, erosion rates are accelerating. The table shows for Reach 3 erosion averaged between 6 to 9 feet per year between 1963 and 1996 and now is averaging 5 to 17 feet per year between 2004 and 2009.

Table 5-1: Estimated Erosion Rates

Period of Erosion	Reach 1 (feet/year)	Reach 2* (feet/year)	Reach 3 (feet/year)
1963 – 1996	6.8 to 7.7	4.4 to 5.1	6.0 to 9.8
1996 – 2004	5.0 to 8.2	2.5 to 7.5	3.8 to 10.0
2004 – 2009	3.0 to 4.0	4.2 to 5.9	5.0 to 17.0
Full study period 1963 – 2009	7	6	9

Notes: *Excludes erosion along the revetment, which is negligible.

The overall erosion rates calculated for the period of 1963 through 2009 are consistent with the rates reported by USACE for the period of 1963 through 2004.

The erosion rates are not steady; they are ever changing with the geometry of the river. As the river migrates further to the east, the current hits the bank at a more direct angle in Reach 3, near Kuguklik Limited's fuel dispensing facility, causing increased erosion rates. Downstream, in Reach 1, the river bend is more gentle, and the current is nearly parallel to the riverbank, resulting in a lower erosion rate. The shape of the riverbank also affects the local erosion rate, for example, areas that protrude into the river are eroded more rapidly than the average erosion rates.

It is difficult to estimate the rates of future erosion due to the ever changing geometry of the river. However, for purposes of planning, the currently calculated erosion rates for the period of 1963 through 2009 have been used to project the location of the riverbank in 10 years, 20 years, and 30 years, as shown on Plates 1.1 through 1.4. These estimates assume current river geometry. The geometry of the river and associated erosion rates may change as the riverbank intersects areas of varying composition, such as soft, unfrozen materials and frozen materials.

USACE estimated the total damages in Kipnuk over a 50-year period would be approximately $30 million (a 2009 value of about $12 million). Estimated damages include over 36 acres of land, 13 residential structures, 8 commercial structures, 3 public buildings, 16 utility poles, over 3,900 feet of boardwalk, 90 feet of water lines, 9 fuel headers, and 30 fuel tanks. Erosion of fuel facilities is of particular concern, and decommission and closures of fuel facilities was included in USACE's damage estimates.

Figure 5-1: Reach 1 Looking South, Reach 2 Looking South, Reach 3 Looking South, Reach 3 Looking North

5.1.2 Flooding and Storm Surges

Flooding and storm surges contribute to the erosion process, as identified by USACE, relayed by residents, and noted in Coastline Engineering's report. Flooding, whether due to upstream runoff or storm surge, is a hazard in itself. During severe flooding, nearly the entire community of Kipnuk may be covered with water. During flooding events, residents are unable to get around and are primarily confined to their homes. Many public buildings, including the school, the designated emergency shelter, are currently inaccessible during times of severe flooding. These flooding events are reported as generally low velocity flow within the community.

Kipnuk is listed as non-participating in Federal Emergency Management Administration's (FEMA) National Flood Insurance Program. No river gauge is present within the Kuguklik River. The nearest tidal gauge is at the mouth of Kuskokwim Bay at Popokamute. Many elder residents recognize when conditions are right for storms. Storm and weather information is available by calling nearby communities on the very high frequency (VHF) radio or calling the National Weather Service Hotline. Residents communicate amongst themselves and with other communities to collect data and pass it on to residents. There is no formal warning system in place to alert residents of incoming storms.

Residents expressed concerns about increased damage to residences (wet insulation, damaged foundations), damage to personal property, potential for personal injury, and health related issues due to potential for floods to spread raw sewage from the lagoons and petroleum products from fuel storage and equipment inundated during flooding.

The ocean floor is shallow at the mouth of the river, and as low pressure systems move across the Bering Sea, seawater rises on the shelf and is funneled up the river, raising river stage. Depending on the barometric pressure and coincidence with tides, storm surges of various magnitudes can affect Kipnuk.

Historic surge heights have not been recorded at Kipnuk; however, regional information is available. According to the State Climate Change Center, a 12-foot surge is considered the 100-year event for the Bristol Bay coastline, and surges in the Kuskokwim Delta were estimated to be up to 12 feet in height along exposed areas during the 1980 storm event (Wise, Comiskey, and Becker, 1981). While these represent regional storm surge heights, the actual surge height would decrease as the storm surge moves up river, thereby decreasing the actual height observed at Kipnuk.

Residents reported the most flood activity in the fall and indicated the duration of the floods to be “until the tide goes out” or “one day or overnight.” Some reported that the flood “went in my trailer and covered the whole floor” another said “we couldn’t get out of the house” yet another stated that the “whole community was flooded; we couldn’t get to the school.”

When residents were asked about the worst flooding event they could remember, a fairly consistent response was the fall of 2007, some thought it was 2008. Residents reported that the late-season storm caused ice to be pushed through the community. The flooding came late at night. One resident stated that she awoke, and when she looked at her window, she saw water. Some residents reported standing in the flood water as it rose pushing ice chucks away from their homes.

A photograph of flooding, see Figure 5-15, that took place in October of 2005 was provided by Jimmy Paul, Kipnuk Traditional Council. A minor storm surge event in October of 2004 occurred during a water level monitoring study conducted in the Nukalpiartsunarluk Slough, south of the north taxiway site as part of the Airport Relocation Project by Hattenburg Dilley & Linnell (HDL, 2007) for the Alaska Department of Transportation and Public Facilities (ADOT&PF).

In order to illustrate the degree to which Kipnuk suffers from flooding, existing topography was utilized to show inundation at various river stages. The topographic contours were developed by AeroMetric Inc. for previous ADEC and Coastal Villages Regional Fund (CVRF) projects using 2002 and 2004 aerial photography. AutoCad files containing the 2004 contours were provided by ADEC for use in this study. The topographic contours are color-coded to illustrate areas inundated by various flood levels on the Flood Maps, Plates 3.1 through 3.4.

According to the Aerometric topographic contours (local datum), if the river level rises approximately 4 vertical feet over normal high tide (estimated -10 feet), some areas of the community will experience flooding (see yellow line). If the river level rises approximately 6 vertical feet above normal high tide, nearly the entire community could be subject to flooding (see green line).

As residents described the 2007 flood event, they were asked to identify areas that did and did not flood during this event. Based on a visual comparison of anecdotal data and the Aerometric topographic contours, it appears the 2007 flood level may correspond fall between the -6 and -4 foot contours.

Figure 5-2: Slough near Traditional Council near High and Low Tides

A change in wind patterns or in storm frequency or severity could affect flooding in Kipnuk. Coastline Engineering reviewed wind data for Nome, which contains the closest long-term tidal monitoring record of comparison for Kipnuk, for a period of 37 years (1973 through 2009). No significant change in storm activity or strength was identified over the period of record, suggesting that the increase in flooding may be due primarily to thaw subsidence and loss of elevation relative to flood elevation. Ultimately, tidal/river stage monitoring equipment could be installed near Kipnuk to better determine if flood activity is increasing in frequency or severity at the community.

5.2 Permafrost Degradation

5.2.1 Kipnuk Foundations

The older houses in Kipnuk are primarily supported on post and pad foundations and are re-leveled periodically with use of timber shims. Various types of blocking indicate that houses have been releveled numerous times. Some housing in Kipnuk was constructed on pile foundations. The houses are raised above ground to provide a blow-through space typical of pile foundations in permafrost soils. The AVCP Housing, on the western side of Kipnuk, was constructed on steel pile foundations. These foundations have performed well, with little to no visually observed movement; however, corrosion of the piles is occurring, most likely from the highly saline conditions. Many of the public buildings are pile supported.

Figure 5-3: Residents Re-Leveling Home and Corrosion of Piling

The Traditional Council Office was originally constructed in the late 1970's as a school. Soon after construction, movement of the foundation was reported. An investigation, completed in 1974 by Harding Lawson Associates, revealed soils consisting of organic silt and silt with some unfrozen brine. The building is founded on timber adfreeze piles with a passive refrigeration system installed in the sand-water slurry annulus. Subsequent differential movement of the foundation resulted in an additional investigation by A.W. Murfitt, PE, in 1983. Discontinuous permafrost was found in the area, with frozen ground temperatures between 30°F and 32°F. Some visible ice was evident in the permafrost and measured pore water salinity ranged from 2 to 7 parts per thousand (ppt). Pore water salinity of 8 ppt depresses the freezing point nearly 1°F. At the time of DMA's 2009 site visit, the condenser portion of the thermal probes was corroded considerably.

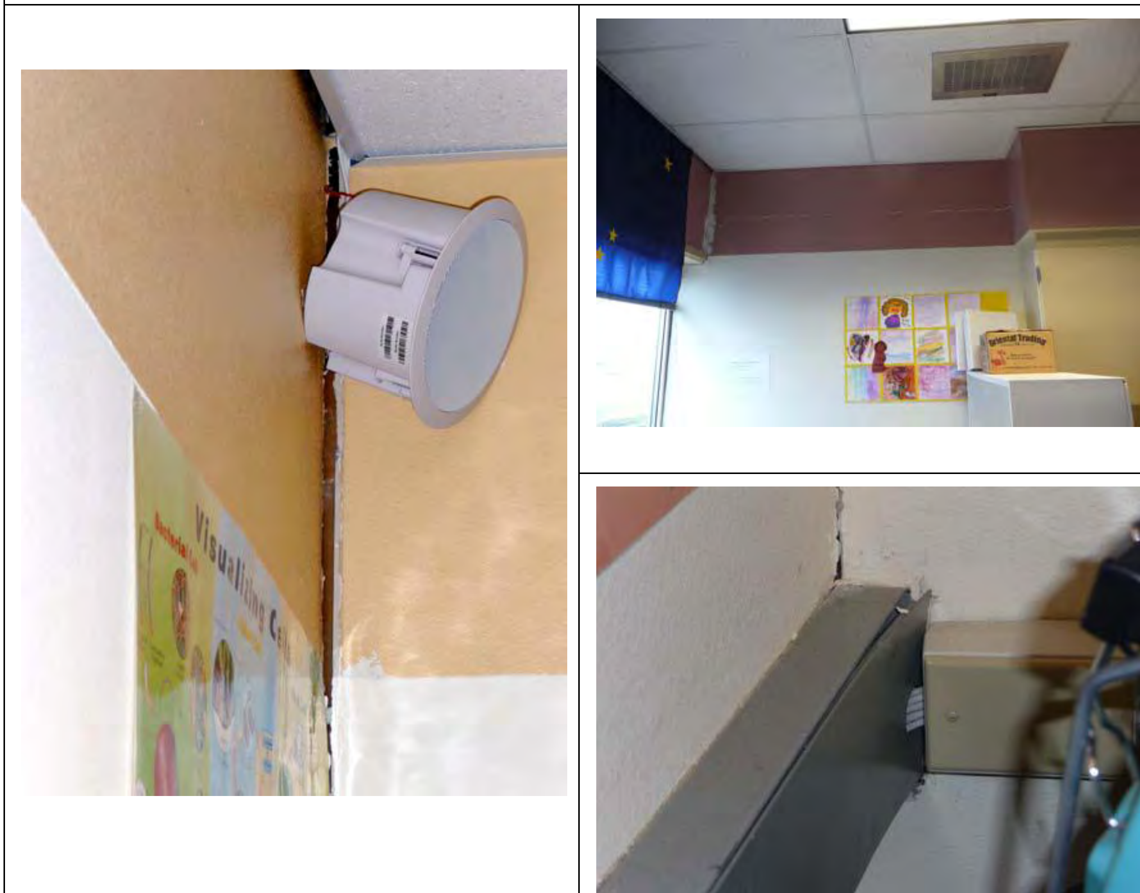
Figure 5-4 : Traditional Council Building

Shannon and Wilson's 1988 test borings at the Chief Paul Memorial K-12 School site encountered surface peat underlain by organic silt and silt with fine grained sand. All borings encountered frozen soil with ground temperatures measured from 29°F to 30°F. Unbonded permafrost was encountered and pore water salinity contents ranged from 1 to 8 ppt. The school is founded on passive refrigeration piling (thermal piles) and some differential movement has been observed since construction.

