Report of Investigation 2024-5

COASTAL FLOOD IMPACT ASSESSMENT FOR KIPNUK, ALASKA

Keith C. Horen, Autumn C. Poisson, Zachary J. Siemsen, Jessica E. Christian, and Nora M. Nieminski

Aerial photograph of Kipnuk, Alaska, taken via drone in 2022. Photo: K.C. Horen, DGGS.

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State of Alaska
Department of Natural Resources
Division of Geological & Geophysical Surveys

STATE OF ALASKA
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COASTAL FLOOD IMPACT ASSESSMENT FOR KIPNUK, ALASKA

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OVERVIEW

This Division of Geological & Geophysical Surveys (DGGS) report is an investigation of the historical flood record and provides an assessment of flood impacts for the community of Kipnuk, Alaska. This community-specific report has three sections: data description, flood impact categorization, and historical flood record. Methods used to evaluate historical floods and delineate flood impact categories (minor, moderate, major), as defined by the National Weather Service (NWS), are described in detail in Horen, Poisson, and others (2024), an update from the methods described by Buzard and others (2021). Flood and infrastructure heights are relative to the local mean higher high water (MHHW) datum in feet (ft).

SUMMARY

The community of Kipnuk, whose name in Yup'ik is *Qipneq*, meaning bend in the river, is located on a southern cutbank of the Kugkaktlik River in the Yukon-Kuskokwim Delta approximately four miles inland from the Bering Sea and 100 miles southwest of Bethel. The average ground height in Kipnuk is only a few feet above the local high tide height, leaving it subject to flooding during severe coastal storm events (AECOM, 2016) and high tides. The 2019 Denali Commission Statewide Threat Assessment stated that Kipnuk is considered vulnerable to flooding and expected to suffer damaging impacts to critical infrastructure in the short-term (University of Alaska Fairbanks Institute of Northern Engineering and others, 2019). Additional data collection will improve our understanding of the flooding threat to this community.

Six disaster declarations (1979, 1982, 2006, 2009, 2015, and 2022) have been reported for flooding in Kipnuk (Alaska Division of Homeland Security & Emergency Management [DHS&EM], 2008; Federal Emergency Management Agency [FEMA], 2009; The Village of Kipnuk Hazard Mitigation Planning Team, 2013; LeMay Engineering and Consulting, Inc., 2018; State of Alaska [SOA], 2022). Based on research done for this report, Kipnuk experienced at least 30 flood events between 1979 and 2022 (26 from storm surges, two from ice jams, and two from snowmelt events). We estimated the peak still water heights for 11 of these flood events, categorizing six as minor, two as moderate, and three as major. The highest flood occurred on November 13, 2000, reaching an estimated still water height of 4.7 ft (1.43 m) MHHW.

DATA

DGGS used geospatial data to assess infrastructure impacts and estimate flood heights from various sources of evidence (e.g., personal accounts, photographs, official reports, etc.). We used ArcGIS Pro version 3.2.1 to process and map these geospatial data.

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Digital Elevation Models and Orthoimagery

Accurate, high-resolution elevation models and orthoimagery are used to measure flood heights in the absence of high-water mark (HWM) data. Four digital elevation models (DEM; table 1) and three orthoimages (table 2) are available for Kipnuk. Orthoimagery was collected in 2004 for a Community Profile Map (CPM; Alaska Division of Community & Regional Affairs [DCRA], 2004). Aerial imagery was collected in 2015 and 2022, which was used to create digital surface models (DSM) and orthoimagery derived from photogrammetric structure from motion (SfM) processing (Overbeck and others, 2016; Horen, Buzard, and others, 2024). DGGS collected light detection and ranging (lidar) data in 2021, with a DSM and digital terrain model (DTM) created in 2022 (Zechmann and others, 2023). Where first-floor height data were unavailable (i.e., unoccupied buildings, some facility-attached infrastructure, and private property), heights were extracted from the 2021 DTM unless a first-floor height was discernable from the 2022 SfM model, orthoimagery, and DSM (e.g., decking at entrances to buildings, visible platforms extending from building edges, etc.). All DEM and orthoimagery will be referenced in this report by the names assigned in tables 1 and 2.

First-Floor Height Survey

The Alaska Native Tribal Health Consortium (ANTHC) completed a field survey of the first-floor heights of occupied buildings in Kipnuk on January 10 and 11, 2023. These data were collected in the North American Vertical Datum 1988 with Geoid 12B applied (NAVD88 [GEOID12B]) in U.S. survey feet (usft) (app. A). The reported vertical accuracy achieved during this survey is ± 0.1 ft (0.04 m). This survey will be referenced within this report as the 2023 first-floor survey. DGGS spatially joined these first-floor heights to building footprints digitized from the 2022 orthoimagery, identifying 248 as occupied buildings (i.e. residential, public, or commercial structures in which people live or work), 177 of which are residential.

GNSS Survey

DGGS performed a Global Navigation Satellite System (GNSS) survey on June 21, 2022, during a visit to Kipnuk. The purpose of this survey was to collect community reports and photo-identified HWM data. These data were collected in the NAVD88 (GEOID12B) vertical datum in meters (m) and reported in feet (ft) (app. B). The vertical accuracy achieved during this survey is ± 0.3 ft (0.08 m). This survey will be referenced within this report as the 2022 survey.

Water Level Sensor

DGGS installed a Stilltek iGage radar water level sensor in Kipnuk on June 21, 2022. This sensor was replaced on October 16, 2023, and is attached to the south side of the bridge connecting the central portion of the village to the northern portion of the village (figs. 1 and 2). Data collected

Table 1. Summary of digital elevation models available for Kipnuk, Alaska.

	2015 DSM	2021 DSM	2021 DTM	2022 DSM
Collection date	2015-AUG-23	2021-AUG-18	2021-AUG-18	2022-JUN-21
Elevation type	Photogrammetric SfM	Lidar Surface	Lidar Bare Earth	Photogrammetric SfM
Vertical datum	NAVD88 (GEOID12B)	NAVD88 (GEOID12B)	NAVD88 (GEOID12B)	NAVD88 (GEOID12B)
Ground sample distance	0.6 ft (0.19 m)	1.6 ft (0.50 m)	1.6 ft (0.50 m)	0.2 ft (0.06 m)
Accuracy	0.2 ft (0.05 m)	0.2 ft (0.06 m)	0.2 ft (0.06 m)	0.2 ft (0.06 m)

Table 2. Summary of orthoimagery available for Kipnuk, Alaska.

	2004 Orthoimagery	2015 Orthoimagery	2022 Orthoimagery
Collection date	2004-JUN-04	2015-AUG-23	2022-JUN-21
Ground sample distance	1.0 ft (0.30 m)	0.3 ft (0.10 m)	0.1 ft (0.02 m)

by this sensor, updated hourly, are available from Alaska Water Level Watch at portal.aoos.org/#metadata/119627/station/data. The vertical accuracy of these data is ± 0.3 ft (0.08 m).

Vertical Datums

Local tidal datums (table 3) for Kipnuk are described by National Oceanic and Atmospheric Administration (NOAA) Center for Operational Oceanographic Products (CO-OPS) tide station 946 5951 available from tidesandcurrents.noaa.gov/stationhome.html?id=9465951. Two additional vertical datums exist for Kipnuk, a local project datum associated with a CPM commissioned by the DCRA in 2004 and an Alaska Department of Transportation and Public Facilities (ADOT&PF) local project datum established in 2010 and described on Bethel recording district plat 2011-17, found at dnr.alaska.gov/ssd/recoff/search/docdisplay?District=402&SelectedDoc=20110012880. The ADOT&PF datum was created by adding 1,000.0 ft to the NAVD88 (GEOID99) datum. In 2015, during their site investigation, AECOM compared heights derived from the 2004 CPM with heights collected in the ADOT&PF datum to approximate the relationship between these two datums (AECOM, 2016). DGGS used NOAA's Vertical Datum Transformation software version 4.3 to convert NAVD88 (GEOID99) elevations to NAVD88 (GEOID12B) elevations. Vertical transformation values between relevant datums are listed in tables 4 and 5.

FLOOD IMPACT CATEGORIES

Flood impact categories are used by the NWS to define and communicate flood risk to the public. These categories are designated as major, moderate, and minor (NWS, 2016). Definitions for these categories in the NWS guidance specific

Figure 1. Location of Stilltek iGage radar water level sensor in Kipnuk, Alaska.

Figure 2. Stilltek iGage radar water level sensor installation in Kipnuk, Alaska, located on the south side of bridge.

Table 3. Local tidal datums for Kipnuk, Alaska (NOAA CO-OPS tide station 946 5951).

Tidal Datum	Abbreviation	ft MHHW	m MHHW	ft NAVD88 (GEOID12B)	m NAVD88 (GEOID12B)
Mean Higher High Water	MHHW	0.0	0.00	7.8	2.36
Mean High Water	MHW	-1.4	-0.43	6.4	1.94
Mean Sea Level	MTL	-4.2	-1.28	3.5	1.08
Mean Tide Level	MSL	-4.4	-1.35	3.3	1.02
Mean Low Water	MLW	-7.4	-2.27	0.3	0.10
North American Vertical Datum 1988 (GEOID12B)	NAVD88 (GEOID12B)	-7.8	-2.36	0.0	0.00
Mean Lower Low Water	MLLW	-8.3	-2.53	-0.5	-0.16

to Alaska are provided in the form of statements regarding flood impacts, some of which are more qualitative than quantitative (NWS, 2016). To ensure impact assessments are consistent and repeatable, DGGS developed a set of quantitative criteria for each category (Horen, Poisson, and others, 2024). A fourth category, extreme flooding, as defined by DGGS, is included in this report to delineate critical infrastructure situated at heights above the anticipated maximum based on the specifics of the local historical flood record, though flooding is still possible above this height (Horen, Poisson, and others, 2024).

Table 4. Vertical datum conversion chart for Kipnuk, Alaska, in feet. To convert from one datum to another, locate the row of the datum in which the data are currently projected and the column of the datum in which the data will be projected, then add the value in the cell where the row and column meet.

		To Datum				
	ft	**NAVD88 (GEOID99)**	**CPM (2004)**	**MHHW (946 5951)**	**NAVD88 (GEOID12B)**	**ADOT&PF (2010)**
From Datum	**NAVD88 (GEOID99)**	0.0	+4.5	+12.0	+19.7	+1000.0
	CPM (2004)	-4.5	0.0	+7.5	+15.2	+995.5
	MHHW (946 5951)	-12.0	-7.5	0.0	+7.8	+988.0
	NAVD88 (GEOID12B)	-19.7	-15.2	-7.8	0.0	+980.3
	ADOT&PF (2010)	-1000.0	-995.5	-988.0	-980.3	0.0

Table 5. Vertical datum conversion chart for Kipnuk, Alaska, in meters. To convert from one datum to another, locate the row of the datum in which the data are currently projected and the column of the datum in which the data will be projected, then add the value in the cell where the row and column meet.

		To Datum				
	m	**NAVD88 (GEOID99)**	**CPM (2004)**	**MHHW (946 5951)**	**NAVD88 (GEOID12B)**	**ADOT&PF (2010)**
From Datum	**NAVD88 (GEOID99)**	0.00	+1.37	+3.65	+6.01	+304.80
	CPM (2004)	-1.37	0.00	+2.28	+4.64	+303.43
	MHHW (946 5951)	-3.65	-2.28	0.00	+2.36	+301.15
	NAVD88 (GEOID12B)	-6.01	-4.64	-2.36	0.00	+298.79
	ADOT&PF (2010)	-304.80	-303.43	-301.15	-298.79	0.00

Short definitions for each flood impact category are listed below and are explained in greater detail by Horen, Poisson, and others (2024). Table 6 provides a list of key infrastructure heights and the risk categories they fall within. Additional information about each piece of key infrastructure is detailed in the category blocks that follow table 6. The map series that accompanies this report depicts the potential inundation extents for each flood impact category.

Minor Flooding: "Minimal or no property damage, but possibly some public threat" (NWS, 2016).

Moderate Flooding: "Some inundation of structures and roads… Some evacuations of people and/or transfer of property to higher elevations may be necessary" (NWS, 2016).

Major Flooding: "Extensive inundation of structures and roads. Significant evacuations of people and/or transfer of property to higher elevations are necessary" (NWS, 2016).

Extreme Flooding: Any flooding that reaches a height above the highest estimated flood height plus the confidence of that estimate. (Horen, Poisson, and others, 2024; NWS, 2018).

Coastal Flood Impact Map

Kipnuk, Alaska

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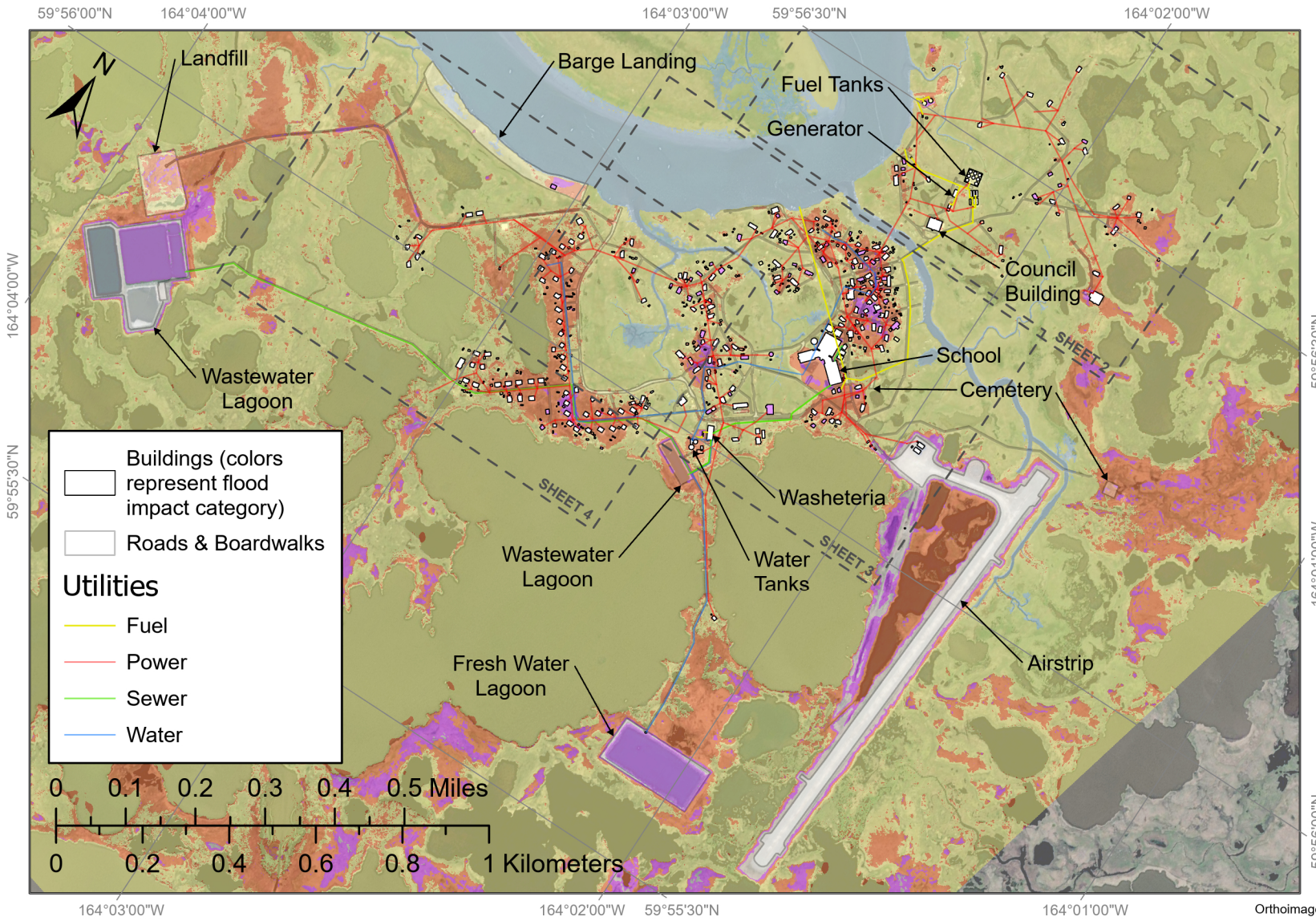
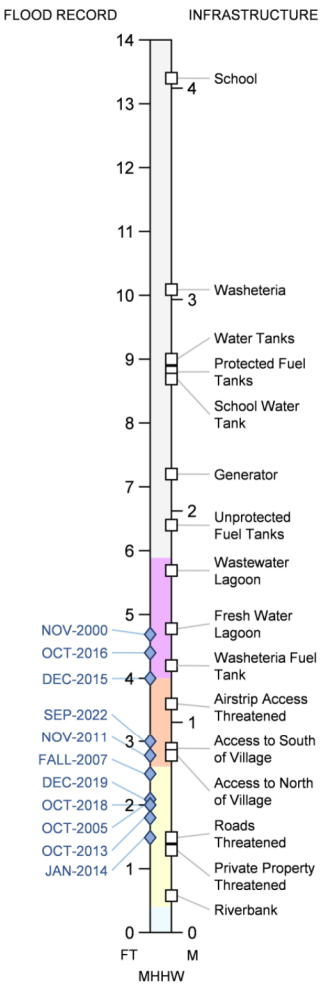
SHEET 1 OF 4





To calculate height above
NAVD88: add 7.75 ft (2.362 m)
MLLW: add 8.28 ft (2.525 m)

Projection: NAD83 (2011) UTM Zone 3N
Infrastructure based on DCRA community map
Orthoimagery and DSM available from elevation.alaska.gov

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Major Flooding is defined as extensive inundation of structures and roads. Significant evacuation of people and/or transfer of property to higher elevations are necessary.

Moderate Flooding is defined as some inundation of structures and roads at lower elevations. Some evacuation of people and/or transfer of property to higher elevations are necessary.

Minor Flooding is defined as minimal or no property damage. Evacuation of people and/or transfer of property to higher elevations are typically not necessary.

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Coastal Flood Impact Map

Kipnuk, Alaska

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Horen and others, 2024
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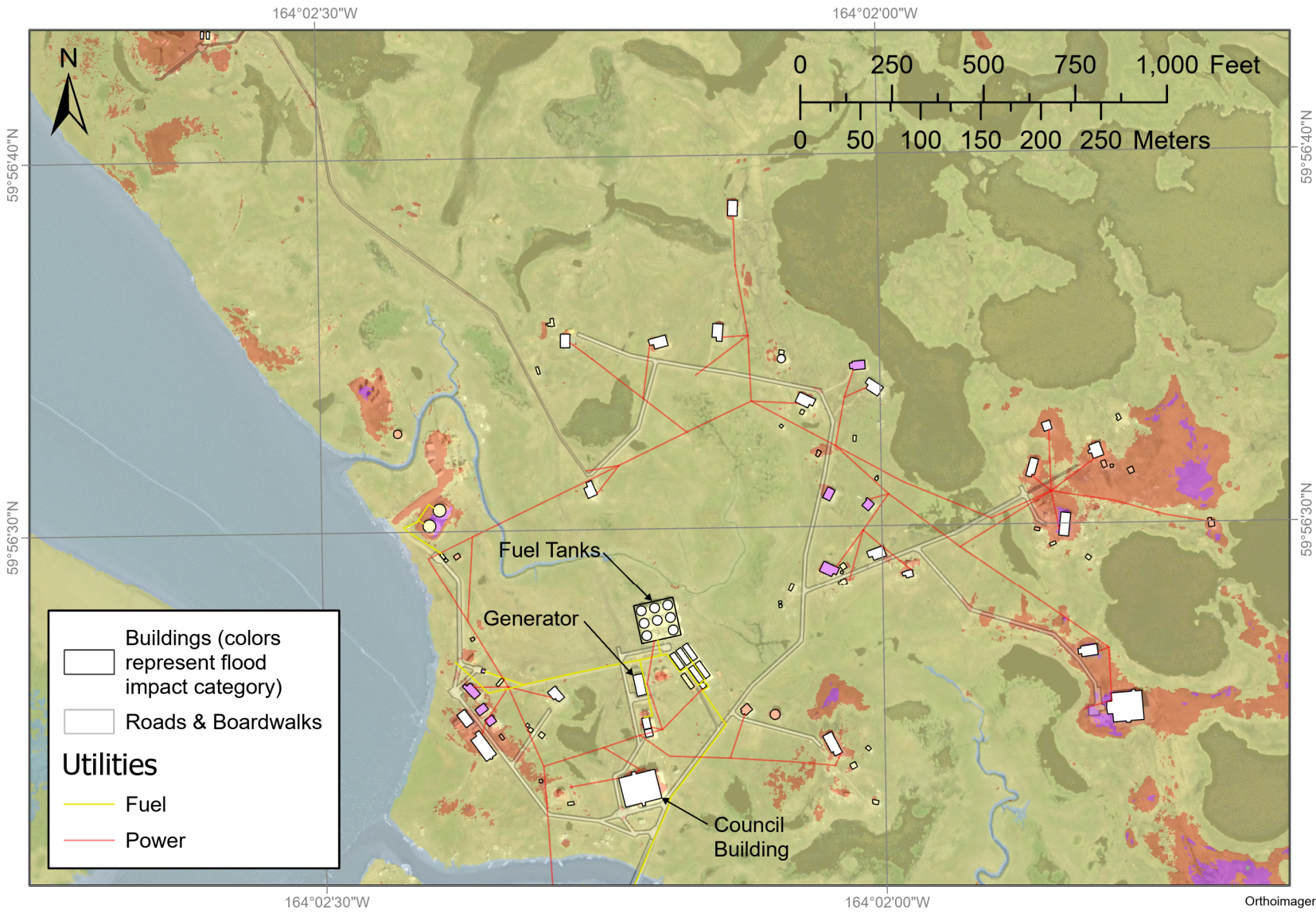

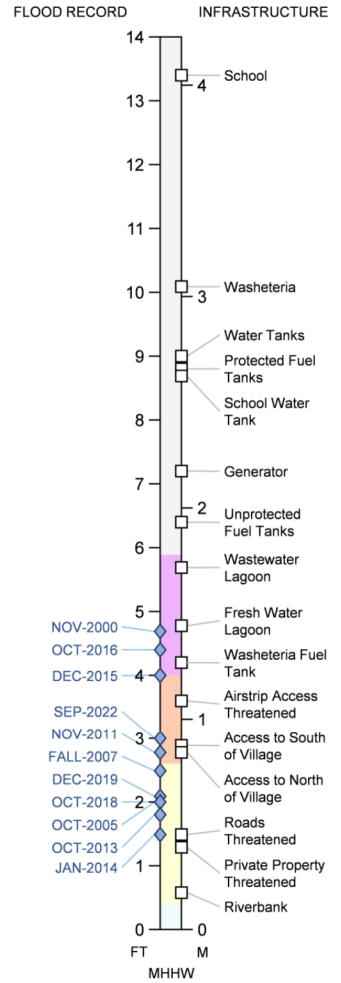

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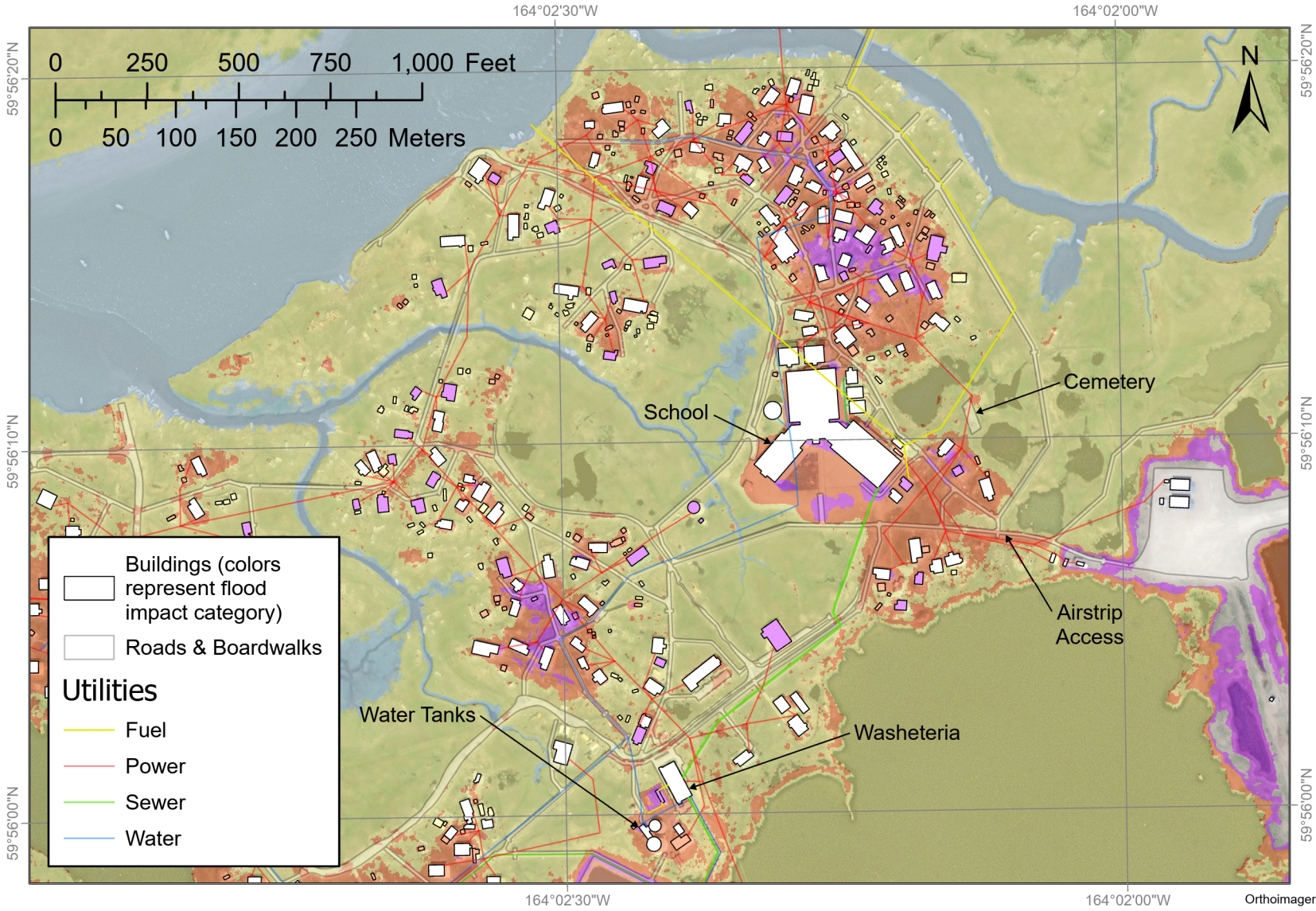
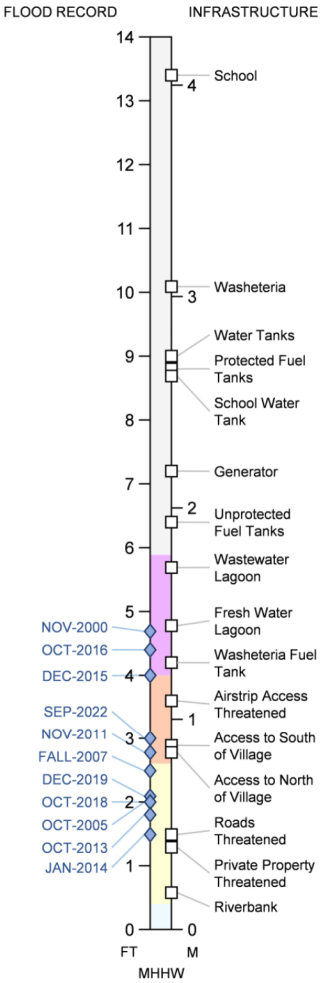
SHEET 3 OF 4





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Coastal Flood Impact Map

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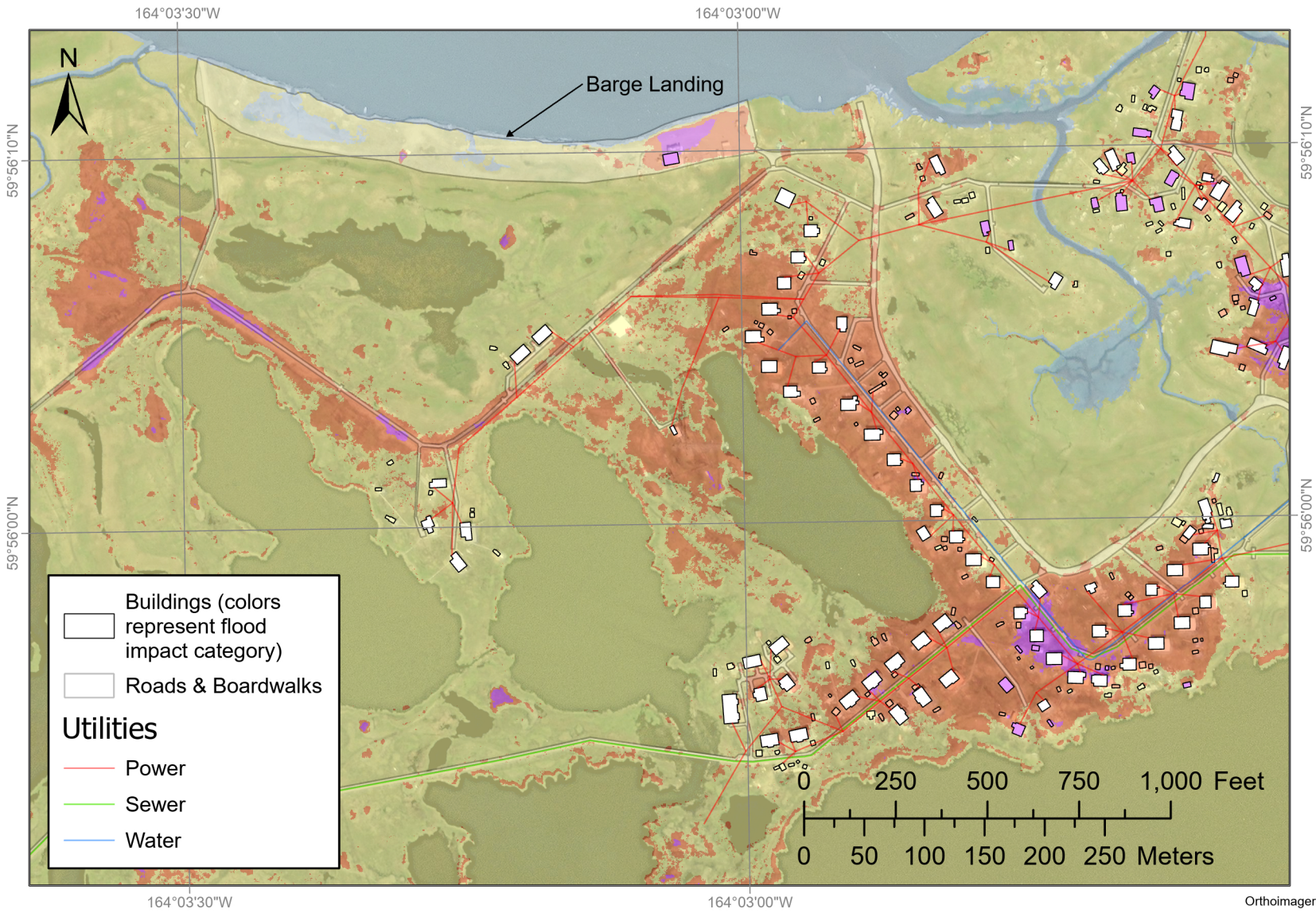
SHEET 4 OF 4



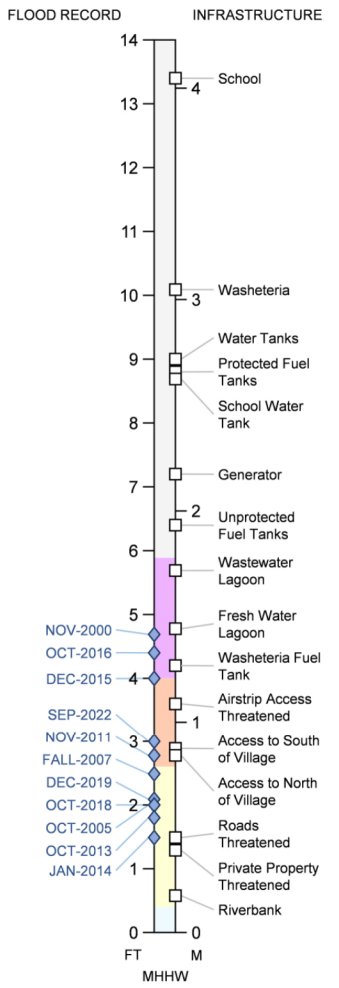


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Table 6. Summary of infrastructure heights and flood categories for Kipnuk, Alaska. Gray = extreme, purple = major, red = moderate, and yellow = minor. The extreme category represents infrastructure situated at heights above the highest estimated flood height with confidence included. Categories are based on current infrastructure conditions.