Figure 5-5: Chief Paul Memorial K-12 School

In the mid 1990's, movement of the school was reported. Pile cap surveys and analysis of ground temperatures were completed by Arctic Foundations Inc. Arctic Foundations Inc. determined that the movement was likely pile tip heave caused from over cooling the soils below the thermal pile foundation. Arctic Foundations Inc. determined that previously unfrozen, saline-rich pore water within the soils was most likely frozen due to cooling created by the thermal piles. To address the situation, some of the thermal piles were decommissioned to prevent further cooling and better control the heave. Recent movement of the school has been reported. Damage was visually observed to include cracks in walls and doorways and un-level floors, Figure 5-6.

Figure 5-6: Photographs show Damages within School



During the site visit, a pile cap survey was completed in order to compare the current measurements with the survey completed in 1996 by Arctic Foundations Inc. The pile cap survey comparison shows that relative differential pile movement since 1996 has ranged from less than a 1/4-inch to about 4.5 inches. Arctic Foundations 1996 survey showed that pile cap movement, since school construction, ranged from less than a 1/4-inch to about 4.5 inches. It appears the school pile foundation is moving. However, it is unclear from the foundation survey comparison if the heave trend is continuing or if pile movement is related to pile settlement (creep). Ground temperatures measured adjacent to thermal piles during the site visit ranged from 23.1 to 28.7°F indicating the passive refrigeration is working.

Figure 5-7: K-12 School Foundation showing Insulation Damage and up to 1.5 feet of Standing Water

Figure 5-8: National Guard Armory

The National Guard Armory is supported on a Triodetic frame. It appears the Triodetic frame is in need of re-leveling so that each Triodetic support point is bearing on the foundation pad. It is not known if the building is experiencing any distress due to Triodetic movement.

The Post Office is supported on steel piles. Differential movement of the Post Office is evident with visual observations. It is unknown if this movement is due to settlement (pile creep) or heave due to frost jacking. Total movement of the facility is not known.

Figure 5-9: Post Office

The Washeteria is supported on steel pipe piles. The facility was constructed in 2002. The piles appear to include a coating to minimize corrosion. The piles also contain a visqueen wrap to serve as a bond break within the active layer (seasonal freeze/thaw zone). The bond break limits frost heave forces on the piles.

Figure 5-10: Washeteria and Clinic

The Clinic is supported on steel pipe piles. The facility was constructed after 2004. The piles did not visually appear to include a corrosion resistant coating.

The GCI Communication Tower and Building are supported on steel piles passively cooled with thermal probes. Two borings were drilled to a depth of 40 feet for the new microwave tower on the southwest side of the village. Borings encountered frozen inorganic silts with some layers of organic silt. Pore water salinity ranged from 6 to 12 ppt. Ground temperatures were measured at 30°F to 30.5°F near 40 feet below the surface.

The Coastal Villages Regional Fund (CVRF) Halibut Plant is currently supported on a Triodetic frame. After construction, the facility experienced settlement due to compression of the underlying organic soils. The facility was re-leveled, and 2x2 foot pads were replaced with 3x3 foot pads in an effort to reduce the settlement. At the time of the site visit, plans were in place to move the plant across the boardwalk to a new site.

Figure 5-11: Halibut Plant	
	

The city water storage tanks and treatment facility are supported on pile foundations. The larger tank is supported on slender thermal piles while the smaller tank is supported on steel H-pile. General visual observations of the larger tank foundation show that minimal differential settlement is occurring. While the smaller tank visually appears to be experiencing differential settlement with increased settlement at the center of the tank foundation.

Figure 5-12: Kipnuk Water Tanks	
	

The tanks at Alaska Energy Authority's (AEA) fuel farm, near the power plant are founded on fill pads composed of the local silt surrounded by earthen or wooden dikes. The tanks are supported on timber sleepers and show signs of differential settlement. DMA conducted a geotechnical exploration in 2007 adjacent to the existing fuel tanks in support of a proposed new power plant and fuel farm. Ground temperatures were recorded during the 2009 site visit within two PVC conduits installed during the 2007 fieldwork. Temperatures recorded were generally consistent with those recorded in 2007. A fuel facility for Kuguktlik Limited was constructed northwest of the community in 1997 with a fill pad of local silt treated with Portland cement. The school's fuel farm has also experienced differential settlement.

Figure 5-13: AEA Power Plant, Kuguklik Fuel Farm, Old Fuel Tanks, and School Fuel Farm




DMA conducted thaw probe cross sections of the boardwalks and did not observe any increased thaw depths within the boardwalk zone as compared to thaw depths located in undisturbed tundra adjacent to the boardwalk zone. The older boardwalk foundations are placed directly on the ground surface, and boardwalk settlement is attributed to consolidation of the organic-rich surface material repeated dynamic loading from four wheelers and other all-terrain vehicles. Boardwalk movement and damage has also been caused by flooding. Reportedly, during recent flooding, boardwalk anchors failed to hold down the boardwalk alignment connecting the community to the lagoon and landfill. Residents coordinated to repair the boardwalk.

Figure 5-14: Boardwalks

The recently constructed boardwalks are supported by anchored sleepers or helical piers. Residents reported that the new boardwalks were not affected by flooding whereas some of the older boardwalks moved with floodwaters. However, observations conducted during previous DMA Kipnuk site visits showed that at times, some of the newer boardwalks (mid-2000's) were floating during high water events.

Kipnuk's solid waste is disposed of in a landfill on the western outskirts of the community. A new lagoon containment area was recently constructed and is now operational. The Chief Paul Memorial School's sewage lagoon is located adjacent to the school, within the community boundary.

The community landfill did not visually appear to have a containment berm. If one did exist it has settled or eroded to a point of no longer functioning. The community landfill contents are not contained within a defined area. The school lagoon is constructed with a perimeter berm. Visual observations showed that the lagoon berm is estimated at 1 to 2 feet higher than adjacent ground elevation. At the time of the 2009 site visit, the freeboard of the school lagoon contents was estimated at 1 foot in some areas.

Figure 5-15: Flood Debris on School Lagoon Fence

Photo, taken in October of 2005, was provided by Jimmy Paul, Kipnuk Traditional Council.

Residents report that during flooding the contents of the sewage lagoons and landfill are dispersed over the adjacent ground. The community sewage lagoon contents are reported to enter the river system. The school sewage lagoon contents are reported to disperse within the adjacent community areas. This dispersal was noted mostly by teachers residing in housing located near the sewage lagoon and the school. They reported solid contents from the lagoon floating by their residences during flooding events.

5.2.2 Permafrost Degradation and Settlement

Residents report community-wide settlement of the land. Some describe it as "flattening" when comparing today's ground surface with previous years of memory. It is reported that the terrain used to be "more hilly" than it is today. Residents also report that floodwaters are reaching more homes. These observations are consistent with degrading permafrost conditions. Some residents noted that every year they dig their seal pits, and every year they must dig deeper to reach the surface of the permafrost. In recent years, they reportedly had to dig as much as 5 feet below grade to reach permafrost. If the seal pits are dug in the same locations each year, the disturbance of the tundra surface could create a localized degrading permafrost scenario. Probes of the active layer were completed throughout the community, and when encountered, the active layer varied from 1.8 to 4 feet in depth, commonly 3 feet.

Widespread permafrost degradation would result in a decrease in ground elevations in some areas. If high water elevations during flooding remain constant, then an increase in the degree of flooding within the community could result from permafrost degradation and related thaw settlement of the ground surface. As the land subsides, smaller floods would cause more inundation of the land.

The existing permafrost soils vary in stages of degradation across the village of Kipnuk. The degradation includes increased depths to the surface of the permafrost, when compared with expected undisturbed tundra conditions in the Kipnuk area. Due to climate conditions trending towards warmer air temperatures in the area, the permafrost soils are expected to continue to degrade.

As the permafrost soils degrade, thaw-strain (settlement) of the soil layer will occur, resulting in settlement at the ground surface. Thaw-strain calculations for the underlying subsurface permafrost soils estimate that the thaw-strain will vary across the project area. Table 5-2 presents estimated high range values for the Kipnuk area.

Thaw-strain tests were not conducted for the project or previous projects analyzed. However, a considerable amount of published data for the Alyeska Pipeline project exists and was utilized for calculating thaw-strain values for this project based on frozen water content and soil classification including peat (Pt), organic silt (OL), silt (ML), silty sand (SM), and sand (SP-SM).

Table 5-2: Thaw Settlement Estimate by Soil Type

Soil Type (USCS)	Thaw Strain (%)			Thaw Settlement (in/ft)		
	Minimum	Maximum	Average	Minimum	Maximum	Average
Peat (Pt), Organic Peat (OL)	8%	49%	18%	0.9	5.9	2.2
Silt (ML)	3%	45%	12%	0.4	5.4	1.5
Silty Sand, Sandy Silt (SM, SP-SM)	2%	14%	7%	0.3	1.7	0.8

Based on the calculated thaw-strain values, the greatest amount of settlement will be in the range of approximately 2 to 6 inches per foot of permafrost soil thawed within the area. The consolidation may occur slowly over time, as ice within the soil thaws. Rapid thawing may also occur due to convective heat transfer related to changing groundwater flow patterns.

Golder modeled the permafrost regime and depth of thaw over time based on subsurface conditions observed in existing test borings in the Kipnuk area. The Modified Berggren method, a 1-dimensional conductive heat transfer model, was utilized to estimate the depths of thaw. Based on the Modified Berggren model, using climate data updated by DMA through year 2008, the average depth of seasonal thaw is about 4 feet in the natural tundra. The depth of thaw could progress by several inches to several feet in the future. Several variables exist that contribute to the seasonal depth of thaw and progression of seasonal thaw, such as, climate conditions, ground surface conditions, snow drifting, snow accumulation, tundra disturbance and other factors.

5.3 Other Hazards

Other potential hazards identified by residents include biological changes. Some species of wildlife are reported to be moving into the area that have not lived near Kipnuk in the past, such as moose and beavers, and some species that used to reside near Kipnuk are reported as no longer observed, such as specific bird species. Ecological evaluations are outside the scope of this study, however additional study may be beneficial.

5.4 Critical Infrastructure

Table 5-3 shows the community survey responses to the question ―What are three most important areas in Kipnuk?" In the written responses, residents talked about how the periodic flooding prohibits access to the school and the importance of access to power and fuel for transportation.

Table 5-3: Community Survey Responses/Most Important Areas

Response	Number of Occurrences
Chief Paul Memorial School	55
Power Plant	47
Fuel Tank Farm	38
Alaska Native Tribal Health Consortium office	16
Barge Landing	12
Kipnuk Traditional Council (KTC) lodge	9
Other: Clinic	5
Other: Post Office	2
Other: Airport	1

Of the facilities listed in Table 5-3, the fuel tank farm and barge landing are the most likely to be compromised in 20 years by the flooding and erosion. The community should plan for the eventual relocation of the fuel tank farm.

The ADOT&PF is planning to rehabilitate and replace about 4.8 miles of boardwalks in the next several years. The community can work with the designers to ensure that design of the boardwalks considers flood mitigation and prioritization for access to critical facilities is established.

Residential structures seem to bear the brunt of the seasonal flooding, particularly those that are older and on post and pad foundations.

6.0 CONCEPTUAL-LEVEL MITIGATION MEASURES

Potential mitigation measures have been identified during the course of this study, Coastline Engineering also addressed conceptual-level mitigation measures in the attached report as summarized in this report. Potential mitigation measures are discussed in the following sections by hazard identification.

6.1 Measures to Address Riverbank Erosion

Shoreline protection could be implemented to reduce the rate of riverbank erosion. Methods of shoreline protection include the use of sheet piles, rip-rap, seawall, and river course modification. Each method's applicability to Kipnuk is discussed below.

6.1.1 Rip Rap Revetment

The current revetment constructed by the USACE has successfully slowed the erosion at its location, however it is in disrepair. In the USACE 2009 Community Erosion Assessment, the revetment was identified as in failure, with most of the protection being provided by the fabric. Residents stated that the revetment has suffered from ice damage. The rocks protecting the shoreline are removed as the ice goes out in the spring. This mechanism was also discussed in Coastline Engineering's attached report. Currently, rocks to approximately 12 inches in diameter are present and the underlying geotextile is exposed in many areas due to voids in the rock.

As demonstrated by the existing revetment, it is possible to slow the erosion with use of geotextile and rip rap. Properly designed and constructed revetment projects could be a solution to reduce riverbank erosion rates.

Suitable materials for riprap are not available within the community. Materials for the existing revetment were imported. Local material consists of highly frost susceptible silt with varying amounts of fine-grained sand. It is possible that boulders from Tern Mountain, approximately 13 miles up the coast from Kipnuk, may provide suitable material. Additional analysis in the suitability of material from Tern Mountain would need to be conducted. Construction of a new airport is underway, and ADOT&PF imported all of the granular surfacing material for the project.

USACE recommended repair of the existing rock revetment in Reach 2 at an estimated cost of $2.8 million. Four new rock revetments were also recommended, totaling 2,000 feet in length, from the fuel terminal to the barge landing at an estimated cost of $9.5 million. These cost estimates were provided in the USACE year 2009 document.

Figure 6-1: Revetment

6.1.2 Sheet Piles or Seawall

Properly designed and constructed sheet pile walls could serve to minimize riverbank erosion. In order to protect the riverbank, the sheet piles would need to be embedded well below the depth of river scour to prevent undercutting and failure of the sheet piling wall.

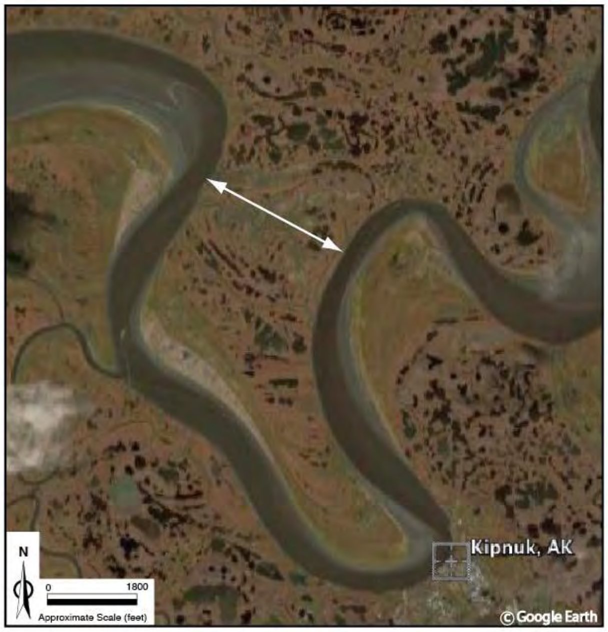
USACE recommended a sheet pile bulkhead for Reach 1, with an estimated cost of $7.4 million. The bulkhead would have a 200-foot face and 50-foot wing walls, with the toe of the structure protected by riprap.

Kipnuk residents expressed a desire to have a seawall similar to the one in Bethel. Bethel's sea wall acts similar to a sheet pile wall. However, Bethel's seawall was constructed by driving piles adjacent to each other.

6.1.3 River Course Change

As an alternative to shoreline protections and armoring, a channel could be constructed that connects both sides of the river on the inside of the meander bend, as shown in Figure 6-2.

Figure 6-2: Kuguklik River



Kipnuk is located on the outside of a meander bend in the river. Rivers naturally avulse (abandon an old river channel and create new ones), cutting off these meander bends in favor of better hydraulic conditions. Based on erosion rates calculated from aerial photography, and assuming constant rates over time, the river's course could naturally change within approximately the next 400 years, based on current migration rates. The river's flow could be redirected by cutting a channel across the inside meander loop, approximately 1 mile north of Kipnuk. This option would reduce the flow into the old channel at Kipnuk, thereby reducing direct riverbank erosion rates; however, this option would not protect Kipnuk from flooding due to high water events that overtop the riverbank. Sedimentation could become a problem within the old channel, possibly affecting barge access to the community and causing residents to travel a greater distance to access the active river channel and barged goods. Before river course modification could be considered as a viable option, additional studies would need to be completed to define the resulting conditions and potential benefits and negative impacts.

6.2 Measures to Address Flooding

6.2.1 Elevated Structures and Boardwalks

Structures could be elevated above flood levels to prevent damage from flooding. A building code could be adopted setting a minimum floor height for new structures. The school and other key parts of the community could be established as safety zones with boardwalk access to allow travel during flood events.

Structures could be elevated when being relocated or leveled. Existing buildings/residences would need to be evaluated to determine whether the structure is suitable to be raised to an increased elevation or if foundation and structure modifications would be required.

6.2.2 Flood Monitoring and Warning System

A flood warning system could be installed in the community to alert residents of rising waters and incoming storms, allowing residents to have more time to prepare and take refuge from floodwaters. This system could also include a monitoring component to collect data useful in forecasting severity of storm surges.

6.2.3 Berm System

A berm system could be constructed in an effort to protect the community from flooding. It may be possible to use silt materials available within the community to construct a berm system. The fine-grained local material would need to be capped with imported larger diameter granular material to protect the silt levee embankments from erosion. Due to the geometry of the sloughs, it would be difficult to construct effective levees without cutting sloughs off from the river. Even with a berm system, structures should be elevated above flood levels to reduce hazards from breaches in a levee. Berms or higher embankments around specific sites such as the sewage lagoons would help alleviate over-topping during flooding. A detailed hydrology study should be conducted to determine if a berm system is a feasible alternative for hazard protection.

6.2.4 Insulated Pad

Subdivision-sized insulated pads could be used to elevate the relative ground surface. Thermal probes could be installed to further reduce permafrost degradation. Such a solution would require homes and other structures to be relocated during construction, and then moved onto the constructed pad. Or, additional adjacent land would need to be made available for constructing the elevated pads with residences moved to the pads after construction. As previously mentioned, construction materials are not available in the Kipnuk vicinity; all granular materials would need to be imported. It may be possible to use local silt capped with imported granular material for pad construction. Further analysis and study would be required to determine the feasibility of insulated pads.

6.2.5 Erosion Protection Wall

Riverbank protection, such as sheet piling and seawall could be extended above grade. The wall may divert some of the current of the floodwaters, but would not prevent floodwaters from flowing around the wall and impacting the community. The tributary sloughs to the Kuguklik river would also allow water to rise behind the wall. Benefits of a wall may include some degree of deflection of current and river ice during flooding, and if combined with levee and/or pad solutions could lessen the degree of flooding.

6.3 Measures to Address Permafrost Degradation

6.3.1 Use of Appropriate Foundations

New facilities should consider permafrost degradation and be constructed on properly designed foundations. Pile foundations with elevated structures is one alternative. Triodetic foundations with routine maintenance is another alternative. Existing older foundations placed on timber blocking could be retrofitted to elevate the houses above flood elevation. Additional retrofit should include utilizing connections within the blocking. Currently, when weight from the house is not on the blocking, the flood water can remove the blocking from that portion of the house. This scenario could pose a safety hazard if the house shifts with no underlying support.

6.3.2 Establish Minimum Building Floor Heights

As discussed under "Measures to Address Flooding", minimum building floor heights for new structures should take into account anticipated settlement over the life of the structure to ensure that the building remains above flood levels throughout its life cycle.

7.0 CONCLUSIONS

7.1 Riverbank Erosion

The Kuguklik River at Kipnuk will continue to erode towards the community, resulting in continued damage to buildings and infrastructure. Conceptual-level options for protection of the riverbank include Riprap revetments, sheet pile bulkheads, and pile-driven seawall. These options should be explored before river course change is considered.

7.2 Flooding

The ground elevation of Kipnuk has not been established relative to sea level; however, it is estimated to be approximately 5 to 10 feet above sea level in various publications, and within flood elevation range. Conceptual-level options to address flooding-related issues include elevating structures and boardwalks, a flood monitoring and warning system, berm system, pad system, and erosion protection wall. Any one of these options alone does not address the flooding problem as a whole. Short-term solutions may include a combination of minimum building heights, elevated boardwalks ensuring access to emergency shelter and critical infrastructure, taller embankments around lagoons, and a flood warning system. Long-term solutions may include levee and pad systems and erosion protection walls.

7.3 Permafrost Degradation

Structures on post and pad or triodetic foundations can continue to be releveled as the permafrost degrades. The risk of and frequency of flooding will increase for structures experiencing subsidence if they are not re-leveled and verified to be above flood elevation on a routine basis. Existing structures in danger of flooding could be elevated with retrofitted foundations designed for the degrading condition. Most existing public buildings are pile-supported, and new construction of critical infrastructure and public facilities should be founded on pile foundations design for the degrading condition with floor elevations above flood levels.

8.0 RECOMMENDATIONS FOR FUTURE STUDY

Site-specific engineering analyses and design should be completed to determine the most suitable combination of solutions to mitigate riverbank erosion, flood damages, and permafrost degradation.

This project was intended to establish a baseline for future studies. Periodic measurement of ground temperatures, rates of riverbank erosion, and subsidence from permafrost degradation monitoring are recommended. These measurements would enable calculation of measurable changes in riverbank erosion and permafrost degradation.

Installation of equipment to monitor air temperature, precipitation, wind speed and direction, tidal fluctuations, and ground temperatures would provide valuable data to evaluate climatic trends and changes over time. These measurements would also help define tidal variation and surge frequency and magnitude at Kipnuk and rate of permafrost degradation. The river stage gauge instrumentation could also be connected to a warning system that could alert residents to rising waters above a certain flood stage. The installation of webcams would allow for consistent documentation of the degree of flooding (during daylight hours), and visible changes in riverbank erosion over time. The Alaska Ocean Observing System (AOOS) has installed similar instrumentation at several locations within the state. The possibility of including Kipnuk to the AOOS network should be considered.

Potential changes in river dynamics due to degradation of permafrost within the watershed and ecological impacts of climate change were not addressed as part of this study. Health-related impacts of flooding were also not discussed herein. Additional study in these areas would be beneficial.

9.0 POSSIBLE FUNDING SOURCES

There are many programs that provide funding for erosion and flood mitigation projects, as shown in Table 9-1.

Table 9-1: Possible sources of funding for the various hazard mitigation projects

Mitigation Project	Source of funding
Rip Rap Revetment	US Army Corps of Engineers State of Alaska
Sheet Piles	US Army Corps of Engineers State of Alaska
Seawall	US Army Corps of Engineers State of Alaska
River Course Change	US Army Corps of Engineers State of Alaska
Elevated Structures and Boardwalks	AVCP Department of Transportation & Public Facilities
Flood Monitoring and Warning System	State of Alaska, Alaska Coastal Management Program
Levee system	US Army Corps of Engineers State of Alaska
Insulated Pad	State of Alaska
Erosion Protection Wall	US Army Corps of Engineers State of Alaska
Use of Appropriate Foundations	AVCP Rural CAP
Establish Minimum Building Floor Heights	AVCP Native Village of Kipnuk
Engineering Analysis & Design	State of Alaska

9.1 The State of Alaska Division of Homeland Security and Emergency Management (DHS&EM)

DHS&EM utilizes the Department of Homeland Security (DHS) and Federal Emergency Management Agency (FEMA) Unified Hazard Mitigation Assistance (HMA) Grant Programs including the Hazard Mitigation Grant Program (HMGP) and the Pre Disaster Mitigation (PDM) program. The purpose of these mitigation grant programs is to reduce the risk of loss of life and property due to natural hazards.

9.1.1 Hazard Mitigation grant Program (HMGP)

The HMGP is authorized by section 404 of the Robert T. Stafford Disaster Assistance and Emergency Relief Act (Stafford Act), 42 U.S.C. 5170c. Eligible applicants include state and local governments, Indian tribes or authorized Tribal organizations, Alaska Native villages or organizations, and certain private non-profit organizations or institutions. General requirements include a FEMA-approved local mitigation plan in accordance with 44 C.F.R. Parts 201.6 and 206.434(b)

Cost share requirements include 75% Federal and 25% State share. HMGP enables mitigation measures to be implemented as part of recovery from a disaster and funds projects, plans, and initiatives in line with priorities established in State, Tribal, or Local Hazard Mitigation Plans (LHMP). Some examples of mitigation projects include acquisition and relocation of structures, retrofitting of structures to protect them from floods, high winds, earthquakes, or other natural hazards, and construction of certain types of localized flood control projects. HMGP funds can also be used to develop State, local, or Tribal mitigation plans.