Feature	Height (ft MHHW)	Confidence (ft)	Height (m MHHW)	Confidence (m)
School	13.4	0.1	4.07	0.04
Washeteria	10.1	0.1	3.08	0.04
Water tanks	9.0	0.1	2.73	0.04
Fuel tank containment wall	8.8	0.1	2.68	0.04
School water tank	8.7	0.1	2.64	0.04
Generator	7.2	0.1	2.20	0.04
Fuel tanks	6.4	0.1	1.96	0.04
Many buildings flooded	6.2	0.1	1.90	0.04
Extreme	**5.9**		**1.79**	
Several buildings flooded	5.7	0.1	1.74	0.04
Wastewater lagoon	5.7	0.2	1.72	0.06
Freshwater lagoon	4.8	0.2	1.48	0.06
Lowest residences flooded	4.6	0.1	1.40	0.04
Washeteria fuel tank	4.2	0.1	1.27	0.04
Major	**4.0**		**1.23**	
Airstrip access threatened	3.6	0.2	1.09	0.06
Important roads threatened	2.8	0.2	0.84	0.06
Moderate	**2.6**		**0.78**	
Low-lying roads threatened	1.5	0.2	0.46	0.06
Private property threatened	1.3	0.2	0.38	0.06
Riverbank	0.6	0.2	0.17	0.06
Minor	**0.4**		**0.11**	

Extreme Flooding: greater than 5.9 ft (1.79 m) MHHW

School: 13.4 ± 0.1 ft (4.07 ± 0.04 m) MHHW

As the largest building, with the highest first-floor height, the school has been identified as the most suitable flood evacuation point.

Washeteria: 10.1 ± 0.1 ft (3.08 ± 0.04 m) MHHW

Washeterias provide resources such as laundry, showers, toilets, and treated drinking water.

Water tanks: 9.0 ± 0.1 ft (2.73 ± 0.04 m) MHHW

The primary water tanks are adjacent to the washeteria and contain most of the community's treated water supply. There are two tanks with first-floor heights of 9.0 ± 0.1 ft (2.73 ± 0.04 m) and 9.2 ± 0.1 ft (2.80 ± 0.04 m) MHHW.

Fuel tank containment wall: 8.8 ± 0.1 ft (2.68 ± 0.04 m) MHHW

A portion of the fuel tank farm (eight vertical, cylindrical tanks) is protected by a containment wall that is approximately 2.5 ft (0.75 m) above ground level.

School water tank: 8.7 ± 0.7 ft (2.64 ± 0.21 m) MHHW

The school water tank is the second largest reserve of treated water in the community and is the primary water source for the school.

Generator: 7.2 ± 0.1 ft (2.20 ± 0.04 m) MHHW

The generator facility provides power for the village.

Fuel tanks: 6.4 ± 0.1 ft (1.96 ± 0.04 m) MHHW

A portion of the fuel tank farm (six horizontal tanks) is elevated approximately 5.0 ft (1.54 m) above ground level but is unprotected by a containment wall.

Many buildings flooded 1.0 ft (0.30 m) or more: 6.2 ± 0.1 ft (1.90 ± 0.04 m) MHHW

We consider "many" buildings to describe more than five occupied buildings. Occupied buildings are residential, public, or commercial structures in which people live or work.

Major Flooding: 4.0 to 5.9 ft (1.23 to 1.79 m) MHHW

Several buildings flooded less than 1.0 ft (0.30 m): 5.7 ± 0.1 ft (1.74 ± 0.04 m) MHHW

We consider "several" buildings to describe more than one but less than five occupied buildings.

Wastewater lagoon: 5.7 ± 0.2 ft (1.72 ± 0.06 m) MHHW

The wastewater lagoon, located southeast of the village, is surrounded by an earthen berm, this being the lowest height measured from the 2021 DTM. A breach of this lagoon could introduce sewage contamination into the surrounding environment.

Freshwater lagoon: 4.8 ± 0.2 ft (1.48 ± 0.06 m) MHHW

The freshwater lagoon, located west of the south end of the airstrip, is surrounded by an earthen berm, this being the lowest height measured from the 2021 DTM. A breach of this lagoon could result in contamination of the village's primary freshwater source.

Lowest residences flooded 1.0 ft (0.30 m) or more: 4.6 ± 0.1 ft (1.40 ± 0.04 m) MHHW

This is the height at which the two lowest residential buildings would experience major flooding.

Washeteria fuel tank: 4.2 ± 0.1 ft (1.27 ± 0.04) MHHW

The washeteria fuel tank is considered key infrastructure because it is necessary for the operations of the washeteria facility. The height of the washeteria fuel tank forms the basis for the lower limit of the major flooding category.

Moderate Flooding: 2.6 to 4.0 ft (0.78 to 1.23 m) MHHW

Airstrip access: 3.6 ± 0.2 ft (1.09 ± 0.06 m) MHHW

Measured from the 2022 DSM, the ground height of the lowest section of the airstrip access road is 2.6 ± 0.2 ft (0.79 ± 0.06 m) MHHW. The NWS assumes a depth of 1.0 ft (0.30 m) to be the maximum for reasonably safe travel on flooded roads (NWS, 2023).

Access to southern portion of village: 2.9 ± 0.2 ft (0.89 ± 0.06 m) MHHW

Measured from the 2022 DSM, at this height a portion of the village south of the school would be cut off from the remainder of the village by water 1.0 ft (0.30 m) in depth.

Access to northern portion of village: 2.8 ± 0.2 ft (0.84 ± 0.06 m) MHHW

Measured from the 2022 DSM, at this height a portion of the village north of the bridge crossing near the council building would be cut off from the remainder of the village by water 1.0 ft (0.30 m) in depth. The height of this portion of boardwalk forms the basis for the lower limit of the moderate flooding category.

Minor Flooding: 0.4 to 2.6 ft (0.11 to 0.78 m) MHHW

Low-lying roads threatened: 1.5 ± 0.2 ft (0.46 ± 0.06 m) MHHW

Measured from the 2021 DTM, flood waters would reach but not overtop the lowest portions of boardwalks and roads at this height. The integrity of roads and boardwalks may be impacted by erosion and water damage, even if flood waters do not overtop these surfaces. Additionally, water on roads and boardwalks may make these surfaces difficult to traverse safely.

Private property threatened: 1.3 ± 0.2 ft (0.38 ± 0.06 m) MHHW

Measured from the 2021 DTM, flood waters would reach the lowest private property at this height. Private property may include storage sheds, boats, fishing equipment, vehicles, and other property at ground level outside of occupied structures. From the 2022 orthoimagery, we identified 342 features meeting this description and extracted the average ground height beneath each from the 2021 DTM.

Riverbank: 0.6 ± 0.2 ft (0.17 ± 0.06 m) MHHW

Measured from the 2021 DTM, the upper edge of the riverbank, including the banks of tributaries within the boundary of the village, would be overtopped by flood waters at this height. The height of the riverbank forms the basis for the lower limit of the minor flooding category.

HISTORICAL FLOOD RECORD

The historical flood record for Kipnuk is listed in chronological order below, with estimated floods identified by impact category. This record was compiled from local knowledge shared with DGGS staff during a June 2022 site visit and from information available to the public through open sources or upon request. It is possible that additional, undocumented flood events have impacted the community. Historical information was used in conjunction with the best available, temporally relevant geospatial data to estimate flood heights where possible.

All estimates and confidences were calculated following the methods developed by Horen, Poisson, and others (2024). As described by Horen, Poisson, and others (2024), each estimate is accompanied by two confidence metrics, an estimate confidence based on the combined known potential errors and a time-based confidence based on the temporal relevance of the data used to estimate a given event. Temporal confidence values are noted with an asterisk (*) where the data used to estimate the flood event height were collected 20 years or more before or after the event: in these cases, the large temporal discontinuity may result in a value that could potentially exceed what the confidence model predicts (Horen, Poisson, and others, 2024).

For each flood event, a list and summarization of sources is included, as well as an explanation of the data used and steps performed during estima-

tion, where relevant. Each flood height estimate is classified into a single flood impact category, but estimate confidences may span more than one category. Table 7 provides a complete list of the flood events found during our research, with estimated floods categorized and listed in order from highest to lowest, and floods not estimated listed in chronological order. Figure 3 provides a timeline of the estimated flood events and a visual representation of the flood height estimates and confidences.

Table 7. Summary of historical floods in Kipnuk, Alaska. Flood categories are included for reference: purple = major, red = moderate, yellow = minor.

Estimated Floods

	Flood Date	Type	Height (ft MHHW)	Estimate Confidence (ft)	Temporal Confidence (ft)	Height (m MHHW)	Estimate Confidence (m)	Temporal Confidence (m)
Major	2000-NOV-13	Storm surge	4.7	± 0.2	± 1.0*	1.43	± 0.05	± 0.31*
	2016-OCT-28	Storm surge	4.4	± 0.4	± 0.3	1.35	± 0.13	± 0.10
	2015-DEC-19	Storm surge	4.0	± 0.2	± 0.4	1.22	± 0.07	± 0.11
Moderate	2022-SEP-17	Storm surge	3.0	± 0.2	± 0.0	0.91	± 0.06	± 0.00
	2011-NOV-09	Storm surge	2.8	± 1.3	± 0.6	0.86	± 0.39	± 0.18
Minor	2007-FALL	Storm surge	2.5	± 1.1	± 0.2	0.76	± 0.34	± 0.05
	2019-DEC-10	Snow melt	2.1	± 0.4	± 0.1	0.64	± 0.12	± 0.03
	2018-OCT-04	Storm surge	2.0	± 0.2	± 0.2	0.61	± 0.06	± 0.05
	2005-OCT-17	Storm surge	2.0	± 0.1	± 0.1	0.61	± 0.04	± 0.02
	2013-OCT-25	Storm surge	1.8	± 0.4	± 0.4	0.54	± 0.12	± 0.13
	2014-JAN-22	Snow melt	1.5	± 0.3	± 0.4	0.45	± 0.11	± 0.11

Floods Not Estimated

Date	Type	Date	Type
1973-FALL	Storm surge	2004-OCT-20	Storm surge
1979-NOV-09	Storm surge	2004-NOV-19	Storm surge
1980-AUG-17	Storm surge	2006-SEP-08	Storm surge
1982-SEP-20	Storm surge	2006-OCT-11	Storm surge
1982-WINTER	Ice jam	2006-OCT-15	Storm surge
1987-OCT-17	Storm surge	2009-MAY-08	Ice jam
2001-SEP-05	Storm surge	2012-OCT-05	Storm surge
2002-SEP-13	Storm surge	2013-NOV-09	Storm surge
2003-DEC-09	Storm surge	2021-DEC-06	Storm surge
2004-SEP-09	Storm surge		

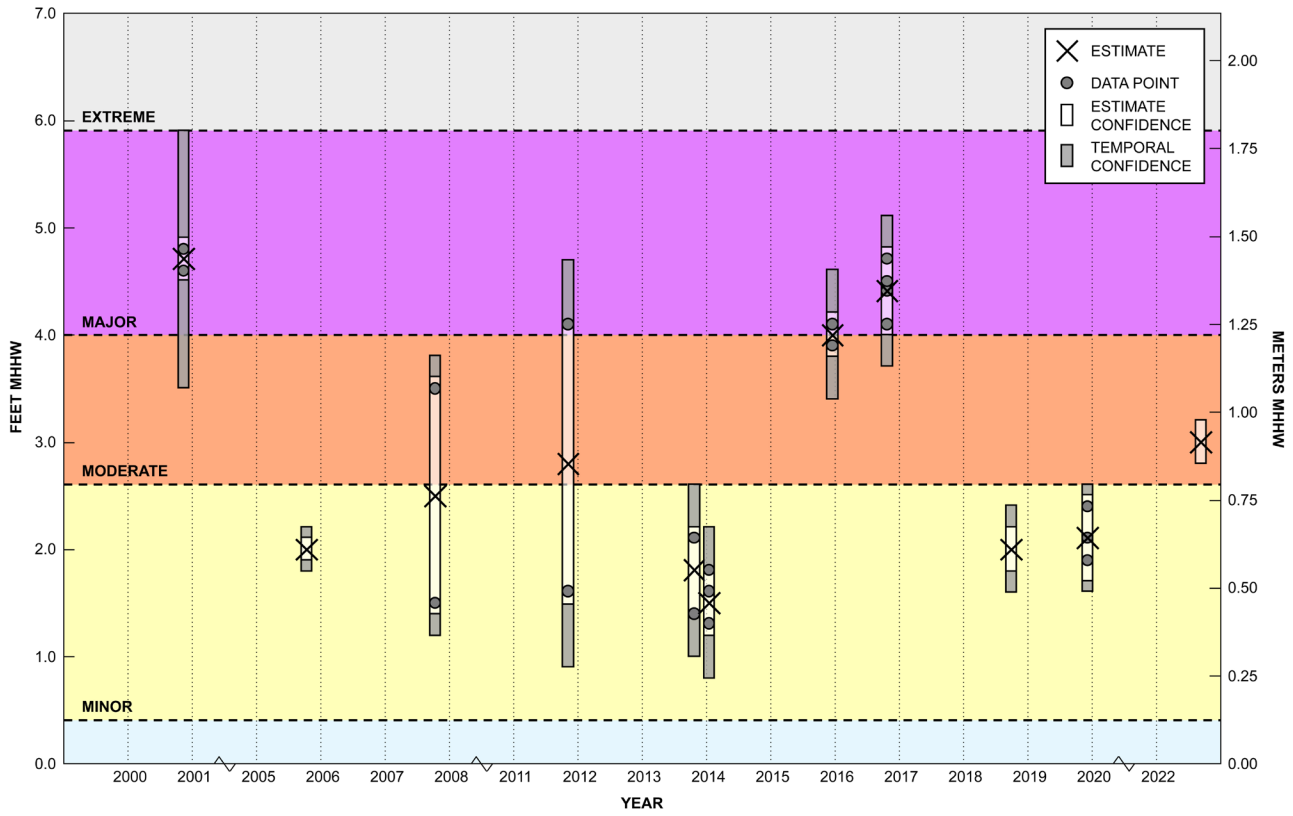

Figure 3. Timeline of estimated flood events and visual representation of flood height estimates and confidences for Kipnuk, Alaska. Flood height estimates were calculated following the methods developed by Horen, Poisson, and others (2024). Estimates are denoted by black X symbols. Data points used during estimation are represented by dark-gray dots. Estimate confidences are displayed as vertical, light-gray boxes. Temporal confidences are displayed as vertical, dark-gray boxes. Each flood height estimate may only be classified into a single flood impact category, but total estimate confidences may exceed the upper and lower bounds of the data used during estimation and may span more than one flood impact category.

Flood Event Summaries

Flood Date	Height (ft MHHW)	Estimate Confidence (ft)	Temporal Confidence (ft)	Height (m MHHW)	Estimate Confidence (m)	Temporal Confidence (m)	Category
1973-FALL	–	–	–	–	–	–	No flood height estimate

A United States Army Corps of Engineers (USACE, 1973) historical flood data sheet, dated September 15, 1973, indicated Kipnuk experienced flooding during the months of November and December, with a maximum water depth of 0.5 ft (0.15 m) covering 10 percent of the village.

From visual comparison of historical aerial photographs (1965 and 1975), we noted that the size and location of the village has changed multiple times during the years between aerial observations (fig. 4).

The community is situated on the outer bank of a large meander and has experienced a maximum linear erosion rate of -9.8 ± 0.7 ft/yr (-3.00 ± 0.20 m/yr) between 1952 and 2015 (Overbeck and others, 2020), such that large portions of the pre-1973 village are no longer present in the available DEM datasets.