The Eligibility and Completeness Review includes Benefit Cost Analysis (BCA), Engineering Feasibility and Mitigation Planning requirements, Environmental and Historic Preservation Reviews.

9.1.2 Pre-Disaster Mitigation (PDM)

PDM is authorized by section 203 of the Stafford Act, 42 U.S.C. 5133. Eligible applicants include State-level agencies and institutions, federally recognized Indian Tribal governments, local governments, state-recognized Indian tribes, authorized Indian Tribal organizations, Alaska Native villages, public colleges and universities, and Indian Tribal colleges and universities. General requirements include a FEMA-approved local mitigation plan in accordance with 44 C.F.R. Parts 201 by the application deadline. PDM planning grants are available to applicants that do not have a FEMA-approved hazard mitigation plan.

Cost share requirements include 75% Federal and 25% Applicant share, although qualified *"Small and Impoverished Communities*" may receive up to a 90% Federal cost share. PDM provides funds for LHMPs and the implementation of mitigation projects prior to a disaster event. Some project examples include acquisition of real property for open space conversion, relocation of public or private structures, elevation of existing public or private structures to avoid flooding, structural and non-structural retrofitting of existing public or private structures to meet/exceed applicable building codes, hydrologic and Hydraulic studies/analyses, engineering studies and drainage studies for the proposed project design and feasibility design.

The Eligibility and Completeness Review includes Applicant eligibility, BCA, and Mitigation Planning requirements, and National Ranking. The National Ranking Score is calculated by FEMA for all eligible planning and project applications based on predetermined, objective, quantitative factors.

9.2 Alaska Climate Change Impact Mitigation Program

The Alaska Climate Change Impact Mitigation Program (3 AAC 195), Commerce, Community and Economic Development provides grants to communities to allow them to complete community hazard impact assessments similar to this one. Additional funding may be available to Kipnuk.

9.3 US Army Corps of Engineers

US Army Corps of Engineers (USACE) - requires matched funding. Matching funding could come from the State of Alaska through legislative appropriation or other means.

The following table was pulled from the US General Accounting Office Testimony for the Committee on Appropriations, US Senate, Alaska Native Villages, Villages affected by Flooding and Erosion Have Difficulty Qualifying for Federal Assistance.

Table 9-2: Authorities that Address Flooding and Erosion Under the USACE Continuing Authorities Program

Program Authority	Description
Section 14 of the Flood Control Act of 1946	For emergency streambank and shoreline erosion protection for public facilities
Section 205 of the Flood Control Act of 1948	Authorizes flood control projects
Section 208 of the Flood Control Act of 1954	Authorizes flood control activities
Section 103 of the River and Harbor act of 1962	Protect shores of publicly owned property from hurricane and storm damage
Section 111 of the River and Harbor Act of 1968	Mitigate shoreline erosion damage caused by federal navigation projects.

Notes: Source: GAO analysis of USACE program information

Other USACE authorities that may address problems related to flooding and erosion in Kipnuk include:

Section 206 of the Flood Control Act of 1960 which provides states and local government technical services and planning guidance needed to support effect flood plain management.

The GAO report underscores USACE's report that indicated that projects have difficulty qualifying for assistance because USACE cannot take on projects whose costs exceed its expected economic benefits. When communities meet USACE's cost/benefit criteria they cannot provide or find sufficient funding to meet the cost-share required for the project, often the cost share is between 25 and 50 percent of the project planning and construction costs.

9.4 Agriculture Department's Natural Resource Conservation Service (NRCS) Emergency Watershed Protection Program

The NRCS considers social and environmental factors when calculating the benefits of a proposed project—protecting the subsistence lifestyle of an Alaska Native village can be included as one of these factors and may allow Kipnuk to be considered for the funding. The cost sharing, while required, can be waived if the community is unable to provide funding. The GAO report says that of the 25 villages requesting assistance, 19 were turned down because the problems they wished to address were recurring and ineligible for the program. The State of Alaska has provided some matching funds in the past. NRCS programs are summarized in Table 9-3.

Table 9-3: NRCS programs responding to Flooding and Erosion

Program	Description
Watershed Protection and Flood Prevention Program	Provides funding for projects that control erosion and prevent flooding. Limited to watersheds that are less than 250, 000 acres.
Emergency Watershed Protection Program	Provides assistance where there is some imminent threat—usually from some sort of erosion caused by river flooding.
Conservation Technical Assistance Program	Provides technical assistance to communities and individuals to solve natural resource problems including reducing erosion, improving air and water quality, and maintaining or restoring wetlands and habitat.

Notes: Source: GAO analysis of NRCS program information.

Recommendations to the Governor's subcabinet on Climate Change outline steps to begin formulating action recommendations and prioritization for projects, policy and implementation actions that will ~~e~~effectively address climate impacts, which we anticipate impacting many more Alaska communities." (Source: Recommendations Report to the Governor's Subcabinet on Climate Change, Final Report from the Immediate Action Workgroup, March 2009)

The GAO report further states that other federal agencies have programs that can assist Alaska Native villages in responding to the consequences of flooding by funding tasks such as moving homes, repairing roads and boardwalks, or rebuilding airport runways. The report identified State of Alaska programs that also provide assistance.

Some funding resources are identified as noted above, however, for Alaskan communities, funding may not be identified to address all needs. Kipnuk is not in a position to provide matching funding. It will be necessary for this funding to come from another source such as the State of Alaska. It is also possible that different funding sources could be leveraged.

10.0 USE OF REPORT

This report has been prepared exclusively for the use of the Kipnuk Traditional. The work program followed the standard of care expected of professionals undertaking similar work in the State of Alaska under similar conditions. No warranty expressed or implied is made.

11.0 CLOSING

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FIGURES

Image provided by Aero-Metric, Inc.-Alaska Division, dated October 2004.

0 500 1000 2000

Approximate Scale (feet)

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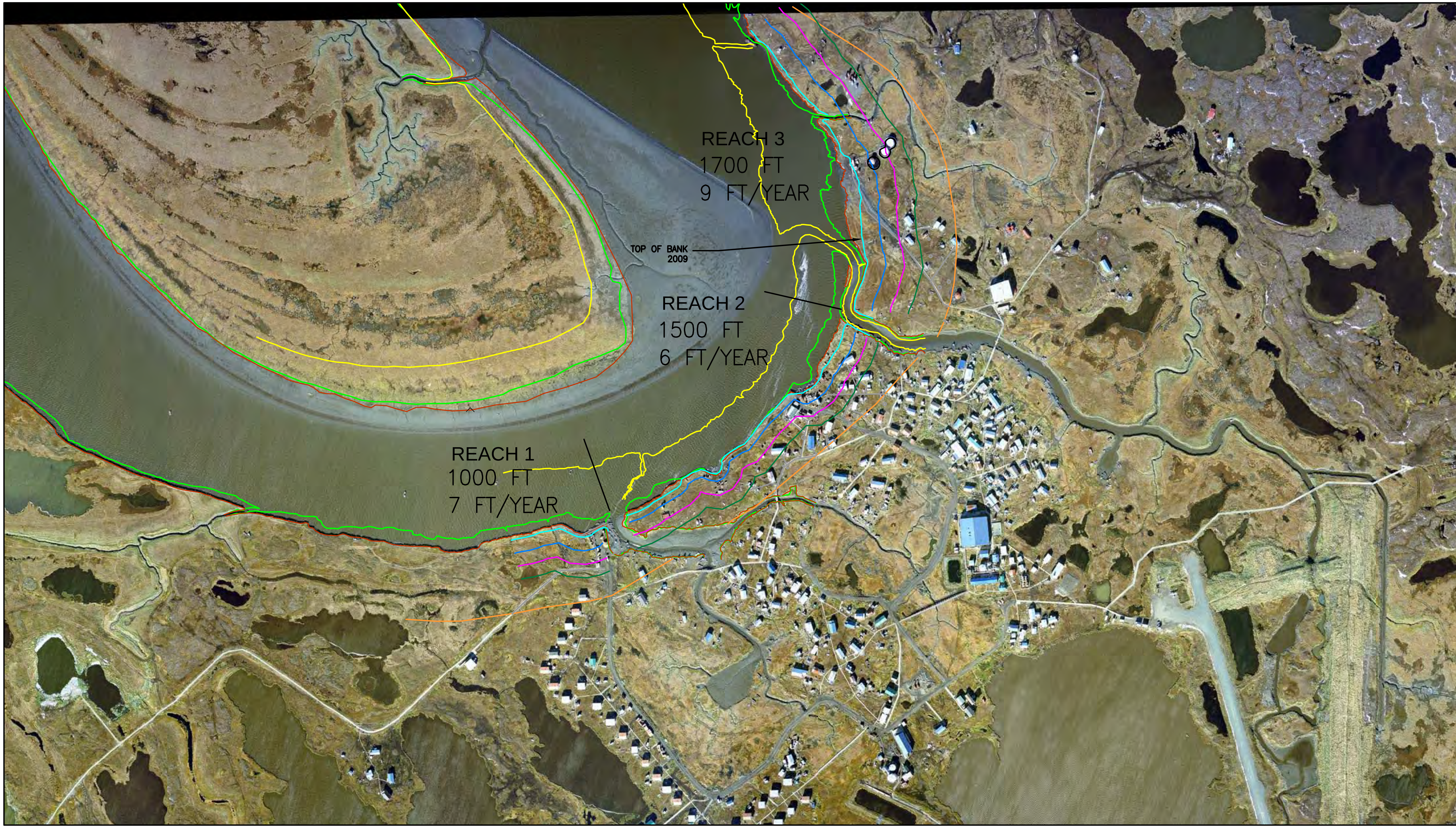
Date: October 2011

Golder Associates

LOCATION MAP
Hazard Impact Assessment
Kipnuk, Alaska

Plate
1



Notes: Photo acquired by AeroMetric and provided by the Alaska Department of Commerce, Community and Economic Development. US Corps of Engineers' (USACE) riverbank and erosion estimates were provided by USACE as published in their *Community Erosion Assessment; Kipnuk, Alaska*, Jan. 2009.

N

500 0 500
1 inch = 500 feet FEET

- 1963 Riverbank (USACE)
- 1996 Riverbank (USACE)
- 2004 Riverbank (USACE)
- 2009 Riverbank (DMA)
- 2019 Riverbank (Projected)
- 2029 Riverbank (Projected)
- 2039 Riverbank (Projected)
- 2059 Riverbank (USACE)