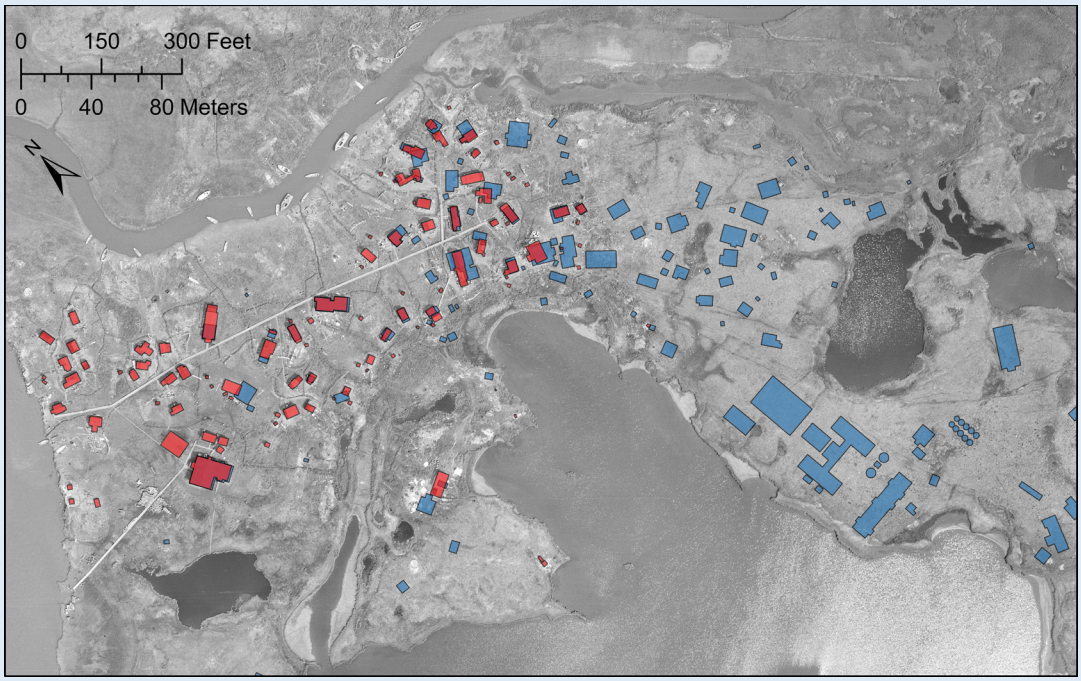

Figure 4. Comparison of building footprints in Kipnuk, Alaska, from 1965 (red) and 1975 (blue) overlaid on an aerial photograph from 1965.

Flood Date	Height (ft MHHW)	Estimate Confidence (ft)	Temporal Confidence (ft)	Height (m MHHW)	Estimate Confidence (m)	Temporal Confidence (m)	Category
1979-NOV-09	–	–	–	–	–	–	No flood height estimate

A 2008 State of Alaska (SOA) Department of Military and Veteran Affairs (DMVA) report prepared by the Division of Homeland Security and Emergency Management (DHS&EM) listed a "major sea storm" impacting 14 villages along the west coast of Alaska in 1979. This storm led to a state declared disaster "from [Nunum Iqa] to Togiak" (DHS&EM, 2008). This event is identified in the NOAA Storm Data archives, with "coastal flooding from Togiak to Kinak Bay" (NOAA, 1979), the latter of which is located at the mouth of the Kugkaktlik River northeast of Kipnuk. Flooding on the coast of Kuskokwim Bay was described as "the worst in the memory of long-time residents" (NOAA, 1979).

A flood height could not be estimated for this event because no specific impacts to the village of Kipnuk were provided.

Flood Date	Height (ft MHHW)	Estimate Confidence (ft)	Temporal Confidence (ft)	Height (m MHHW)	Estimate Confidence (m)	Temporal Confidence (m)	Category
1980-AUG-17	–	–	–	–	–	–	No flood height estimate

A USACE flood data sheet, dated June 30, 2017, listed the flood of record for Kipnuk occurred in 1980. In the floodplain notes, USACE indicated that "the storm surge of record was from an October 1980 storm at Brisol [sic] Bay" (USACE, 2017). The 2008 DHS&EM report notes a disaster emergency was declared on September 2, 1980, for a storm impacting Bristol Bay. This storm also matches the description of a storm that occurred on August 17, 1980 (NOAA, 1980). According to NOAA, "An intense storm moved from the Central Aleutians to the Yukon-Kuskokwim Delta coast… Southwest winds gusting to 65 knots to the south of the storm brought above normal tides and high seas to the coastal areas of Bristol Bay" (NOAA, 1980). Based on the evidence for this event, we believe the date reported by USACE is incorrect and have selected the NOAA reported date of August 17, 1980.

A flood height could not be estimated for this event because no specific impacts to the village of Kipnuk were provided.

Flood Date	Height (ft MHHW)	Estimate Confidence (ft)	Temporal Confidence (ft)	Height (m MHHW)	Estimate Confidence (m)	Temporal Confidence (m)	Category
1982-SEP-20	–	–	–	–	–	–	No flood height estimate

NOAA reported "an intense storm moved out of Bristol Bay and along the west coast of Alaska on the 19th and 20th… An oil rig platform under tow in the Bering Sea broke its tow and went aground off Nunivak Island" (NOAA, 1982), which is due west of Kipnuk.

A flood height could not be estimated for this event because no specific impacts to the village of Kipnuk were provided.

Flood Date	Height (ft MHHW)	Estimate Confidence (ft)	Temporal Confidence (ft)	Height (m MHHW)	Estimate Confidence (m)	Temporal Confidence (m)	Category
1982-WINTER	–	–	–	–	–	–	No flood height estimate

According to DHS&EM, "during the winter of 1982, the bridge connecting the village of Kipnuk with the community school was damaged by high water and ice flows…" (DHS&EM, 2008).

A flood height could not be estimated for this event because neither a flood height nor the height of the damaged bridge were available.

Flood Date	Height (ft MHHW)	Estimate Confidence (ft)	Temporal Confidence (ft)	Height (m MHHW)	Estimate Confidence (m)	Temporal Confidence (m)	Category
1987-OCT-14	–	–	–	–	–	–	No flood height estimate

NOAA reported "an intense Bering Sea storm brought winds… and minor flooding to the Yukon-Kuskokwim delta coast" (NOAA, 1987).

A flood height could not be estimated for this event because no specific impacts to the village of Kipnuk were provided.

Flood Date	Height (ft MHHW)	Estimate Confidence (ft)	Temporal Confidence (ft)	Height (m MHHW)	Estimate Confidence (m)	Temporal Confidence (m)	Category
2000-NOV-13	4.7	± 0.2	± 1.0*	1.43	± 0.05	± 0.31*	Major

NOAA reported "Kipnuk has boardwalk damage especially to the sanitary system dump. Possible minor fuel spill at the tank farm. Personal property damage such as wet insulation in 6 homes, water damage in 2 homes and flooded freezers" (NOAA, 2000).

To estimate this flood, we gathered building footprints derived from the 2004 orthoimagery, building footprints derived from the 2022 orthoimagery, and first-floor heights from the 2023 survey. Comparing these three datasets, we identified residences that were present in both 2004 (nearest temporally to the flood event) and 2022 (nearest temporally to the first-floor elevation survey) for which a first-floor height was collected. The flood impact description indicates that, while at least six residences experienced flooding up to the subfloor insulation, no more than two were flooded sufficient to warrant further description of water damage. From this we can infer flood waters would likely have reached a height somewhere between the first-floor heights of the second and third lowest residences, 4.6 ft (1.40 m) and 4.8 ft (1.46 m) MHHW, respectively (table 8). An average of these two heights was calculated to estimate a flood height of 4.7 ft (1.43 m) MHHW. The upper limit of this estimate's confidence forms the basis for the threshold between the major and extreme impact categories.

Table 8. First-floor heights of six lowest residences present in Kipnuk, Alaska, in both 2004 and 2023 (second and third lowest highlighted).

First-Floor Elevation (MHHW)	Source
4.1 ft (1.25 m)	2023 First-Floor Survey
4.6 ft (1.40 m)	2023 First-Floor Survey
4.8 ft (1.46 m)	2023 First-Floor Survey
4.8 ft (1.47 m)	2023 First-Floor Survey
5.0 ft (1.51 m)	2022 DSM
5.0 ft (1.51 m)	2023 First-Floor Survey

Due to the large gap in time between the 2004 and 2023 data, we investigated the likelihood that the heights of residential first floors may have changed between these observations. From a 2011 Hazard Impact Assessment (Golder Associates Inc., 2011) and a 2016 engineering study (AECOM, 2016), we are aware that differential movement (compressive sink and/or frost heave) is common for building foundations in Kipnuk, leading to frequent releveling. This information, along with a recommended minimum building height from the 2016 study (AECOM, 2016), would suggest that changes in first-floor heights should be expected over time in Kipnuk. From visual comparison of historical aerial photographs (1965 and 1975) and the three available orthoimages (2004, 2015, and 2022), we noted demolition, relocation, and new construction has been common in Kipnuk (fig. 5). Comparison of building footprints shows that four residences had been demolished between 2004 and 2022, with 40 residences built over this same timeframe, three of which had first-floor heights within the range of the six lowest residences surveyed in 2023. We were able to identify sufficient remnants of two of the demolished structures such that we were able to extract first-floor heights for these buildings from the 2022 DSM.

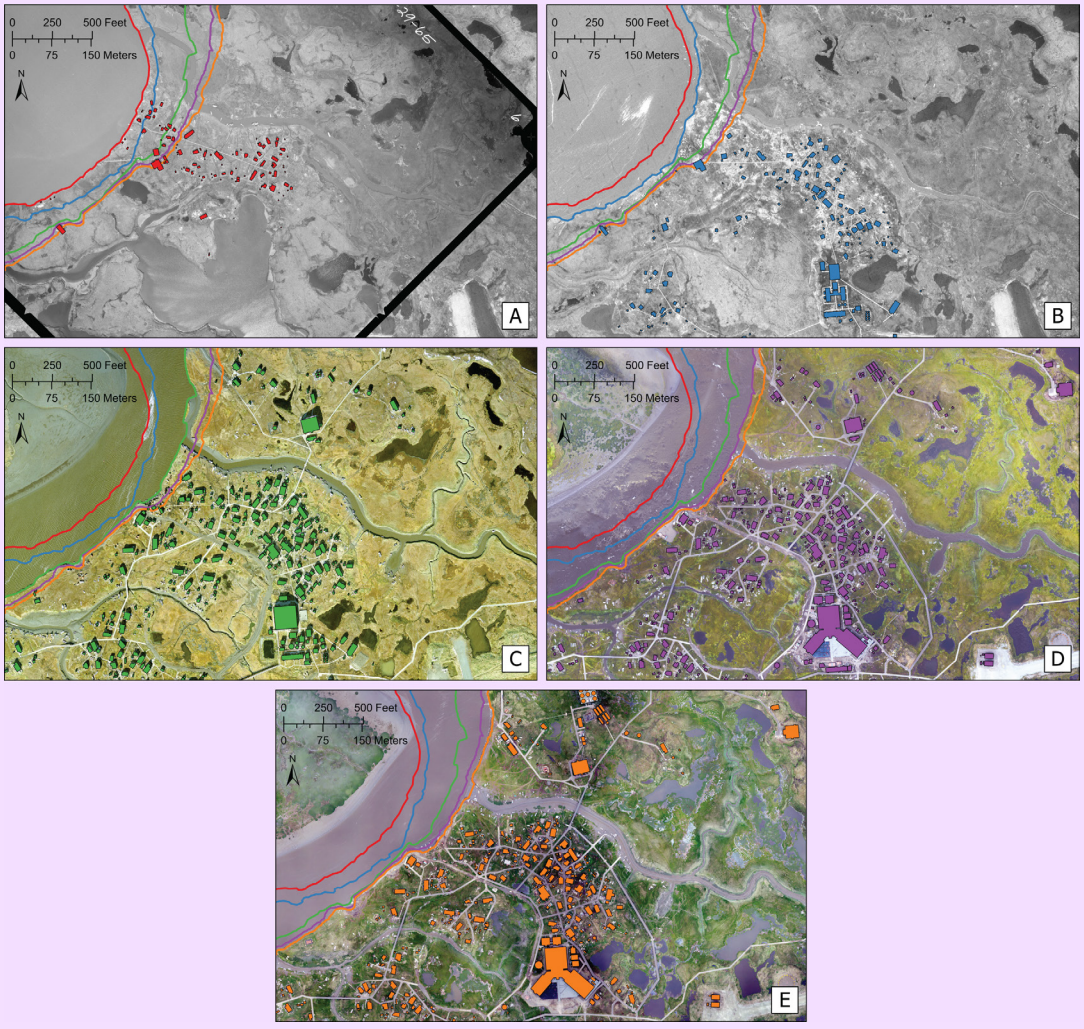

Figure 5. Aerial photographs and orthoimagery of Kipnuk, Alaska, comparing the riverbank and buildings from: (A) 1965, red; (**B**) 1975, blue; (**C**) 2004, green; (**D**) 2015, purple; (**E**) 2022, orange.

Using the 2021 DTM, we extracted the average ground heights beneath buildings and subtracted those results from the first-floor heights to calculate ground clearance information. The average building present in 2023 in Kipnuk was situated 4.4 ± 2.0 ft (1.35 ± 0.62 m) above the ground (fig. 6). Among residential buildings, 16 had a ground clearance more than one standard deviation below the average, with the three lowest residential first-floor heights that existed in both 2004 and 2023 falling within this category. Based on our investigation, it is likely that the first-floor heights of the residences used in this estimate are reasonable representations of the conditions in 2004.

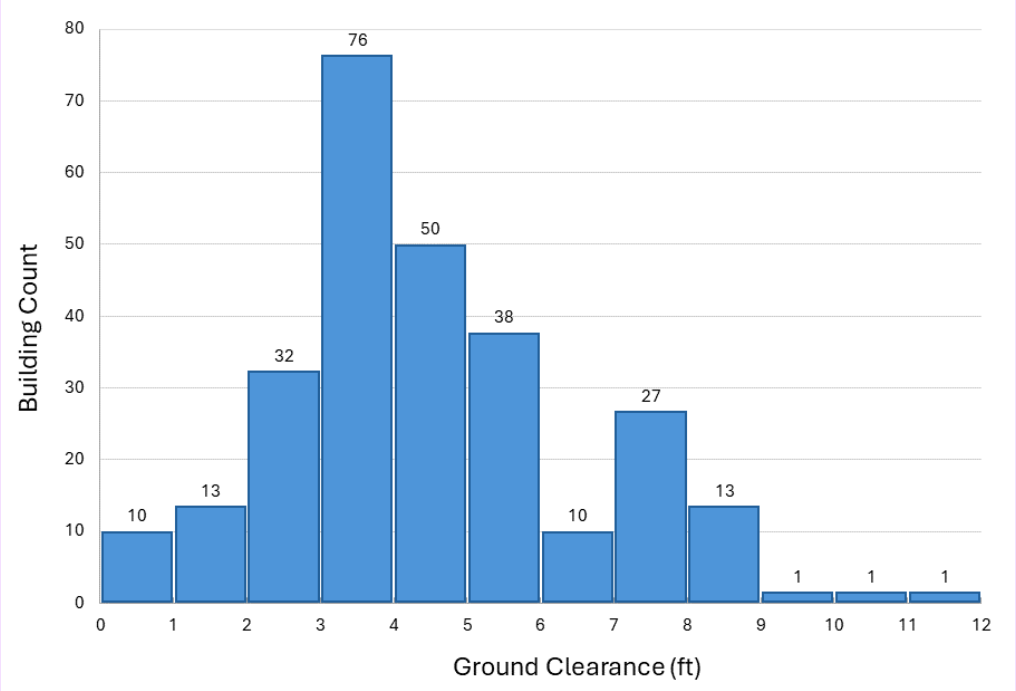

Figure 6. Histogram of ground clearances of buildings present in 2023 in Kipnuk, Alaska.

Flood Date	Height (ft MHHW)	Estimate Confidence (ft)	Temporal Confidence (ft)	Height (m MHHW)	Estimate Confidence (m)	Temporal Confidence (m)	Category
2001-SEP-05	–	–	–	–	–	–	No flood height estimate

NOAA reported a strong low-pressure system impacted the Kuskokwim Delta and Bristol Bay with "gale force southwesterly winds… observed along the south side of the low" (NOAA, 2001). NOAA also noted "coastal flooding potential was highlighted during periods of high tide…" on September 4 and 5, 2001, when "water reached close to vegetation line along parts of the southwest Alaska Coast," characterizing damage from this event as "relatively minor" (NOAA, 2001).

A flood height could not be estimated for this event because no specific impacts to the village of Kipnuk were provided.

Flood Date	Height (ft MHHW)	Estimate Confidence (ft)	Temporal Confidence (ft)	Height (m MHHW)	Estimate Confidence (m)	Temporal Confidence (m)	Category
2002-SEP-13	–	–	–	–	–	–	No flood height estimate

NOAA reported a Bering Sea storm with "strong southerly winds preceded the associated front, while strong westerly winds were observed along the 'back side' of the low" (NOAA, 2002). The storm produced "strong onshore winds combined with maximum astronomical tides to produce the potential for coastal flooding…" (NOAA, 2002).

A flood height could not be estimated for this event because no specific impacts to the village of Kipnuk were provided.

Flood Date	Height (ft MHHW)	Estimate Confidence (ft)	Temporal Confidence (ft)	Height (m MHHW)	Estimate Confidence (m)	Temporal Confidence (m)	Category
2003-DEC-09	–	–	–	–	–	–	No flood height estimate

NOAA reported "…strong long southwest fetch across the Bering Sea resulted in a coastal storm surge along the Yukon and Kuskokwim Delta and northern Bristol Bay" (NOAA, 2003).

A flood height could not be estimated for this event because no specific impacts to the village of Kipnuk were provided.

Flood Date	Height (ft MHHW)	Estimate Confidence (ft)	Temporal Confidence (ft)	Height (m MHHW)	Estimate Confidence (m)	Temporal Confidence (m)	Category
2004-SEP-09	–	–	–	–	–	–	No flood height estimate

The National Centers for Environmental Information (NCEI) Storm Events Database notes "a strong storm in the Bering Sea created a long fetch with high wind. This produced a coastal storm surge resulting in minor coastal flooding along the Kuskokwim Delta" (NCEI, 2004).

A flood height could not be estimated for this event because no specific impacts to the village of Kipnuk were provided.

Flood Date	Height (ft MHHW)	Estimate Confidence (ft)	Temporal Confidence (ft)	Height (m MHHW)	Estimate Confidence (m)	Temporal Confidence (m)	Category
2004-OCT-20	–	–	–	–	–	–	No flood height estimate

NOAA reported "…[storm] surge coupled with high tides resulted in coastal flooding and beach erosion" on the Bering Sea coast along the Kuskokwim Delta (NOAA, 2004). The USACE flood data sheet states, "other flood events reported by residents are October 2004 and October 2005" (USACE, 2017).

A flood height could not be estimated for this event because no specific impacts to the village of Kipnuk were provided.

Flood Date	Height (ft MHHW)	Estimate Confidence (ft)	Temporal Confidence (ft)	Height (m MHHW)	Estimate Confidence (m)	Temporal Confidence (m)	Category
2004-NOV-19	–	–	–	–	–	–	No flood height estimate

NCEI reported "a west to southwest fetch across the Bering Sea, combined with high astronomical tide, resulted in coastal flooding across the west coast of the state" (NCEI, 2004).

A flood height could not be estimated for this event because no specific impacts to the village of Kipnuk were provided.

Flood Date	Height (ft MHHW)	Estimate Confidence (ft)	Temporal Confidence (ft)	Height (m MHHW)	Estimate Confidence (m)	Temporal Confidence (m)	Category
2005-OCT-17	2.0	± 0.1	± 0.1	0.61	± 0.04	± 0.02	Minor

NOAA reported "flooding occurred in Bristol Bay area north to Kipnuk along the Kuskokwim Delta" in reference to this event (NOAA, 2005). The USACE flood data sheet states, "other flood events reported by residents are October 2004 and October 2005" (USACE, 2017). AECOM "… interviewed elders and identified high water marks from the October 2005 storm surge" for their 2016 engineering study, noting "the 2005 event resulted in one of the largest storm surges in recent memory" (AECOM, 2016). According to the AECOM study, "the high-water mark elevations average 990 feet in the ADOT&PF datum; this elevation corresponds to approximately -5.5 feet in the datum developed by Aero-Metric in 2004 for the Kipnuk Community Map" (AECOM, 2016).

To estimate this flood, we applied the vertical datum transformation found in table 4 to the average height reported by AECOM to convert from the CMP (2004) datum to the MHHW (946 5951) datum.

Flood Date	Height (ft MHHW)	Estimate Confidence (ft)	Temporal Confidence (ft)	Height (m MHHW)	Estimate Confidence (m)	Temporal Confidence (m)	Category
2006-SEP-08	–	–	–	–	–	–	No flood height estimate

NOAA and NCEI reported that "…[storm] surge coincided with very high astronomical tides along the Bristol Bay coast and the coast of the Kuskokwim Delta. The combination of the storm surge and the very high tides produced minor coastal flooding along the Bristol Bay coast and the Kuskokwim Delta coast" (NOAA, 2006a; NCEI, 2006a).

A flood height could not be estimated for this event because no specific impacts to the village of Kipnuk were provided.

Flood Date	Height (ft MHHW)	Estimate Confidence (ft)	Temporal Confidence (ft)	Height (m MHHW)	Estimate Confidence (m)	Temporal Confidence (m)	Category
2006-OCT-11	–	–	–	–	–	–	No flood height estimate

NOAA reported coastal flooding for the Kuskokwim Delta and Bristol Bay (NOAA, 2006b).

A flood height could not be estimated for this event because no specific impacts to the village of Kipnuk were provided.

Flood Date	Height (ft MHHW)	Estimate Confidence (ft)	Temporal Confidence (ft)	Height (m MHHW)	Estimate Confidence (m)	Temporal Confidence (m)	Category
2006-OCT-15	–	–	–	–	–	–	No flood height estimate

NOAA reported coastal flooding for the Kuskokwim Delta (NOAA, 2006b). NCEI described "…strong south to southwest wind associated with this storm produce a surge along the coast of the Kuskokwim Delta…" (NCEI, 2006b; LeMay Engineering and Consulting Inc., 2018).

A flood height could not be estimated for this event because no specific impacts to the village of Kipnuk were provided.

Flood Date	Height (ft MHHW)	Estimate Confidence (ft)	Temporal Confidence (ft)	Height (m MHHW)	Estimate Confidence (m)	Temporal Confidence (m)	Category
2007-FALL	2.5	± 1.1	± 0.2	0.76	± 0.34	± 0.05	Minor

Kipnuk residents most-commonly reported fall 2007 as the worst flood event they could remember according to a Hazard Impact Assessment prepared by Golder Associates Inc. (2011). When asked to identify the impacts, details were provided regarding "areas that did and did not flood during this event" (Golder Associates Inc., 2011). Golder Associates Inc. compared the identified locations to the CPM topographic contours, stating "the 2007 flood level may correspond [sic] fall between -6 and -4 foot contours" (Golder Associates Inc., 2011).

To estimate this flood, we took the average of Golder Associates's reported estimate, -5.0 ± 1.0 ft (1.52 ± 0.30m) and applied the vertical datum transformation provided in table 6 to convert this value from the CPM (2004) datum to the MHHW (946 5951) datum.

Though this flood estimate is categorized as minor based on the average, the relatively large confidence range associated with this estimate could also potentially place this flood event within the moderate impact category.

Flood Date	Height (ft MHHW)	Estimate Confidence (ft)	Temporal Confidence (ft)	Height (m MHHW)	Estimate Confidence (m)	Temporal Confidence (m)	Category
2009-MAY-08	–	–	–	–	–	–	No flood height estimate

Late April warming and snowmelt created river ice jams that lead to extensive widespread flooding along 3,000 miles of Interior Alaska rivers and the lower Kuskokwim River (NOAA, 2009). The event led to a federal disaster declaration (FEMA, 2009).

A flood height could not be estimated for this event because no specific impacts to the village of Kipnuk were provided.

Flood Date	Height (ft MHHW)	Estimate Confidence (ft)	Temporal Confidence (ft)	Height (m MHHW)	Estimate Confidence (m)	Temporal Confidence (m)	Category
2011-NOV-09	2.8	± 1.3	± 0.6	0.86	± 0.39	± 0.18	Moderate

NCEI reported "…strong wind and long fetch resulted in a coast storm surge that produced minor coastal flooding in the Kuskokwim Delta region," with a "report from the public in Kipnuk of water reaching homes" (NCEI, 2011).

To estimate this flood, we interpreted the report of water reaching homes as water being under homes or reaching the lowest home. To do this we gathered building footprints derived from the 2015 orthoimagery, building footprints derived from the 2022 orthoimagery, and first-floor heights from the 2023 first-floor survey. Comparing these three datasets, we identified residences that were present in both 2015 (nearest temporally to the flood event) and 2022 (nearest temporally to the

first-floor elevation survey) for which a first-floor height was collected. Ground heights beneath the identified residential buildings were then extracted from the 2021 DTM. The lowest first-floor height among homes that existed in 2015, 4.1 ft (1.25 m) MHHW, was selected as the upper limit of potential flooding. The lowest ground height beneath a residence that was present in 2015, 1.6 ft (0.47 m) MHHW, was selected as the lower limit of potential flooding. An average of these two heights was calculated to estimate a flood height of 2.8 ft (0.86 m) MHHW.

Though this flood estimate is categorized as moderate based on the average, the relatively large confidence range associated with this estimate could potentially place this flood event within the minor, moderate, or major impact category.

Flood Date	Height (ft MHHW)	Estimate Confidence (ft)	Temporal Confidence (ft)	Height (m MHHW)	Estimate Confidence (m)	Temporal Confidence (m)	Category
2012-OCT-05	–	–	–	–	–	–	No flood height estimate

Photographic evidence of this flood event was provided by a local resident. A lack of permanent reference points prevented the identification of the approximate location in the image on the left (fig. 7). The intersection depicted in the image on the right (fig. 7) was altered prior to the collection of the available DEM datasets.

Due to these limitations, a flood height could not be estimated for this event.

Figure 7. Photographic evidence of the flood event on October 5, 2012, in Kipnuk, Alaska.

Flood Date	Height (ft MHHW)	Estimate Confidence (ft)	Temporal Confidence (ft)	Height (m MHHW)	Estimate Confidence (m)	Temporal Confidence (m)	Category
2013-OCT-25	1.8	± 0.4	± 0.4	0.54	± 0.12	± 0.13	Minor

Two pieces of photographic evidence of this flood event were provided by a local resident. The presence of permanent infrastructure as reference points allowed us to identify the approximate location in both images.

To estimate this flood, we identified the buildings and boardwalks in the images, located these within the 2022 orthoimagery, and overlayed this orthoimagery with a simple bathtub model applied to the 2021 DTM to approximate the flood height depicted in the photographs (fig. 8). The images matched flood heights of 1.4 ft (0.44 m) and 2.1 ft (0.64 m) MHHW. An average of these two heights was calculated to estimate a flood height of 1.8 ft (0.54 m) MHHW.

Figure 8. Photographic evidence of the flood event on October 25, 2013, in Kipnuk, Alaska. Water levels reached 1.4 ft (0.44 m) (**A**) and 2.1 ft (0.64 m) MHHW (**B**).

Flood Date	Height (ft MHHW)	Estimate Confidence (ft)	Temporal Confidence (ft)	Height (m MHHW)	Estimate Confidence (m)	Temporal Confidence (m)	Category
2013-NOV-09	–	–	–	–	–	–	No flood height estimate

NCEI reported "an intense and large storm in the Bering Sea produced a long fetch of strong wind across the Bering Sea aligned with the Kuskokwim Delta coast… This produced a surge of up to 5 feet along the Kuskokwim Delta Coast" (NCEI, 2013).

A flood height could not be estimated for this event because no specific impacts to the village of Kipnuk were provided.

Flood Date	Height (ft MHHW)	Estimate Confidence (ft)	Temporal Confidence (ft)	Height (m MHHW)	Estimate Confidence (m)	Temporal Confidence (m)	Category
2014-JAN-22	1.5	± 0.3	± 0.4	0.45	± 0.11	± 0.11	Minor

The Environmental Protection Agency (EPA) Indian General Assistance Program (IGAP) coordinator for Kipnuk at the time of this event, Nick Slim, provided photographic evidence of this flood

event. Slim and the current EPA/IGAP coordinator, Rayna Paul, attributed the flooding to warm temperatures and snow melt (Nick Slim and Rayna Paul, personal commun., 2022). A January 22, 2014, NWS forecast discussion noted, "EXPECT CONTINUED ABOVE NORMAL TEMPERATURES FOR MUCH OF THE MAINLAND AND PERIODS OF PRECIPITATION ESPECIALLY ALONG THE COASTAL AREAS…" (Iowa Environmental Mesonet, 2014).

To estimate this flood, we identified the buildings and infrastructure in the images, located them within the 2022 orthoimagery, and overlayed this orthoimagery with a simple bathtub model applied to the 2021 DTM to approximate the flood height depicted in the photographs. The images matched flood heights of 1.3 ft (0.39 m), 1.8 ft (0.54 m), and 1.6 ft (0.49 m) MHHW (fig. 9). An average of these heights was calculated to estimate a flood height of 1.5 ft (0.45 m) MHHW.

Figure 9. Photographic evidence of the flood event on January 22, 2014, in Kipnuk, Alaska. Water levels reached 1.3 ft (0.39 m) (**A**), 1.8 ft (0.54 m) (**B**), 1.3 ft (0.39 m) (**C**), and 1.6 ft (0.49 m) MHHW (**D**).

Flood Date	Height (ft MHHW)	Estimate Confidence (ft)	Temporal Confidence (ft)	Height (m MHHW)	Estimate Confidence (m)	Temporal Confidence (m)	Category
2015-DEC-19	4.0	± 0.2	± 0.4	1.22	± 0.07	± 0.11	Major

Details of this event were documented in the Kipnuk Hazard Mitigation Plan (LeMay Engineering and Consulting Inc., 2018), which reported "the State Emergency Operations Center was contacted by the President of the Kipnuk Native Village about storm damage to their community-wide boardwalk system and a few surrounding homes." During a visit to Kipnuk in June 2022, DGGS gathered reports of observed high-water related to this flood event from local community members.

To estimate this flood, we collected 2 GNSS observations during the 2022 survey (table 9; app. B) based on community reports (fig. 10). An average of these heights was calculated to estimate a flood height of 4.0 ft (1.22 m) MHHW.

Though this flood estimate is categorized as major based on the average, the confidence range associated with this estimate could also potentially place this flood event within the moderate impact category.

Figure 10. GNSS observations of reported heights of the flood event on December 14, 2015, in Kipnuk, Alaska. Water levels reached 3.9 ft (1.18 m) MHHW at the bottom stair of the council building (**A**) and 4.1 ft (1.25 m) MHHW at the second stair of Tim Swanson's home (**B**).

Table 9. Observed flood heights associated with the flood event on December 19, 2015, in Kipnuk, Alaska.

Point ID	Height (MHHW)
3001	3.9 ft (1.18 m)
3006	4.1 ft (1.25 m)

Flood Date	Height (ft MHHW)	Estimate Confidence (ft)	Temporal Confidence (ft)	Height (m MHHW)	Estimate Confidence (m)	Temporal Confidence (m)	Category
2016-OCT-28	4.4	± 0.4	± 0.3	1.35	± 0.13	± 0.10	Major

During the DGGS visit to Kipnuk in June 2022, the EPA/IGAP coordinator, Rayna Paul, provided a detailed account of the impacts of this event, stating that it was the worst flood she had experienced in her lifetime (Rayna Paul, personal commun., 2022). NCEI reported "strong low pressure in the western Bering Sea coupled with high pressure over the Arctic produced strong winds along the west coast of Alaska" (NCEI, 2016).

To estimate this flood, we collected 8 GNSS observations (fig. 11; table 10; app. B) during the 2022 survey based on community reports (fig. 12). Two of these observations were not used during estimation as they were deemed to be outliers, diverging from the average by greater than one standard deviation. An average of these heights was calculated to estimate a flood height of 4.4 ft (1.35 m) MHHW.

Though this flood estimate is categorized as major based on the average, the confidence range associated with this estimate could also potentially place this flood event within the moderate impact category.