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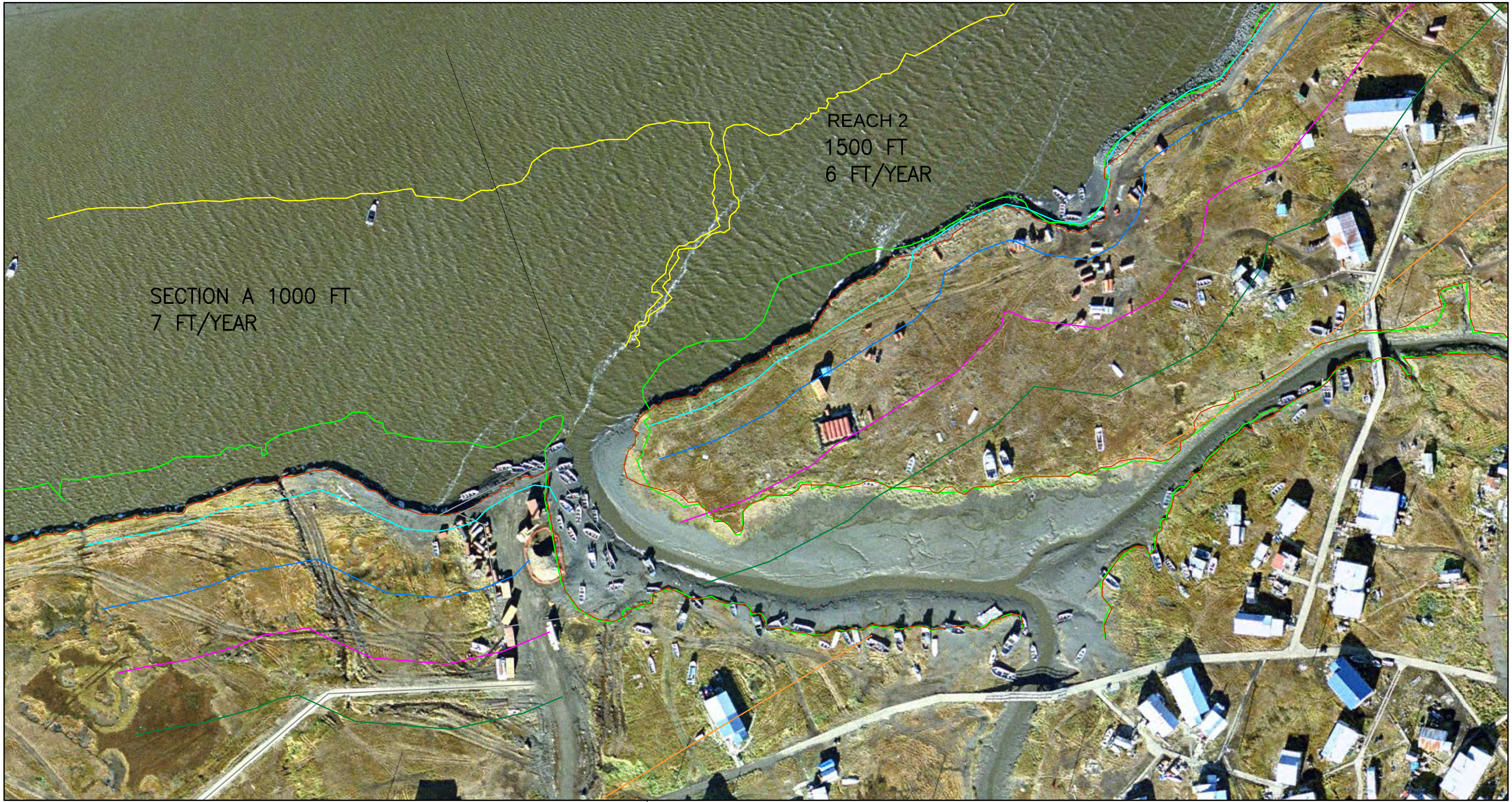
RIVERBANK EROSION
Hazard Impact Assessment
Kipnuk, Alaska

Plate
2 .1



Notes: Photo acquired by AeroMetric and provided by the Alaska Department of Commerce, Community and Economic Development. US Corps of Engineers' (USACE) riverbank and erosion estimates were provided by USACE as published in their *Community Erosion Assessment; Kipnuk, Alaska*, Jan. 2009.

N

100 0 100
1 inch = 100 feet FEET

- 1963 Riverbank (USACE)
- 1996 Riverbank (USACE)
- 2004 Riverbank (USACE)
- 2009 Riverbank (DMA)
- 2019 Riverbank (Projected)
- 2029 Riverbank (Projected)
- 2039 Riverbank (Projected)
- 2059 Riverbank (USACE)

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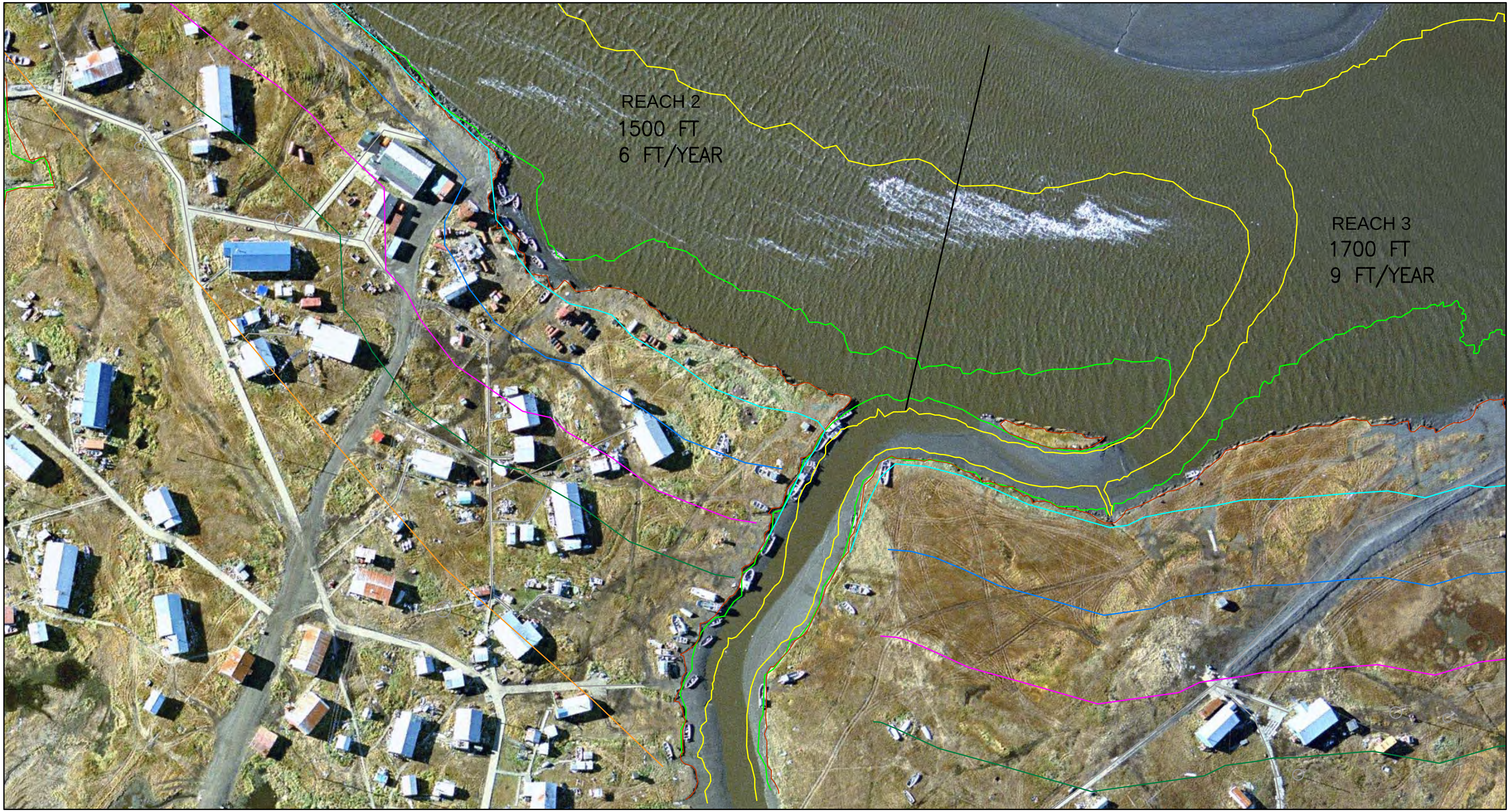
RIVERBANK EROSION
Hazard Impact Assessment
Kipnuk, Alaska

Plate
2.2



Notes: Photo acquired by AeroMetric and provided by the Alaska Department of Commerce, Community and Economic Development. US Corps of Engineers' (USACE) riverbank and erosion estimates were provided by USACE as published in their *Community Erosion Assessment; Kipnuk, Alaska*, Jan. 2009.

N

100 0 100

1 inch = 100 feet FEET

- 1963 Riverbank (USACE)
- 1996 Riverbank (USACE)
- 2004 Riverbank (USACE)
- 2009 Riverbank (DMA)
- 2019 Riverbank (Projected)
- 2029 Riverbank (Projected)
- 2039 Riverbank (Projected)
- 2059 Riverbank (USACE)

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Date: October 2011

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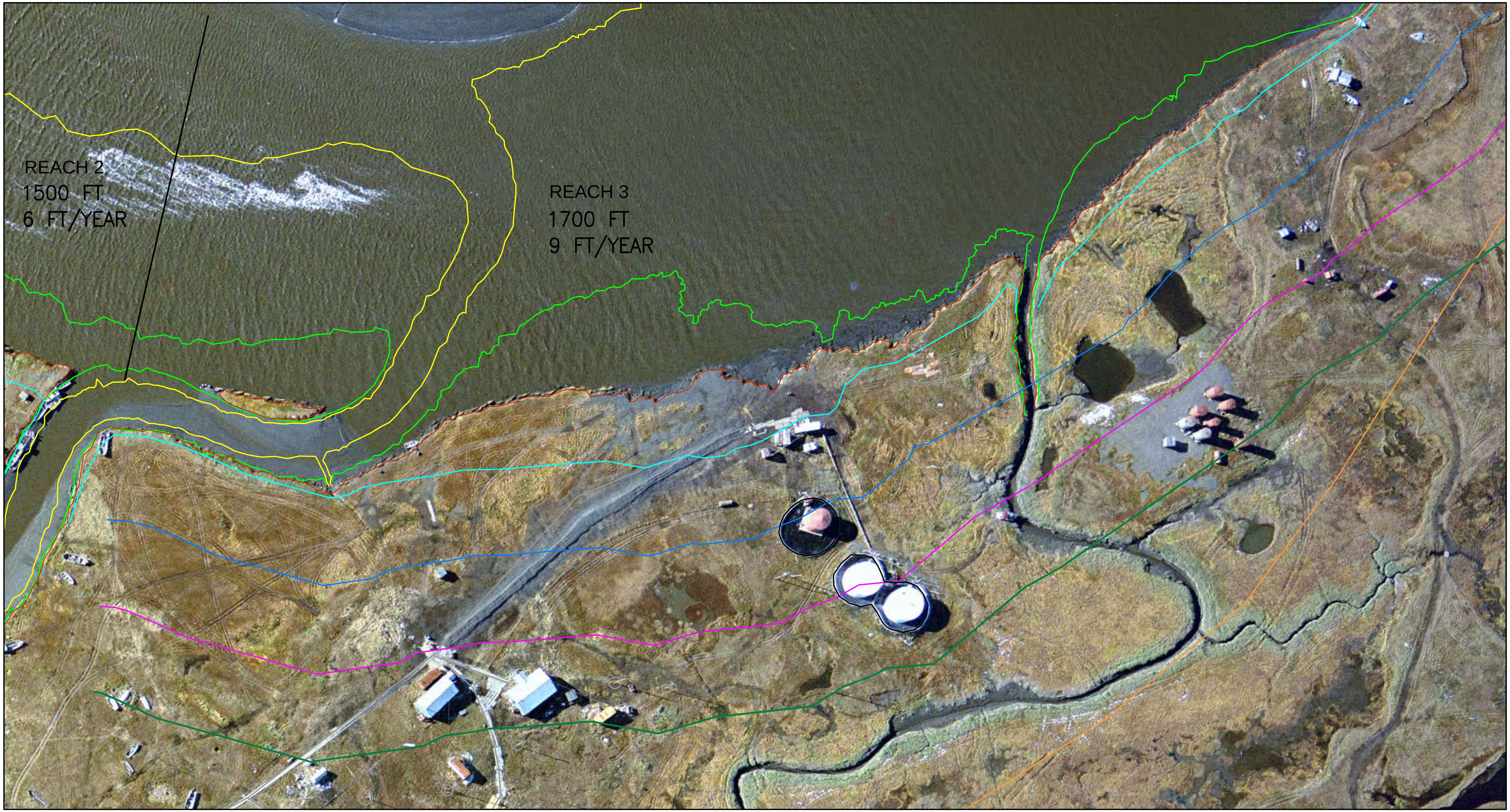
RIVERBANK EROSION
Hazard Impact Assessment
Kipnuk, Alaska

Plate
2.3



Notes: Photo acquired by AeroMetric and provided by the Alaska Department of Commerce, Community and Economic Development. US Corps of Engineers' (USACE) riverbank and erosion estimates were provided by USACE as published in their *Community Erosion Assessment; Kipnuk, Alaska*, Jan. 2009.

100 0 100
1 inch = 100 feet FEET

- 1963 Riverbank (USACE)
- 1996 Riverbank (USACE)
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Date: October 2011

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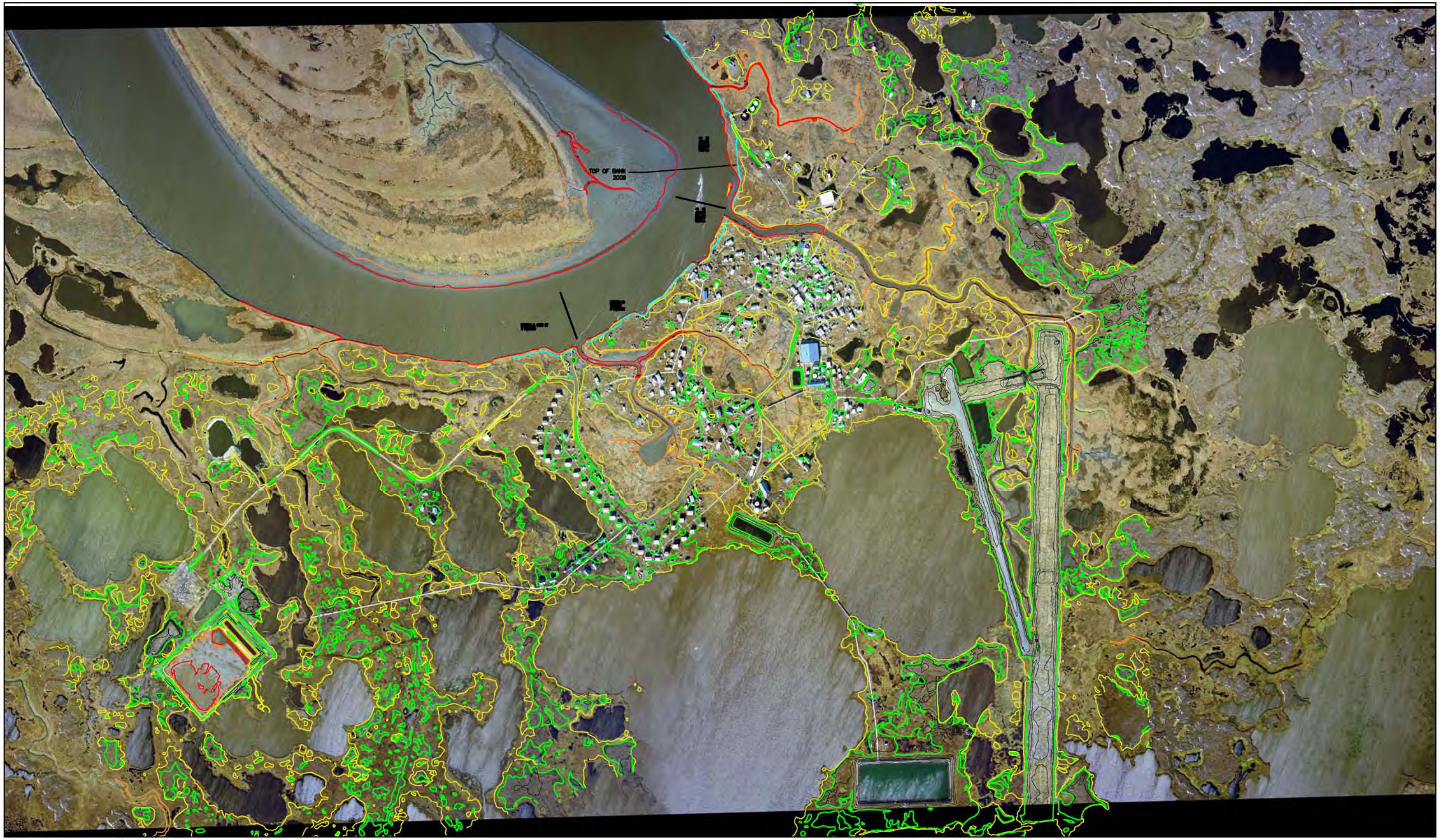
RIVERBANK EROSION
Hazard Impact Assessment
Kipnuk, Alaska

Plate
2.4



Notes: All elevations are relative. Photo acquired and elevations interpreted by AeroMetric and provided by the Alaska Department of Commerce, Community and Economic Development.

750 0 750
1 inch = 750 feet FEET

-2 foot elevation and above
-4 foot elevation
-6 foot elevation
-8 foot elevation
-10 foot elevation
Estimated 2009 Riverbank

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Date: October 2011

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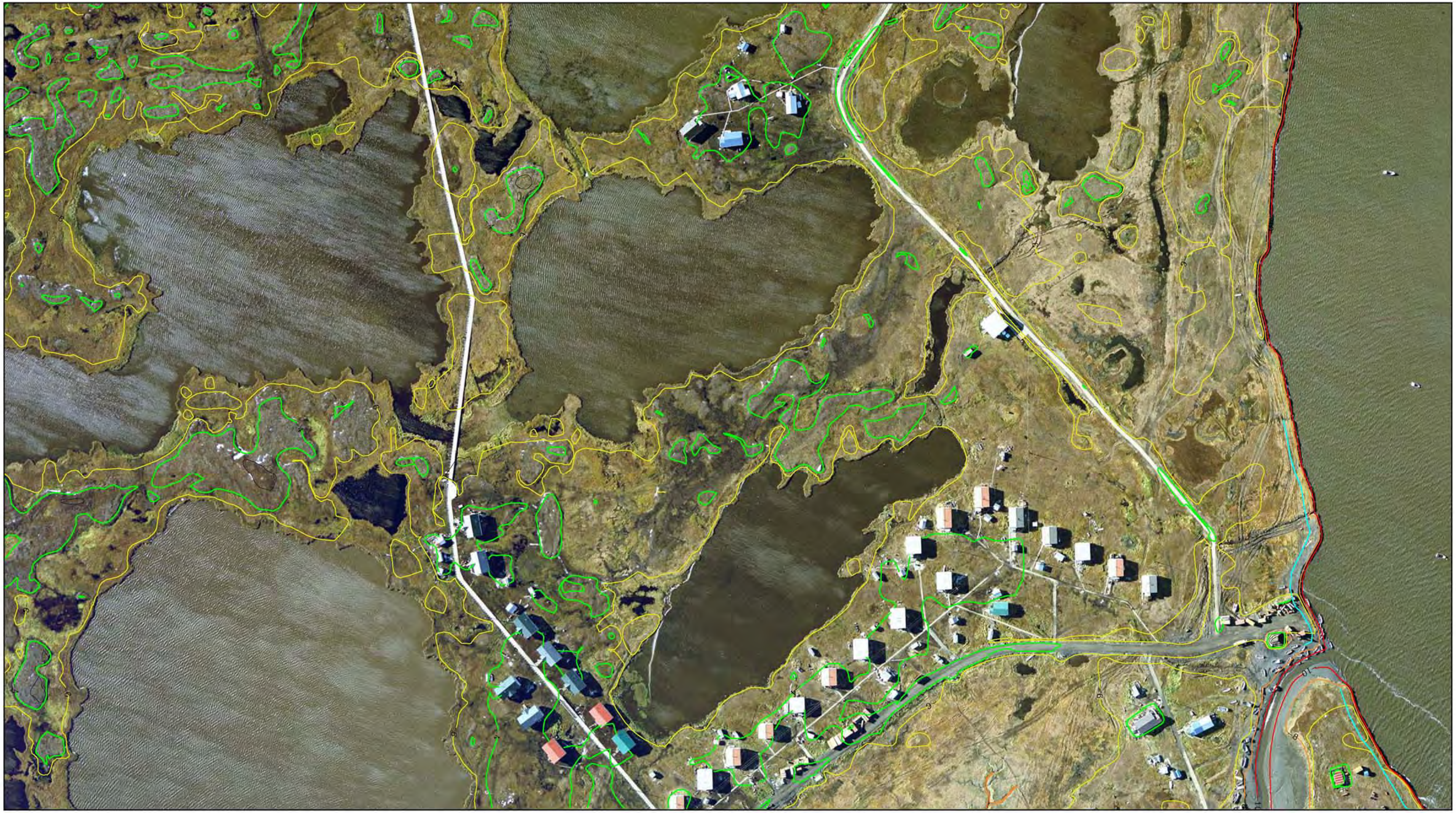
FLOOD MAP
Hazard Impact Assessment
Kipnuk, Alaska

Plate
3.1



Notes: All elevations are relative. Photo acquired and elevations interpreted by AeroMetric and provided by the Alaska Department of Commerce, Community and Economic Development.

N

200 0 200
1 inch = 200 feet FEET

-2 foot elevation and above
-4 foot elevation
-6 foot elevation
-8 foot elevation
-10 foot elevation
Estimated 2009 Riverbank

Duane Miller Associates LLC
Job No.: 4279.001 / 093-95344
Date: October 2011

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FLOOD MAP
Hazard Impact Assessment
Kipnuk, Alaska

Plate
3.2

Notes: All elevations are relative. Photo acquired and elevations interpreted by AeroMetric and provided by the Alaska Department of Commerce, Community and Economic Development.

N

200 0 200

1 inch = 200 feet FEET

-2 foot elevation and above
-4 foot elevation
-6 foot elevation
-8 foot elevation
-10 foot elevation
Estimated 2009 Riverbank

Duane Miller Associates LLC
Job No.: 4279.001 / 093-95344
Date: October 2011

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FLOOD MAP
Hazard Impact Assessment
Kipnuk, Alaska

Plate
3.3

Notes: All elevations are relative. Photo acquired and elevations interpreted by AeroMetric and provided by the Alaska Department of Commerce, Community and Economic Development.

N

200 0 200

1 inch = 200 feet FEET

- -2 foot elevation and above
- -6 foot elevation
- -10 foot elevation
- -4 foot elevation
- -8 foot elevation
- Estimated 2009 Riverbank

Duane Miller Associates LLC
Job No.: 4279.001 / 093-95344
Date: October 2011

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FLOOD MAP
Hazard Impact Assessment
Kipnuk, Alaska

Plate
3.4

APPENDIX A
COMMUNITY SURVEY SUMMARY

Duane Miller Associates LLC
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Anchorage, AK 99518-1654
(907) 644-3200 Fax 644-0507
Arctic & Geotechnical Engineering
www.alaskageo.com

Kipnuk Hazard Survey

The following is a complete summary of the results of a survey distributed and collected in Kipnuk over October 14 through 16, 2009. The surveys incorporated a door prize drawing ticket to encourage response and participation. In all 73 surveys were returned. 50 people signed in and attended the public meeting.

Survey respondent names are on file.

How many generations has your family lived in Kipnuk?

Response	Number of occurrences
Always	2
All	4
>6	4
5	12
4	5
3	7
Long time	1

Comments:

- Some respondents provided their age rather than the number of generations the family resided in Kipnuk.

How many floods do you remember occurring in Kipnuk?

Response	Number of occurrences
Many/too many/lots	10
Every year	16
Two or three	6
More than or equal to 4	9

Comments:

- *Its expected ever fall—never know how big it be year by year.*
- *Fall times*
- *Every year*
- *30 times*
- *3 major floods*

When was the worst flood that you remember or have heard stories about?

Response	Number of occurrences
1960s	1
1968	1
1990s	1
1994	2
1997	1
1998	1
1999	1
2000	1
2003	1
2004	3
2005/06	1
2006, December 3	1
2006/2007	5
2005	7
2007	8
2007, December	3
2008, Fall	10
2008, December	1

Comments:

- *6 years ago and its over due, were expecting even worse floods ahead*
- *One time my mom and sister were on the top of the house.*
- *2008*
- *When I was about 10 years old*
- *During the night and next morning*
- *All the same to me*
- *I was young, maybe 10*
- *A flood that happened approximately 50 years ago.*
- *Yearly since they build roads and boat harbors*

What time of year do you remember the most flooding occurring?