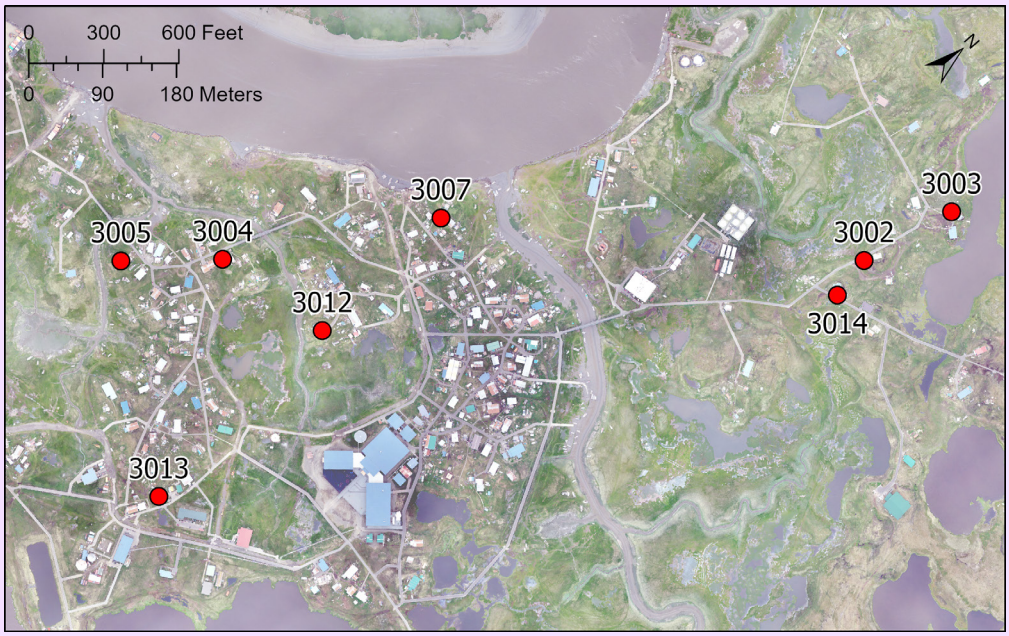

Figure 11. Map of GNSS observations collected for the flood event on October 28, 2016, in Kipnuk, Alaska.

Figure 12. Examples of community members reporting the height of the flood event on October 28, 2016, in Kipnuk, Alaska.

Table 10. Observed flood heights associated with the flood event on October 28, 2016, in Kipnuk, Alaska (excluded observations highlighted).

Point ID	Height (MHHW)
3002	4.4 ft (1.35 m)
3003	3.7 ft (1.14 m)
3004	4.5 ft (1.38 m)
3005	4.4 ft (1.33 m)
3007	4.7 ft (1.44 m)
3012	5.5 ft (1.69 m)
3013	4.5 ft (1.38 m)
3014	4.1 ft (1.24 m)

Flood Date	Height (ft MHHW)	Estimate Confidence (ft)	Temporal Confidence (ft)	Height (m MHHW)	Estimate Confidence (m)	Temporal Confidence (m)	Category
2018-OCT-04	2.0	± 0.2	± 0.2	0.61	± 0.06	± 0.05	Minor

An aerial photograph of flooding was posted to social media on October 4, 2018, showing flood water throughout Kipnuk (fig. 13).

To estimate this flood, we overlayed the 2022 orthoimagery with a simple bathtub model applied to the 2021 DTM to approximate the flood height depicted in the photograph.

Figure 13. Photographic evidence of the flood event on October 4, 2018, in Kipnuk, Alaska.

Flood Date	Height (ft MHHW)	Estimate Confidence (ft)	Temporal Confidence (ft)	Height (m MHHW)	Estimate Confidence (m)	Temporal Confidence (m)	Category
2019-DEC-10	2.1	± 0.4	± 0.1	0.64	± 0.12	± 0.03	Minor

An Alaska Public Media article stated, "High winds and warm temperatures caused flooding in Kipnuk this week" (Shallenberger, 2019). Photographs from social media showed flood waters in various parts of the village.

To estimate this flood, we identified the buildings and infrastructure in the photographs shared on social media, located them within the 2022 orthoimagery, and overlayed this orthoimagery with a simple bathtub model applied to the 2021 DTM to approximate the flood height depicted. The images matched flood heights of 2.4 ft (0.74 m), 2.1ft (0.64 m), and 1.9 ft (0.59 m) MHHW (fig. 14). An average of these heights was calculated to estimate a flood height of 2.1 ft (0.64 m) MHHW.

Figure 14. Photographic evidence of the flood event on December 10, 2019, in Kipnuk, Alaska. Water levels reached 2.4 ft (0.74 m) (**A**), 2.1ft (0.64 m) (**B**), 1.9 ft (0.59 m) (**C**), and 1.9 ft (0.59 m) (**D**) MHHW.

Flood Date	Height (ft MHHW)	Estimate Confidence (ft)	Temporal Confidence (ft)	Height (m MHHW)	Estimate Confidence (m)	Temporal Confidence (m)	Category
2021-DEC-06	–	–	–	–	–	–	No flood height estimate

NCEI reported a coastal flood event occurred December 4–6, 2021, noting "Kipnuk PD reports flooding in airport overflow area and one road covered in water" (NCEI, 2021).

A flood height could not be estimated for this event because there was not enough detail provided to identify the locations listed in the description of this flood event.

Flood Date	Height (ft MHHW)	Estimate Confidence (ft)	Temporal Confidence (ft)	Height (m MHHW)	Estimate Confidence (m)	Temporal Confidence (m)	Category
2022-SEP-17	3.0	± 0.2	± 0.0	0.91	± 0.06	± 0.00	Moderate

NCEI reported the remnants of Typhoon Merbok reached the Kuskokwim Delta coast in the early evening on September 16, 2022, noting that "impacts, including damaging wind gusts and storm surge, were observed from the Kuskokwim Delta to the Yukon Delta…" (NCEI, 2022).

To estimate this flood, we gathered water level data from the Stilltek iGage located in Kipnuk (figs. 1 and 2) for the time period relevant to this flood event (fig. 15). The peak recorded water level during this event was 3.0 ft (0.91 m) MHHW.

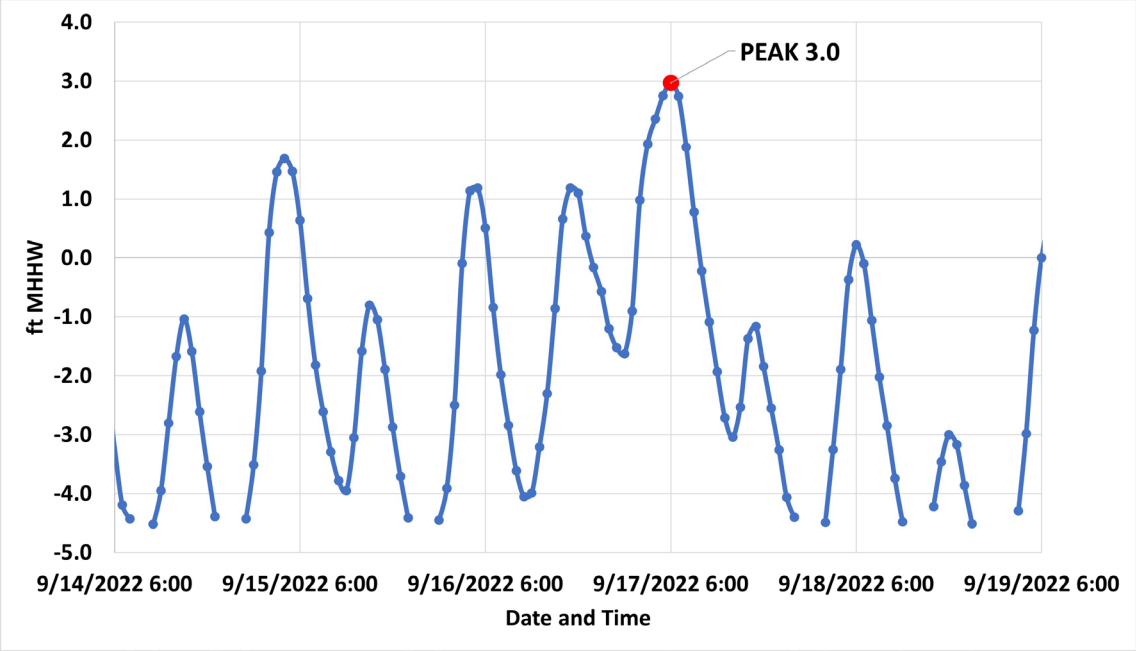

Figure 15. Water level data collected in Kipnuk, Alaska, from 6:00 AM AKDT on September 14, 2022, to 6:00 AM AKDT on September 19, 2022.

ACKNOWLEDGMENTS

We thank the Native Village of Kipnuk for supporting this work, made possible with the National Fish and Wildlife Foundation's National Coastal Resilience Funding through DGGS partners at the Alaska Native Tribal Health Consortium. Sincere thanks to Raya Paul, of Kipnuk, for reviewing this report before publication. The authors also thank Richard Buzard and Jacquelyn Overbeck for their contribution to the data collection that was instrumental to this work. The views and conclusions contained in this document are those of the authors and should not be interpreted as representing the opinions or policies of the Alaska Division of Geological & Geophysical Surveys, the U.S. Government, the National Fish and Wildlife Foundation, or the National Fish and Wildlife Foundation's funding sources. Mention of trade names or commercial products does not constitute endorsement by the Alaska Division of Geological & Geophysical Surveys, the U.S. Government, the National Fish and Wildlife Foundation, or the National Fish and Wildlife Foundation's funding sources.

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APPENDIX A: KIPNUK, ALASKA, FIRST-FLOOR HEIGHT SURVEY

ALASKA NATIVE TRIBAL HEALTH CONSORTIUM
Environmental Health & Engineering

January 20, 2023

Kipnuk, Alaska Finish Floor Elevation Study
ANTHC Project No. 10-0189-01-01

The data provided is from a field survey completed by ANTHC on January 10, 2023 through January 11, 2023. Project elevations are NAVD88 Orthometric heights (U.S. Feet), computed using GEIOD12B, and were measured utilizing Trimble R10 GPS Receivers using RTK GPS.

BASIS OF HORIZONTAL CONTROL:
The Basis of Horizontal Control is the Primary Airport Control Station IIK A (ANTHC Control Point 552), NGS Datasheet PID: DQ2643, as retrieved on December 30, 2022, a 9/16" stainless steel drive rod incased in a 6" PVC pipe with an aluminum logo cover stamped IIK-A 2015. Said station has the following record coordinates:

NAD83(2011)(EPOCH2010.00) Geodetic Coordinates:
Latitude = 59° 56' 06.00744" N
Longitude = 164° 01' 52.76037" W

NAD83(2011)(EPOCH2010.00) Alaska State Plane Zone 8, U.S. Feet:
Northing = 2,173,505.9328'
Easting = 2,001,458.7392'

BASIS OF VERTICAL CONTROL:
The Basis of Vertical Control is the Primary Airport Control Station IIK A (ANTHC Control Point 552), NGS Datasheet PID: DQ2643, as retrieved on December 30, a 9/16" stainless steel drive rod incased in a 6" PVC pipe with an aluminum logo cover stamped IIK-A 2015. Said station has a computed record NAVD88 Orthometric height of 4.483m/14.71' (Ellip. Ht. – Geiod Ht. = Ortho. Ht.). Elevations were verified by checking into NOAA Benchmark 5951 C 2021, the northwest bolt on a bridge on the north side of Kipnuk. The elevation error was +0.13'.

Sincerely,

Paul Russell, PLS
Survey Manager

Enclosures:
- Kipnuk-FF_AKSPZ8.csv
- Kipnuk-FF_NAD83(2011).csv
- IIK A Datasheet.pdf
- Published Bench Mark Sheet for 9465951 KIPNUK, KUGUKLIK RIVER AK.pdf

Alaska Native Tribal Health Consortium//Division of Environmental Health & Engineering
4500 Diplomacy Drive, Suite 454, Anchorage, Alaska 99508//Main: (907) 729-3600 //Fax: (907) 729-4090//anthc.org

FF = Finish Floor

551	2173504.93	2001458.74	14.71	IIK A
552	2174997.15	2000369.76	15.92	5951 C 2021
4001	2171803.84	2000686.57	14.81	FF HOME
4002	2172432.26	1998141.62	14.8	FF HOME
4003	2172395.43	1998057.79	14.6	FF HOME
4004	2172324.29	1998035.54	15.78	FF DUPLEX HOME
4005	2172340.83	1998085.19	16.03	FF HOME
4006	2172248.22	1998042.37	15.85	FF DUPLEX HOME
4007	2172180.69	1998126.14	17.68	FF HOME
4008	2172196.08	1998206.08	17.88	FF HOME
4009	2172362.81	1998151.49	16.66	FF HOME
4010	2172288.01	1998336.04	16.88	FF HOME
4011	2172340.19	1998396.93	18.44	FF HOME
4012	2172303.3	1998476.05	17.79	FF HOME
4013	2172336.54	1998517.59	17.25	FF HOME
4014	2172392.04	1998457.73	17.35	FF HOME
4015	2172453.03	1998530.64	17.04	FF HOME
4016	2172380.13	1998641.87	17.54	FF HOME
4017	2172502.3	1998588.37	16.97	FF HOME
4018	2172657.69	1998750.55	18.9	FF HOME
4019	2172719.05	1998699.1	18.27	FF HOME
4020	2172751.61	1998648.57	18.68	FF HOME
4021	2172753.04	1998539.46	13.81	FF HOME
4022	2172851.18	1998588.81	18.57	FF HOME
4023	2172918.67	1998532.54	18.81	FF HOME
4024	2172988	1998474.87	18.99	FF HOME
4025	2173055.04	1998425.56	18.61	FF HOME
4026	2173122.58	1998359.1	19.22	FF HOME
4027	2173212.8	1998271.31	19.62	FF HOME
4028	2173143.64	1998197.91	18.26	FF HOME
4029	2173235.95	1998091.15	18.17	FF UNOCCUPIED HOME
4030	2173288.84	1998089.56	16.81	FF HOME
4031	2173370.35	1998141.44	16.97	FF HOME
4032	2173327.13	1998297.2	15.49	FF HOME
4033	2173436.08	1998169.14	16.77	FF UNOCCUPIED HOME
4034	2173536.59	1998203.62	16.56	FF HOME
4035	2173579.77	1998239.32	16.47	FF HOME
4036	2173655.87	1998159.6	15.78	FF UNOCCUPIED BLDG
4037	2173053.01	1997844.13	16.19	FF UUI COMM BLDG
4038	2172736.38	1997293.72	14.36	FF HOME
4039	2172693.29	1997253.85	14.42	FF HOME
4040	2172752.86	1997191.49	13.87	FF HOME
4041	2172878.44	1997192.31	13.78	FF HOME
4042	2173271.96	1997484.2	15.69	FF HOME
4043	2173250.38	1997461	15.58	FF HOME
4044	2173755.08	1998561.29	15.21	FF HOME

4045	2173683.98	1998539.9	14.98	FF HOME
4046	2173600	1998710.24	11.89	FF HOME
4047	2173463.67	1998872.19	14.25	FF HOME
4048	2172650.87	1998848.82	14.75	FF HOME
4049	2172556.99	1998828.8	19.06	FF HOME
4050	2172511.77	1998871.98	19.85	FF HOME
4051	2172450.3	1998923.34	20.03	FF HOME
4052	2172356.02	1998793.7	13.53	FF HOME
4053	2172262.25	1998793.32	12.89	FF UNOCCUPIED HOME
4054	2172324.51	1998879.51	13.72	FF UNOCCUPIED HOME
4055	2172370.19	1998982.77	19.3	FF HOME
4056	2172361.89	1999011.46	19.43	FF HOME
4057	2172632.6	1999017.22	14.65	FF HOME
4058	2172527.09	1999041.78	19.08	FF HOME
4059	2172437.27	1999089.91	19.63	FF HOME
4060	2172495.17	1999158.63	19.56	FF HOME
4061	2172584.59	1999110.69	19.49	FF HOME
4062	2172642.44	1999180.09	19.33	FF HOME
4063	2172552.66	1999228.32	19.51	FF HOME
4064	2172610.41	1999297.57	19.33	FF HOME
4065	2172671.31	1999249.97	19.1	FF HOME
4066	2172668.16	1999365.89	19.14	FF HOME
4067	2172757.64	1999318	19.9	FF HOME
4068	2172823.89	1999349.04	13.68	FF HOME
4069	2172925.4	1999329.99	13.8	FF HOME
4070	2172821.93	1999304.21	14.63	FF HOME
4071	2172805.89	1999268.34	14.42	FF HOME
4079	2172809.96	1999780.97	16.64	FF WATER TANK BLDG
4080	2172769.29	1999798.36	16.95	FF WATER TANK
4081	2172820.23	1999840.92	16.71	FF WATER TANK
4082	2172969.47	1999832.13	17.84	FF WASHETERIA
4083	2172893.21	1999829.93	11.91	FF FUEL CONTAINMENT BOTTOM
4084	2172917.64	1999818.14	12.29	FF FUEL CONTAINMENT TOP
4085	2173039.55	1999573.44	17.04	FF SERVICE CENTER
4086	2173225.59	1999645.1	13.99	FF HOME
4087	2173239.44	1999615.8	13.87	FF HOME
4088	2173254.15	1999499.9	16.07	FF HOME
4089	2173277.67	1999459.39	15.6	FF HOME
4090	2173278.18	1999385.6	16.79	FF UNOCCUPIED HOME
4091	2173422.59	1999445.18	15.02	FF HOME
4092	2173470.43	1999417.99	15.27	FF HOME
4093	2173496.1	1999390.17	12.57	FF HOME
4094	2173534.15	1999504.17	15.41	FF HOME
4095	2173542.74	1999584.06	14.83	FF HOME
4096	2173560.38	1999638.14	15.22	FF HOME
4097	2173525.04	1999748.26	12.89	FF HOME
4098	2173386.12	1999642.68	15.01	FF HOME

4099	2173371.88	1999581.17	16.67	FF HOME
4100	2173328.41	1999597.13	14.33	FF HOME
4101	2173048.44	1999756.95	13.46	FF POLICE BLDG
4102	2173106.43	1999807.39	15.34	FF POLICE BLDG
4103	2173191.64	1999842.84	14.83	FF OLD STORE
4104	2173246.18	1999839.12	12.88	FF UNOCCUPIED HOME
4105	2173284.75	1999835.08	14.25	FF CORPORATION BLDG
4106	2173184.53	1999915.41	15.5	FF YK HEALTH CO BLDG
4107	2173025.51	2000068.68	15.46	FF POST OFFICE
4108	2173065.29	2000212.19	16.39	FF ARMY NATIONAL GUARD BLDG
4109	2173157.42	2000138.97	15.76	FF ARMY NATIONAL GUARD BLDG
4110	2173174.4	2000185.51	14.75	FF ARMY NATIONAL GUARD BLDG
4111	2173355.15	2000107.11	13.2	FF STORE
4112	2173674.22	1999898.52	12.47	FF UNKNOWN BLDG
4113	2173683.89	1999393.58	14.98	FF HOME
4114	2173748.07	1999342.12	15.39	FF HOME
4115	2173742.71	1999309.56	15.24	FF HOME
4116	2173699.77	1999277.33	13.85	FF HOME
4117	2173639.48	1999217.11	14.09	FF HOME
4118	2173692.91	1999143.81	12.82	FF UNOCCUPIED HOME
4119	2173708	1999052.54	12.99	FF HOME
4120	2173692.79	1998983.28	11.86	FF HOME
4121	2173766.37	1999039.44	14.98	FF HOME
4122	2173791.9	1999082.43	12.54	FF HOME
4123	2173751.23	1999218.86	12.85	FF HOME
4124	2173830.94	1999195.95	14.31	FF HOME
4125	2173862.81	1999143.9	13.21	FF HOME
4126	2173940.36	1999202.98	13.81	FF HOME
4127	2173965.93	1999149.26	13.06	FF HOME
4128	2173979.04	1999221.68	12.91	FF HOME
4129	2174250.49	1999232.52	12.71	FF HOME
4130	2174392.17	1999279.43	15.09	FF HOME
4131	2174558.96	1999313.42	14.21	FF ABANDONED KTC LODGE & GARAGE
4132	2174497.61	1999477.41	14.24	FF HOME
4133	2174426.42	1999506.41	13.53	FF HOME
4134	2174408.21	1999409.49	14.85	FF HOME
4135	2174264.88	1999524.72	14.71	FF HOME
4136	2174171	1999597.42	14.05	FF HOME
4137	2174082.09	1999694.75	13.37	FF HOME
4138	2174219.37	1999777.98	14.43	FF HOME
4139	2174354.87	1999830.83	12.34	FF HOME
4140	2174236.81	1999685.76	13.52	FF UNOCCUPIED HOME
4141	2174601.88	1999624.98	14.01	FF HOME
4142	2174478.37	1999840.77	12.07	FF ABANDONED KTC JAIL HOUSE
4143	2174499.59	1999871.5	14.51	FF UNOCCUPIED HOME
4144	2174538.79	1999764.67	14.48	FF HOME
4145	2174617.95	1999766.48	13.53	FF HOME

4146	2174715.06	1999602.12	14.6	FF HOME
4147	2174755.6	1999651.22	13.72	FF HOME
4148	2174708.63	1999785.51	14.65	FF HOME
4149	2174766.75	1999879.17	13.55	FF HOME
4150	2174654.29	1999929.53	14	FF HOME
4151	2174727.51	1999962.21	14.03	FF HOME
4152	2174624.88	2000009.37	15.2	FF HOME
4153	2174587.74	2000027.97	13.58	FF HOME
4154	2174598.86	2000087.13	15.75	FF HOME
4155	2174682.37	2000074.46	15.03	FF HOME
4156	2174717.26	2000061.32	13.44	FF HOME
4157	2174782.03	2000091.17	14.89	FF HOME
4158	2174810.11	2000167.88	15.61	FF HOME
4159	2174765.81	2000183.39	15.12	FF HOME
4160	2174732.65	2000177.02	14.82	FF HOME
4161	2174478.37	2000180.82	14.91	FF HOME
4162	2174464.31	2000139.52	14.19	FF HOME
4163	2174511.56	2000140.38	13.59	FF HOME
4164	2174586.55	2000201.06	14.87	FF HOME
4165	2174565.16	2000204.41	15.28	FF HOME
4166	2174700.63	2000250.06	15.97	FF HOME
4167	2174682.75	2000299.74	15.16	FF STORE
4168	2174660.7	2000283.24	13.53	FF STORAGE
4169	2174631.24	2000265.35	14.37	FF HOME
4170	2174593.6	2000271.06	13.92	FF UNOCCUPIED HOME
4171	2174565.57	2000343.09	14.3	FF HOME
4172	2174538.56	2000282.19	15.65	FF HOME
4173	2174512.98	2000260.48	14.87	FF HOME
4174	2174496.76	2000286.07	13.72	FF HOME
4175	2174505.48	2000376.68	13.49	FF HOME
4176	2174428.23	2000340.01	16.3	FF HOME
4177	2174430.93	2000283.06	15.53	FF HOME
4178	2174348.7	2000233.62	16.6	FF HOME
4179	2174354.69	2000158.93	14.22	FF KIPNUK TRADING COMPANY
4180	2174274.16	2000299.1	14.31	FF HOME
4181	2174354.72	2000298.19	16.4	FF HOME
4182	2174381.99	2000419.44	15.13	FF HOME
4183	2174408.36	2000477.51	14.74	FF HOME
4184	2174386.61	2000538.82	13.49	FF HOME
4185	2174263.34	2000559.36	16.35	FF HOME
4186	2174203.65	2000548.04	14.28	FF HOME
4187	2174109.93	2000474.84	14.63	FF HOME
4188	2174183.08	2000362	14.95	FF HOME
4189	2174254.58	2000350.43	14.74	FF UNOCCUPIED HOME
4190	2174268.88	2000441.22	16	FF HOME
4191	2174331.4	2000465.42	15.74	FF HOME
4192	2174205.53	2000229.79	13.78	FF HOME

4193	2174171.23	2000249.82	14.76	FF HOME
4194	2174144.62	2000290.38	13.9	FF HOME
4195	2174126.18	2000164.96	18.27	FF TEACHER HOUSING
4196	2174133.38	2000235.48	18.42	FF TEACHER HOUSING
4197	2174075.61	2000339.23	17.33	FF TEACHER HOUSING
4198	2173995.42	2000375.56	17.24	FF TEACHER HOUSING
4199	2173954.11	2000332.24	17.03	FF TEACHER HOUSING
4200	2173817.66	2000484.52	21.11	FF SCHOOL
4201	2173834.82	2000581.82	13.76	FF HOME
4202	2173852.45	2000249.16	21.1	FF SCHOOL
4203	2173514.76	2000404.75	15.53	FF HOME
4204	2173543.91	2000514	13.65	FF HOME
4205	2173514.54	2000526.25	12.68	FF HOME
4206	2173520.65	2000564.26	14.42	FF HOME
4207	2173568.73	2000611.15	14.66	FF HOME
4208	2173716.42	2000720.39	15.22	FF HOME
4209	2173580.36	2000899.65	15.31	FF COMM HUT
4210	2173716.23	2001270.97	19.36	FF DOT BLDG
4211	2173778.47	2001272.53	18.61	FF DOT BLDG
4213	2175149.09	2000331.49	17.88	FF TRIBAL OFFICE
4214	2175297.31	2000900.14	15.59	FF HOME
4215	2175437.74	2001635.71	17.66	FF CHURCH
4216	2175592.38	2001556.59	15.95	FF HOME
4217	2175910.24	2001501.76	16.4	FF HOME
4218	2176066.51	2001422.16	15.16	FF HOME
4219	2176192.65	2001457.64	14.5	FF HOME
4220	2176134.01	2001579.62	16.81	FF HOME
4221	2175801.84	2001074.58	14.12	FF HOME
4222	2175841.61	2000984.27	14.31	FF HOME
4223	2175794.09	2000892.52	13.6	FF HOME
4224	2175452.28	2000355.99	14.96	FF GENERATOR BLDG
4225	2175368.95	2000371.37	18.19	FF OLD GENERATOR BLDG
4226	2175606.97	2000418.54	16.54	FF FUEL CONTAINMENT TOP
4227	2175630	2000416.39	14.07	FF FUEL CONTAINMENT BOTTOM
4228	2175474.84	2000524.03	14.18	FF APPROX BOTTOM OF FUEL TANKS
4229	2176004.09	2000976.64	12.17	FF HOME
4230	2176319.1	2000966.64	13.88	FF HOME
4231	2176358.68	2000920.83	12.46	FF HOME
4232	2176253.43	2000821.21	14.5	FF HOME
4233	2176380.55	2000721.96	14.53	FF ABANDONDED DOPLAR RADAR BLDG
4234	2176425.45	2000557.57	13.61	FF HOME
4235	2176766.58	2000610.12	13.82	FF HOME
4236	2176411.7	2000376.26	14.02	FF HOME
4237	2176437.81	2000133.51	13.65	FF HOME
4238	2176034.74	2000209.88	14.62	FF HOME
4239	2175515.55	1999930.75	13.23	FF GAS PUMP
4240	2175467.84	1999877.6	13.23	FF GAS STATION

4241	2175408.32	1999887.16	14.36	FF STORAGE BLDG
4242	2175407.4	1999914.93	11.79	FF STORAGE BLDG
4243	2175363.66	1999953.78	12.27	FF STORAGE BLDG
4244	2175351.17	1999926.26	13.88	FF HARDWARE STORE
4245	2175434.13	2000135.67	13.63	FF HOME

FF = Finish Floor

551	59° 56' 06.00744" N	164° 01' 52.76037" W	14.71	IIK A
552	59° 56' 21.01542" N	164° 02' 13.25402" W	15.92	5951 C 2021
4001	59° 55' 49.48748" N	164° 02' 08.89809" W	14.81	FF HOME
4002	59° 55' 56.41481" N	164° 02' 58.45115" W	14.8	FF HOME
4003	59° 55' 56.07654" N	164° 03' 00.11685" W	14.6	FF HOME
4004	59° 55' 55.38263" N	164° 03' 00.59439" W	15.78	FF DUPLEX HOME
4005	59° 55' 55.53111" N	164° 02' 59.61098" W	16.03	FF HOME
4006	59° 55' 54.63184" N	164° 03' 00.50447" W	15.85	FF DUPLEX HOME
4007	59° 55' 53.94275" N	164° 02' 58.90030" W	17.68	FF HOME
4008	59° 55' 54.07103" N	164° 02' 57.32342" W	17.88	FF HOME
4009	59° 55' 55.72818" N	164° 02' 58.29776" W	16.66	FF HOME
4010	59° 55' 54.93834" N	164° 02' 54.72116" W	16.88	FF HOME
4011	59° 55' 55.43436" N	164° 02' 53.49663" W	18.44	FF HOME
4012	59° 55' 55.04821" N	164° 02' 51.96592" W	17.79	FF HOME
4013	59° 55' 55.36336" N	164° 02' 51.13196" W	17.25	FF HOME
4014	59° 55' 55.92712" N	164° 02' 52.27405" W	17.35	FF HOME
4015	59° 55' 56.50635" N	164° 02' 50.80858" W	17.04	FF HOME
4016	59° 55' 55.75633" N	164° 02' 48.66896" W	17.54	FF HOME
4017	59° 55' 56.97455" N	164° 02' 49.64767" W	16.97	FF HOME
4018	59° 55' 58.45718" N	164° 02' 46.37644" W	18.9	FF HOME
4019	59° 55' 59.07608" N	164° 02' 47.35026" W	18.27	FF HOME
4020	59° 55' 59.41136" N	164° 02' 48.32248" W	18.68	FF HOME
4021	59° 55' 59.45711" N	164° 02' 50.46199" W	13.81	FF HOME
4022	59° 56' 00.40886" N	164° 02' 49.43701" W	18.57	FF HOME
4023	59° 56' 01.08965" N	164° 02' 50.50174" W	18.81	FF HOME
4024	59° 56' 01.78890" N	164° 02' 51.59294" W	18.99	FF HOME
4025	59° 56' 02.46314" N	164° 02' 52.52133" W	18.61	FF HOME
4026	59° 56' 03.14732" N	164° 02' 53.78600" W	19.22	FF HOME
4027	59° 56' 04.06099" N	164° 02' 55.45596" W	19.62	FF HOME
4028	59° 56' 03.40146" N	164° 02' 56.93570" W	18.26	FF HOME
4029	59° 56' 04.34108" N	164° 02' 58.97669" W	18.17	FF UNOCCUPIED HOME
4030	59° 56' 04.86224" N	164° 02' 58.97722" W	16.81	FF HOME
4031	59° 56' 05.64956" N	164° 02' 57.91251" W	16.97	FF HOME
4032	59° 56' 05.17895" N	164° 02' 54.88203" W	15.49	FF HOME
4033	59° 56' 06.28862" N	164° 02' 57.33102" W	16.77	FF UNOCCUPIED HOME
4034	59° 56' 07.26801" N	164° 02' 56.59649" W	16.56	FF HOME
4035	59° 56' 07.68272" N	164° 02' 55.87126" W	16.47	FF HOME
4036	59° 56' 08.45503" N	164° 02' 57.39100" W	15.78	FF UNOCCUPIED BLDG
4037	59° 56' 02.61185" N	164° 03' 03.92798" W	16.19	FF UUI COMM BLDG
4038	59° 55' 59.65432" N	164° 03' 14.90744" W	14.36	FF HOME
4039	59° 55' 59.24168" N	164° 03' 15.71442" W	14.42	FF HOME
4040	59° 55' 59.84612" N	164° 03' 16.90327" W	13.87	FF HOME
4041	59° 56' 01.08213" N	164° 03' 16.81484" W	13.78	FF HOME
4042	59° 56' 04.87157" N	164° 03' 10.86206" W	15.69	FF HOME
4043	59° 56' 04.66583" N	164° 03' 11.32960" W	15.58	FF HOME
4044	59° 56' 09.31502" N	164° 02' 49.45372" W	15.21	FF HOME