Response	Number of occurrences
Summer	4
Fall	71
Spring	0

How much of Kipnuk was covered in water during normal floods and the worst you remember or have heard about? (Check all that apply)

During Normal Floods

Response	Number of occurrences
The whole community was flooded, we couldn't get to the school.	14
Only near the river was flooded.	25
Only the low area flooded.	23
We could not get to the airport because of the flooding.	15
We could not use the boardwalks to get around the community.	7

During Worst Floods

Response	Number of occurrences
The whole community was flooded, we couldn't get to the school.	35
Only near the river was flooded.	13
Only the low area flooded.	17
We could not get to the airport because of the flooding.	18
We could not use the boardwalks to get around the community.	38

Comments:

- *Went in my trailer—whole floor covered with water*
- *We couldn't get out of the house*
- *My house is kinda high and has reached half of my house concerned about the next one*
- *Some of bulk fuel tanks floating and spilling*
- *And land was under water*
- *Some areas we couldn't get to*
- *Mud roads some parts covered*

How long is the floodwater normally in Kipnuk? (Check all that apply)

Response	Number of occurrences
More than one week	2
One week	2
Two (2) or three (3) days	41
Other: One day	7
Other: Less than 2 days	2

Comments:

- *1 night or 2 nights*
- *24 hours and to 2 days*
- *Comes with the tide and wind*
- *During the night*
- *Mostly 1 tide*
- *Once major flood then lower after*
- *One day comes and goes*
- *One day or overnight*
- *One day then lower after to normal*
- *One tide*
- *Only on high tide*
- *Only when tide comes in*
- *Overnight*
- *Sometimes it goes out with tide*
- *When tide come in*

What problems did you and your family have during the flooding?

Response	Number of occurrences
We could not get to fishing, hunting resources.	16
We could not to the school.	34
We could not get to the health clinic.	25
We could not get to the barge landing or fuel tanks.	12
Our elders cannot go out during the flooding.	30
Other: All of the above	7

Comments:

- *Stay home to those who can watch belongings.*
- *I couldn't get to my house from the bridge [to TC] because boardwalk was covered with water about knee high*
- *Personal belongings drifted away*
- *High water and water just inches below the house*
- *Boats drifted away*
- *Couldn't get anywhere*
- *We have to wait until the flood gets low*
- *Happens during night fall*
- *Stuck at home/all of the above*
- *Couldn't go across main village*
- *Watching out for our belongings*
- *Only remember Kipnuk lowlands covered with flood*

What are the three most important areas in Kipnuk? Check three

Response	Number of occurrences
Chief Paul Memorial School	55
Alaska Native Tribal health Consortium office	16
Kipnuk Traditional Council (KTC) lodge	9
Power Plant	47
Barge Landing	12
Fuel Tank Farm	38
Other: Clinic	5
Other: Airport	1
Other: Post Office	2

Comments:

- *Building outside rotten after Rural Cap Weatherization-ized it.*
- *Private residences*
- *Kipnuk Clinic, Church, airport*
- *Need seawall to stop erosion*
- *Food storage*

Tell us about your house? Check all that apply.

Response	Number of occurrences
The floor is uneven.	27
The doors and windows do not open and close easily	26
The foundation seems to change from summer to winter	47
Other: Needs weatherization	1

Comments:

- *Trailer is sitting on the swamp by the council office.*
- *[House is] Too small for a family of four*
- *I think we need higher foundations, some houses are reached by floods and damaged insulation under houses*
- *Draft comes in thru the windows*
- *Cold floor and frosty side/edges*
- *We need a major flood plan within the whole community even in our homes*
- *The outer wall is getting old and needs to be replaced or repaired*
- *It sits too low, outer walks are loose*
- *Roof is bad*
- *Gets cold along with weather*
- *House gets cold with weather*
- *Really needs leveling*
- *Siding is falling apart on the south side*
- *It mostly tilts towards the south*
- *Porch door can't close due to snow*

What are the most troubling changes in Kipnuk you think are caused by warming temperatures? (✓= answer occurs more than once)

- All the mud roads get so bad very muddy
- Bank erosion, sinking of land mass
- Buildings shifting, move water and soggy grounds
- By the river its eroding
- Changes that elders mention is the land is sinking, use to be nice & dry and it was like hilly (small) now it is mostly wet areas & grassy area
- Community wise, the base is sinking every year or the ground/soil is lower than before. We NEED to protect and upgrade tanks (bulk) for heating/travelling and extra help for Hazwopper equipments
- Easily gets to flood stage even if conditions are not ideal for flood
- Erosion ✓✓✓
- Erosion and the ground where the houses site is becoming messy. Sinking
- Erosion by the river
- Erosion watery/mossy (mushy) areas
- Erosion, road getting soft
- Erosions caused by flooding
- Erosions, watery mushy areas
- Everywhere is muddy even the sidewalks
- Flooding, erosion to the bank, high land sinking probably due to global warming, high winds
- Floods
- High water and winds
- Hunting in springtime
- Its alright
- Land ✓
- Land is flattening, higher grounds lowering cause of permafrost melting
- Less snow
- Longer summers
- Lot of unseen weather conditions are happening (i.e., sudden storms)
- More water and softer land, land change
- More winds unpredictable weather changes
- Most troubling is the ground on the village is shrinking low. We need high post foundations on the mean time like housing foundations
- No more early freeze up
- Not sure
- Not sure
- Nothing really
- Our hunting and fishing
- River bank erosion ✓✓
- Riverbank erosion, bushes were still to grow
- Rivers and lakes eroding
- Sickness, flooding is worse, water level is higher
- Sinking land
- Small berries that did not grow to actual size because the weather was unusually cold this spring
- Storm ✓✓
- The area in the village seems to be getting more water every year
- The change in the permafrost ✓✓
- The foundation and the land
- The ground
- The ground is sinking
- The land and river
- The mud is getting mushier
- There has been storms lately in the fall season
- To hot outside
- Too low boardwalks due to floods and caused by flood is sinking lower than before, mud is everywhere
- Too much rain
- Water level go up, village sinking
- Water risen since last major flood
- Winter time snow storms

How does Kipnuk look different than the elders describe it? What has changed?

- As far as I've heard from our elders, the two sloughs are much winder and the ground is more swampier from flooding
- Barge landing down by the old school/sea wall has eroded when the mouth of the nuqallpiarcun'aq river
- Before all those electric poles were dug, the ground was pretty solid with lots of high grounds.
- Buildings, new sighting
- Climate-land sinking
- Climate, more high winds, storms
- Elders said in the big flood years and years ago that this was the only place that was not flooded but they also said that with warmer weather that it is sinking
- Erosions is eating the land especially on the river
- Everything
- Everything has changed from the past
- Everything, more population, vehicles
- Global warming
- Ground lower
- High water, sink village
- I haven't lived at Kipnuk for many years but from what I've been told by elders there is a lot of erison northwest side of the village and the stream is now a slough, wide enough for boats to go in and out. About 45 years ago it was just a marrow stream like
- It has changed a lot. The land is sinking.
- Kipnuk is a very low land. Easily covered by flood and out board walks are not completed. Some of us are using very old rotting boardwalks.
- Kipnuk seems to be getting low and changing from old times till now
- Land fluffier due to heavy thick growth tundra
- Land sinking, river erosion
- Modern life is finally catching up. Used to be dependent on land.
- More erosion and the land forms seem to be sinking compared to the stories I used to hear and some lands are disappearing or sinking
- More house/too close together presenting fire hazards, no effective fire department
- More populations (people increasing), culture—some people know more about culture/some don't; climate & geography, citizenship (behavior); transportation(s) boats, four-wheelers. Snowmachines. Next generation only depends on stores not subsistence skills
- Move stuffs✓✓
- New bridge, school and houses
- Not to many
- Nuqallqiaq river eroded
- Our riverbank and our roads
- Plants animals and weather has change a lot
- Population boom, more flooding, more high winds, high land sinking
- River flow, expansion of population, lack of infrature in modern age
- River is eroding fast and the land is getting low
- Rivers and lakes eroding and less fish and birds some we don't see anymore and other animals showing up
- Rivers are getting wider, ground getting low, climate changed
- Rivers are wider! Land is more watery in some places land seems lower
- Roads, getting worse and no funding to get them fixed. Need new sidewalks and running water but no funding for those too.
- Sidewalks getting bad, road getting bad, need running water
- Sinking down from long time ago
- Sinking lower than before, more people mean more complains about this and that
- Steam houses smoke
- Terrains sinking
- The land and river and weather
- The land and the river
- The land by the main river has eroded a lot of land. The land were the original villagers have lived has eroded and people have to move in further upland.
- The mud is worst and the ground is lower in most places
- The river at the mouth is gone now
- The rivers are getting wider
- The roads are getting bad the floods are getting little worse
- The roads… ✓✓
- The village is sinking
- The village seems to be getting low, sinking slowly

- The whole village is sinking warming temperature and heavy equipments don't mix in our tundra village
- There are a lot of changes here in Kipnuk
- There is less snow and birds
- There were no roads, smaller boardwalks, more people out and about and most of all---clean
- Time has made a difference although with modern technology—human waste disposal is at third world conditions still
- Weather – land, water
- Weather change
- Weather change late winter; early spring; get warm in mid winter
- Weather different
- Wind, water level

APPENDIX B
COMMUNITY MEETING NOTES

Meeting Notes

SUBJECT:	Kipnuk Hazard Impact Assessment
PROJECT NO.:	Duane Miller Associates LLC Project No. 4272.001
GROUP:	Public
DATE:	Friday, October 16, 2009
TIME:	1:00 to 3:00 p.m.
LOCATION:	Kipnuk Traditional Council Office
MEETING OUTREACH:	CB radio transmissions, personal phone calls, word of mouth
MEETING ATTENDANCE:	44 individuals signed in
MEETING MATERIALS:	Annotated aerial photo
STAFF PRESENT:	DMA: Susan Wilson, Project Manager; Jeremiah Drage, P.E., Project Engineer
	Brooks & Associates: Anne Brooks, P.E., Public Participation
MEETING INFORMATION:	

The meeting rescheduled from Wednesday, October 15 to ensure the presence of Kipnuk Traditional Council President and Administrator, Paul J. Paul and Jimmy Paul respectively.

Paul J. Paul opened the meeting with a welcome and requested a member of the audience to say a prayer. Afterwards, he provided some background to the Kipnuk residents assembled. He turned the floor over to Anne Brooks who provided some background on what we had been doing in Kipnuk. She explained that the Susan Wilson would provide an overview of what the team had learned in the last two days in Kipnuk. We would then ask folks to provide information because we had remaining questions.

Susan briefly reviewed the information on the team had gathered in the last several days – elevations on the pile caps under the school, probes of thaw depths around the community, measurements of ground temperatures, etc. The map was highlighted showing the location of field data collection efforts.

Anne provided copies of the Corps of Engineers graphic showing the historic bank erosion in Kipnuk along with the predicted shore line.

The following is a summary of the comments folks had at the meeting. The team's questions are in *italics* followed by the community member response in regular type.

What causes flooding?
Spring ice jams. Fall storms coinciding with high tides driven by winds from forth and west

What happens during flooding?

- Floor insulation gets wet. This makes it harder to heat the house. Can't drive on the mud roads. It is hard to stop nature. For the short period of flooding you have to take precautions.
- Roofing comes off due to high winds
- House foundations get moved around. Sometimes houses come off the foundation.
- All private houses have food storage (seal pits, freezers, etc). The floodwaters may damage freezers.
- The sewage lagoons (at the school and existing honeybucket) overtop.

Discussion about the sewage lagoons led to the suggestion that fixing the problem could be an emergency project because it would be a worthwhile.

How long until the floodwaters recede?
It depends on the weather. South floods stay for a few days.
In 2008 we had a flood after freeze up and chunks of ice were scattered around the community.

What changes have you seen in Kipnuk?

- Hail storms
- Good fall this year for first time, wind comes early
- Weather changes
- Maybe it is HAARP causing the changes
- Ice removed rocks from the river protection
- Maybe we need something better than rocks for river protection
- Green stuff on the bodies of the tomcod and smelt
- Paint chewed up on the steel foundations
- The ground is sinking

How deep is the river near the community?
It is uneven – maybe 15-20 feet deep

What could help Kipnuk?
Salt proof paint

Paul J. Paul – talked about how the community is being "squeezed" between the river and the lakes and the need to protect the land that is currently occupied.

He stated and many attendees agreed that Kipnuk could use a seawall like Bethel so the next generation will be able to use the community.

Anne provided thanks to: 1) Patty for videotaping the meeting; 2) Paul and Jimmy Paul for their hospitality and assistance in setting up the meeting; 3) Community members for information; 4) School for providing a place to stay; 5) Daniel Mann and Dan ? for the ride from the airport and interpreter services; and 6) the elders for their wonderful memory.

Related documents on file:

Sign in Sheets, Handouts (COE Figure)
Annotated aerial photo

APPENDIX C
COASTLINE ENGINEERING REPORT

Erosion and Flooding for the Community of Kipnuk Alaska:
A Report to Assist in Community Planning

Prepared for:
Golder Associates, Inc
2121 Abbott Road, Suite 100
Anchorage, AK 99507

Prepared by:
Coastline Engineering
5900 Lynkerry Circle
Anchorage, AK 99504

October 10, 2011

River Bank Erosion

Kipnuk is located on the outside bend of the Kugkaklik River approximately 6.5 river miles upstream from its mouth and delta on the Bering Sea. It is subject to daily tide variations of several feet and storm surges, particularly during fall storms, that can increase the water levels several more feet. According to local residents, the major river bank erosion occurs during these storms. The cause for most of the erosion is not exactly known, but locals seem to indicate that waves may be less important than storm increased water levels.

The U.S Army Corps of Engineers (2009) compiled a report on erosion at Kipnuk (based on analyzing historical aerial photographs) that suggested that the rate of river bank erosion was not uniform along the community waterfront. They divided the waterfront into 3 distinct reaches with Reach 1 extended from the barge landing downstream (away from the village) for a distance of 1,000 feet, Reach 2 proceeded upstream from the landing for 1,500 feet to the slough near the tribal offices, and Reach 3 proceeded a distance of 1,700 feet upstream from the slough.

The Corps estimated the annual erosion rate for each reach to be 7, 6, and 9 feet respectively for Reach 1, 2, and 3. They then projected the location for the position of the river bank 50 years from the time of their study and found that several important buildings and structures would have to be removed or relocated to avoid being incorporated into the shoreline retreat. The estimated cost for this was projected at several tens of millions of dollars. It is predicated on a uniform rate of erosion that has occurred during the time for which the rates were calculated.

It is likely the only way the erosion of the river bank can be stopped or slowed is to reduce the amount of time that the moving river comes in contact with the melted active layer that sits on top of the permafrost. This document will briefly discuss some of the methods that might reduce or eliminate this contact

Erosion Mitigation Options

The solutions for stopping the river bank erosion are limited by several factors. These include:

- Lack of construction of materials in proximity to the community
- Low lying setting of the area
- Severe ice and current conditions that can occur on the outside bend of the river
- Severe water elevations particularly during fall storms
- Lack of maintenance capabilities (materials and equipment)

The possible alternatives to reduce or stop river bank erosion are limited to constructing rock revetments or installing vertical wall (probably steel sheet piling) bulkheads or a combination of both. A third option to remove the bank erosion is to relocate the river channel to the north. A fourth solution is to prepare for the most likely erosion that can occur for a given time period—the next 50 or 100 years for example. Then attempt to devise strategies to minimize damage caused by flooding and erosion by developing allowable construction set back distances for new development and relocation of existing structures. This is referred as the "do nothing" alternative. Each will be described.

Rock Revetment

At some point an attempt was made to stem bank erosion using a revetment constructed of armor riprap. According to the Corps' report, this structure still exists but has lost much of the rock. They stated that only the geotextile fabric was providing any protection. This was confirmed by the DMA team that visited the site in October. The ice during the winter and especially during the spring thaw probably is effective at plucking even large pieces of armor off the revetment. Such a structure would need considerable maintenance to function as a long-term solution to eliminate bank erosion. It is likely that continued use of similar materials would only provide relatively short term protection and would require a high degree of maintenance.

Besides ice removing the armor directly, the ice can also accelerate slope failure by scouring below the toe of the revetment. It is likely that to truly be effective the armor (perhaps less that the largest size at the greater depths) would have to extend to near the bottom of the slope. Erosion in front of revetments on shorelines is largely dependent on water depth at its toe; however, in a river the potential for erosion by currents and ice can extend all the way to the bottom of most river bank slopes. Then as the material is eroded, it is swept away by the currents leaving a scour hole that can cause slope failure. During the breakup, ice probably scours at or near the toe of the slope particularly along the outside of a river bend.

Vertical Wall

A vertical wall probably constructed from sheet pilings that are driven into the side of the bank and which interlock with the pile on each side is a possible solution for curbing bank erosion. It is commonly used along rivers. It can be driven below the depth of erosion and it must be further anchored to the shore using various methods of "tie backs." To be effective the shoreline along Kipnuk would probably require 2,000 to 2,500 feet of lineal length to provide adequate protection. This would be effective at keeping water and ice from off the slope and prohibiting erosion.

Rerouting Kugkaklik River

Both of the above methods would probably not prohibit flooding of the community during storm surges. The ground surface elevations in Kipnuk are low nearly everywhere and neither of these two solutions would be able to reduce the water surface elevations to avoid flooding. A possible solution to reduce flooding might be to engineer a "cutoff" to reroute the river so that it does not flow directly in front of the community. This is a serious action and would involve excavating perhaps as much as 1,000,000 cubic yards of material much of which is frozen. It would cause a major change in the way the community uses the river, including freight and fuel delivery and subsistence and commercial fishing. Flood reduction is not guaranteed by such a plan and much analysis would be required. Before such a plan could even be considered, many sociological factors would have to be evaluated, such as the possible change in community life style, ways of getting access to the river for freight and fuel deliveries, ways of using and managing private boats, and possible impacts on the river system. Environmental impacts would also have to be evaluated.

"Do-Nothing" Option

The "do-nothing" option is not necessarily that but only in the sense that nothing will be done to stop the river bank erosion. The 50-year or 100-year erosion line could be re-evaluated and then strict building codes enacted for any building inside that line. A plan of relocating or rebuilding important infrastructure could be developed. Structures that are or could be in danger but cannot be removed might have to be diked to protect from flooding. Important roads and boardwalks could be elevated. A place of refuge could be designated or constructed that would be large enough to hold the entire population in the case of severe flooding.

Warning System

Regardless of which method is considered the best for the community, some thought ought to be given to a flood warning system. Such a device, at a minimum, would audibly warn residents of the potential for high water. It could effectively warn the population even at night to take the necessary preparations to reduce the damage from flooding. This might also include evacuation to designated areas and providing special attention to in-need residents. Such a device might be triggered by actual water levels and could be combined with calculations using wind measurements to predict potential water levels.

Storm Analysis

A long-term wind record does not exist for Kipnuk; however, they do exist for other locations that are influenced by the same weather systems. It was decided to investigate Nome as a proxy for testing weather climate change that might be influencing more active erosion and flooding at Kipnuk for the most recent past. The number of storms and their severity were considered.

Figure 1 is a plot of the number of storms at Nome since 1973. A storm is defined as an event where the wind speed exceeds 25 knots. The plot is for storms from June through October. These are the months when the extent of open water makes it most likely that a storm surge can develop at Kipnuk. The figure clearly shows no obvious increase in the number of storms over the 37 year period (1973 to 2009).

Figure 2 is for the same period and for the same months (June through October). It again shows the intensity of the storms, expressed as maximum wind speeds, do not increase over the recent few years. In both cases only the winds from the south were considered. The importance of the wind direction can be area specific and will depend also on the offshore depth of the marine water near the mouth of the river and on the shoreline orientation there, neither of which has changed over the period or record. North winds are more likely to cause a negative storm surge or a set-down at Kipnuk. Set-downs are usually much less than set-ups for a given wind speed.

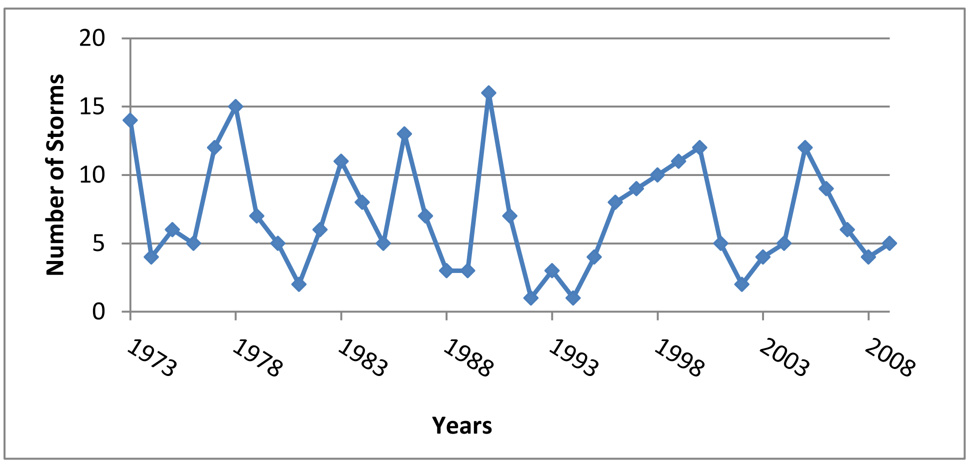

Figure 1. Number of storms per year at Nome between 1973 and 2009 and from June through October.

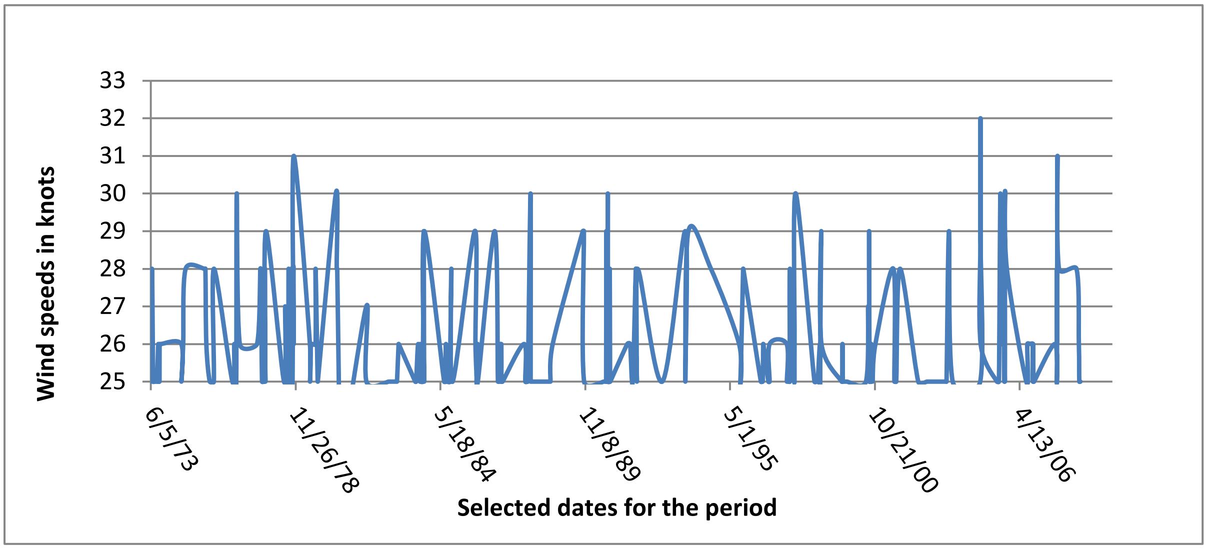

Figure 2. Storm magnitude as expressed through the wind speed for the same period and conditions as Figure 1.

Conclusions

The river bluff erosion at Kipnuk appears to be getting worse and the community is concerned about the effects of erosion and flooding on residents' safety and quality of life. The bluff erosion seems to be worse when wind-induced storm surges on top of high tide increase the water level elevation to near or above the river banks. This is likely to occur during fall storms which may be more intense than the remainder of the year but certainly occur when there is no protective ice cover and when the active layer depth may be at its maximum.

This report has suggested some alternatives for dealing with the erosion and providing more security for the village from flooding. None of the options for this are inexpensive and all require monitoring and maintenance.

There does not appear to be a significant change in the storm activity or strength over the last few years that could be related to climate change. However, there is little doubt that surface air temperatures have noticeably increased in the last 30 years and that could have a direct effect on the depth of the active layer. This could easily exacerbate storm impacts due to increased storm water levels and waves. It is also unknown whether increases in surface temperatures may have contributed to changes in river discharges and dynamics. Minor changes in these may be directly related to climate changes and in increased erosion. River dynamics is beyond the scope of this report.

It is hoped that this report has provided some information that might be useful to the community as they attempt to devise strategies to maintain a more livable and safe community.

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