4045	59° 56' 08.62130" N	164° 02' 49.91437" W	14.98	FF HOME
4046	59° 56' 07.74518" N	164° 02' 46.62142" W	11.89	FF HOME
4047	59° 56' 06.35601" N	164° 02' 43.52364" W	14.25	FF HOME
4048	59° 55' 58.36144" N	164° 02' 44.45291" W	14.75	FF HOME
4049	59° 55' 57.44305" N	164° 02' 44.89992" W	19.06	FF HOME
4050	59° 55' 56.98539" N	164° 02' 44.07922" W	19.85	FF HOME
4051	59° 55' 56.36531" N	164° 02' 43.10736" W	20.03	FF HOME
4052	59° 55' 55.47491" N	164° 02' 45.70474" W	13.53	FF HOME
4053	59° 55' 54.55195" N	164° 02' 45.76658" W	12.89	FF UNOCCUPIED HOME
4054	59° 55' 55.13979" N	164° 02' 44.03991" W	13.72	FF UNOCCUPIED HOME
4055	59° 55' 55.55937" N	164° 02' 41.98799" W	19.3	FF HOME
4056	59° 55' 55.46940" N	164° 02' 41.43009" W	19.43	FF HOME
4057	59° 55' 58.13264" N	164° 02' 41.16012" W	14.65	FF HOME
4058	59° 55' 57.08680" N	164° 02' 40.73967" W	19.08	FF HOME
4059	59° 55' 56.18859" N	164° 02' 39.84770" W	19.63	FF HOME
4060	59° 55' 56.73859" N	164° 02' 38.46609" W	19.56	FF HOME
4061	59° 55' 57.63285" N	164° 02' 39.35452" W	19.49	FF HOME
4062	59° 55' 58.18209" N	164° 02' 37.95968" W	19.33	FF HOME
4063	59° 55' 57.28423" N	164° 02' 37.06573" W	19.51	FF HOME
4064	59° 55' 57.83261" N	164° 02' 35.67386" W	19.33	FF HOME
4065	59° 55' 58.44594" N	164° 02' 36.57223" W	19.1	FF HOME
4066	59° 55' 58.38125" N	164° 02' 34.30024" W	19.14	FF HOME
4067	59° 55' 59.27597" N	164° 02' 35.18784" W	19.9	FF HOME
4068	59° 55' 59.91919" N	164° 02' 34.54048" W	13.68	FF HOME
4069	59° 56' 00.92395" N	164° 02' 34.85523" W	13.8	FF HOME
4070	59° 55' 59.91295" N	164° 02' 35.42098" W	14.63	FF HOME
4071	59° 55' 59.76548" N	164° 02' 36.13398" W	14.42	FF HOME
4079	59° 55' 59.65618" N	164° 02' 26.07609" W	16.64	FF WATER TANK BLDG
4080	59° 55' 59.25076" N	164° 02' 25.75861" W	16.95	FF WATER TANK
4081	59° 55' 59.73981" N	164° 02' 24.89417" W	16.71	FF WATER TANK
4082	59° 56' 01.21154" N	164° 02' 24.97983" W	17.84	FF WASHETERIA
4083	59° 56' 00.46147" N	164° 02' 25.06737" W	11.91	FF FUEL CONTAINMENT BOTTOM
4084	59° 56' 00.70541" N	164° 02' 25.28431" W	12.29	FF FUEL CONTAINMENT TOP
4085	59° 56' 01.97683" N	164° 02' 30.01358" W	17.04	FF SERVICE CENTER
4086	59° 56' 03.78730" N	164° 02' 28.49988" W	13.99	FF HOME
4087	59° 56' 03.93223" N	164° 02' 29.06671" W	13.87	FF HOME
4088	59° 56' 04.11075" N	164° 02' 31.33168" W	16.07	FF HOME
4089	59° 56' 04.35410" N	164° 02' 32.11259" W	15.6	FF HOME
4090	59° 56' 04.38064" N	164° 02' 33.55983" W	16.79	FF UNOCCUPIED HOME
4091	59° 56' 05.78491" N	164° 02' 32.30732" W	15.02	FF HOME
4092	59° 56' 06.26372" N	164° 02' 32.81283" W	15.27	FF HOME
4093	59° 56' 06.52458" N	164° 02' 33.34369" W	12.57	FF HOME
4094	59° 56' 06.86586" N	164° 02' 31.08543" W	15.41	FF HOME
4095	59° 56' 06.92724" N	164° 02' 29.51323" W	14.83	FF HOME
4096	59° 56' 07.08511" N	164° 02' 28.44211" W	15.22	FF HOME
4097	59° 56' 06.70512" N	164° 02' 26.30238" W	12.89	FF HOME
4098	59° 56' 05.36833" N	164° 02' 28.45421" W	15.01	FF HOME

4099	59° 56' 05.24605" N	164° 02' 29.66914" W	16.67	FF HOME
4100	59° 56' 04.81350" N	164° 02' 29.38124" W	14.33	FF HOME
4101	59° 56' 02.01088" N	164° 02' 26.40872" W	13.46	FF POLICE BLDG
4102	59° 56' 02.56705" N	164° 02' 25.38559" W	15.34	FF POLICE BLDG
4103	59° 56' 03.39551" N	164° 02' 24.64072" W	14.83	FF OLD STORE
4104	59° 56' 03.93347" N	164° 02' 24.68193" W	12.88	FF UNOCCUPIED HOME
4105	59° 56' 04.31439" N	164° 02' 24.73887" W	14.25	FF CORPORATION BLDG
4106	59° 56' 03.30433" N	164° 02' 23.22137" W	15.5	FF YK HEALTH CO BLDG
4107	59° 56' 01.69423" N	164° 02' 20.30728" W	15.46	FF POST OFFICE
4108	59° 56' 02.04399" N	164° 02' 17.46905" W	16.39	FF ARMY NATIONAL GUARD BLDG
4109	59° 56' 02.97223" N	164° 02' 18.85161" W	15.76	FF ARMY NATIONAL GUARD BLDG
4110	59° 56' 03.12580" N	164° 02' 17.92886" W	14.75	FF ARMY NATIONAL GUARD BLDG
4111	59° 56' 04.92800" N	164° 02' 19.36172" W	13.2	FF STORE
4112	59° 56' 08.12987" N	164° 02' 23.26807" W	12.47	FF UNKNOWN BLDG
4113	59° 56' 08.37214" N	164° 02' 33.16780" W	14.98	FF HOME
4114	59° 56' 09.01897" N	164° 02' 34.14010" W	15.39	FF HOME
4115	59° 56' 08.97570" N	164° 02' 34.78196" W	15.24	FF HOME
4116	59° 56' 08.56237" N	164° 02' 35.43919" W	13.85	FF HOME
4117	59° 56' 07.98639" N	164° 02' 36.65533" W	14.09	FF HOME
4118	59° 56' 08.53363" N	164° 02' 38.06244" W	12.82	FF UNOCCUPIED HOME
4119	59° 56' 08.70876" N	164° 02' 39.84408" W	12.99	FF HOME
4120	59° 56' 08.57922" N	164° 02' 41.21160" W	11.86	FF HOME
4121	59° 56' 09.28723" N	164° 02' 40.06728" W	14.98	FF HOME
4122	59° 56' 09.52605" N	164° 02' 39.20913" W	12.54	FF HOME
4123	59° 56' 09.08599" N	164° 02' 36.55633" W	12.85	FF HOME
4124	59° 56' 09.87725" N	164° 02' 36.95943" W	14.31	FF HOME
4125	59° 56' 10.20622" N	164° 02' 37.96204" W	13.21	FF HOME
4126	59° 56' 10.95236" N	164° 02' 36.75815" W	13.81	FF HOME
4127	59° 56' 11.21970" N	164° 02' 37.79709" W	13.06	FF HOME
4128	59° 56' 11.32770" N	164° 02' 36.36878" W	12.91	FF HOME
4129	59° 56' 13.99682" N	164° 02' 35.99865" W	12.71	FF HOME
4130	59° 56' 15.37784" N	164° 02' 34.99626" W	15.09	FF HOME
4131	59° 56' 17.00986" N	164° 02' 34.23269" W	14.21	FF ABANDONED KTC LODGE & GARAGE
4132	59° 56' 16.35819" N	164° 02' 31.05107" W	14.24	FF HOME
4133	59° 56' 15.64895" N	164° 02' 30.52355" W	13.53	FF HOME
4134	59° 56' 15.49791" N	164° 02' 32.43543" W	14.85	FF HOME
4135	59° 56' 14.05337" N	164° 02' 30.25798" W	14.71	FF HOME
4136	59° 56' 13.10795" N	164° 02' 28.88629" W	14.05	FF HOME
4137	59° 56' 12.20442" N	164° 02' 27.02854" W	13.37	FF HOME
4138	59° 56' 13.53149" N	164° 02' 25.31601" W	14.43	FF HOME
4139	59° 56' 14.85005" N	164° 02' 24.20054" W	12.34	FF HOME
4140	59° 56' 13.73014" N	164° 02' 27.11512" W	13.52	FF UNOCCUPIED HOME
4141	59° 56' 17.34157" N	164° 02' 28.09540" W	14.01	FF HOME
4142	59° 56' 16.06289" N	164° 02' 23.93384" W	12.07	FF ABANDONED KTC JAIL HOUSE
4143	59° 56' 16.26285" N	164° 02' 23.31864" W	14.51	FF UNOCCUPIED HOME
4144	59° 56' 16.67983" N	164° 02' 25.39150" W	14.48	FF HOME
4145	59° 56' 17.45856" N	164° 02' 25.31010" W	13.53	FF HOME

4146	59° 56' 18.46247" N	164° 02' 28.47824" W	14.6	FF HOME
4147	59° 56' 18.84717" N	164° 02' 27.49131" W	13.72	FF HOME
4148	59° 56' 18.34570" N	164° 02' 24.88414" W	14.65	FF HOME
4149	59° 56' 18.89056" N	164° 02' 23.01288" W	13.55	FF HOME
4150	59° 56' 17.76878" N	164° 02' 22.09013" W	14	FF HOME
4151	59° 56' 18.48004" N	164° 02' 21.40643" W	14.03	FF HOME
4152	59° 56' 17.45600" N	164° 02' 20.54087" W	15.2	FF HOME
4153	59° 56' 17.08496" N	164° 02' 20.19765" W	13.58	FF HOME
4154	59° 56' 17.17717" N	164° 02' 19.03059" W	15.75	FF HOME
4155	59° 56' 18.00291" N	164° 02' 19.23058" W	15.03	FF HOME
4156	59° 56' 18.35026" N	164° 02' 19.46806" W	13.44	FF HOME
4157	59° 56' 18.97912" N	164° 02' 18.84479" W	14.89	FF HOME
4158	59° 56' 19.23310" N	164° 02' 17.32346" W	15.61	FF HOME
4159	59° 56' 18.79249" N	164° 02' 17.04501" W	15.12	FF HOME
4160	59° 56' 18.46792" N	164° 02' 17.18929" W	14.82	FF HOME
4161	59° 56' 15.96364" N	164° 02' 17.26257" W	14.91	FF HOME
4162	59° 56' 15.83728" N	164° 02' 18.08095" W	14.19	FF HOME
4163	59° 56' 16.30225" N	164° 02' 18.03669" W	13.59	FF HOME
4164	59° 56' 17.02272" N	164° 02' 16.80261" W	14.87	FF HOME
4165	59° 56' 16.81113" N	164° 02' 16.74930" W	15.28	FF HOME
4166	59° 56' 18.13138" N	164° 02' 15.77490" W	15.97	FF HOME
4167	59° 56' 17.94094" N	164° 02' 14.81060" W	15.16	FF STORE
4168	59° 56' 17.72870" N	164° 02' 15.14724" W	13.53	FF STORAGE
4169	59° 56' 17.44389" N	164° 02' 15.51542" W	14.37	FF HOME
4170	59° 56' 17.07169" N	164° 02' 15.42524" W	13.92	FF UNOCCUPIED HOME
4171	59° 56' 16.77468" N	164° 02' 14.02839" W	14.3	FF HOME
4172	59° 56' 16.52662" N	164° 02' 15.23894" W	15.65	FF HOME
4173	59° 56' 16.28114" N	164° 02' 15.67958" W	14.87	FF HOME
4174	59° 56' 16.11395" N	164° 02' 15.18712" W	13.72	FF HOME
4175	59° 56' 16.17334" N	164° 02' 13.40447" W	13.49	FF HOME
4176	59° 56' 15.42361" N	164° 02' 14.16869" W	16.3	FF HOME
4177	59° 56' 15.46680" N	164° 02' 15.28446" W	15.53	FF HOME
4178	59° 56' 14.67176" N	164° 02' 16.30225" W	16.6	FF HOME
4179	59° 56' 14.75250" N	164° 02' 17.76395" W	14.22	FF KIPNUK TRADING COMPANY
4180	59° 56' 13.91884" N	164° 02' 15.06087" W	14.31	FF HOME
4181	59° 56' 14.71219" N	164° 02' 15.03197" W	16.4	FF HOME
4182	59° 56' 14.94525" N	164° 02' 12.63749" W	15.13	FF HOME
4183	59° 56' 15.18783" N	164° 02' 11.48293" W	14.74	FF HOME
4184	59° 56' 14.95580" N	164° 02' 10.29272" W	13.49	FF HOME
4185	59° 56' 13.73638" N	164° 02' 09.96159" W	16.35	FF HOME
4186	59° 56' 13.15205" N	164° 02' 10.21835" W	14.28	FF HOME
4187	59° 56' 12.25082" N	164° 02' 11.70899" W	14.63	FF HOME
4188	59° 56' 13.00393" N	164° 02' 13.88009" W	14.95	FF HOME
4189	59° 56' 13.71114" N	164° 02' 14.06539" W	14.74	FF UNOCCUPIED HOME
4190	59° 56' 13.82536" N	164° 02' 12.27592" W	16	FF HOME
4191	59° 56' 14.43376" N	164° 02' 11.76485" W	15.74	FF HOME
4192	59° 56' 13.26353" N	164° 02' 16.46056" W	13.78	FF HOME

4193	59° 56' 12.91999" N	164° 02' 16.08752" W	14.76	FF HOME
4194	59° 56' 12.64625" N	164° 02' 15.30748" W	13.9	FF HOME
4195	59° 56' 12.50127" N	164° 02' 17.77856" W	18.27	FF TEACHER HOUSING
4196	59° 56' 12.55162" N	164° 02' 16.39095" W	18.42	FF TEACHER HOUSING
4197	59° 56' 11.95264" N	164° 02' 14.38920" W	17.33	FF TEACHER HOUSING
4198	59° 56' 11.15261" N	164° 02' 13.72318" W	17.24	FF TEACHER HOUSING
4199	59° 56' 10.75860" N	164° 02' 14.59699" W	17.03	FF TEACHER HOUSING
4200	59° 56' 09.37089" N	164° 02' 11.68917" W	21.11	FF SCHOOL
4201	59° 56' 09.51141" N	164° 02' 09.77032" W	13.76	FF HOME
4202	59° 56' 09.78208" N	164° 02' 16.28603" W	21.1	FF SCHOOL
4203	59° 56' 06.41239" N	164° 02' 13.43026" W	15.53	FF HOME
4204	59° 56' 06.66745" N	164° 02' 11.27014" W	13.65	FF HOME
4205	59° 56' 06.37473" N	164° 02' 11.04687" W	12.68	FF HOME
4206	59° 56' 06.42374" N	164° 02' 10.29777" W	14.42	FF HOME
4207	59° 56' 06.88340" N	164° 02' 09.35003" W	14.66	FF HOME
4208	59° 56' 08.30532" N	164° 02' 07.12100" W	15.22	FF HOME
4209	59° 56' 06.91352" N	164° 02' 03.68384" W	15.31	FF COMM HUT
4210	59° 56' 08.14243" N	164° 01' 56.32052" W	19.36	FF DOT BLDG
4211	59° 56' 08.75468" N	164° 01' 56.25369" W	18.61	FF DOT BLDG
4213	59° 56' 22.52233" N	164° 02' 13.91652" W	17.88	FF TRIBAL OFFICE
4214	59° 56' 23.81531" N	164° 02' 02.67351" W	15.59	FF HOME
4215	59° 56' 24.98231" N	164° 01' 48.16024" W	17.66	FF CHURCH
4216	59° 56' 26.52782" N	164° 01' 49.62224" W	15.95	FF HOME
4217	59° 56' 29.67296" N	164° 01' 50.51235" W	16.4	FF HOME
4218	59° 56' 31.23459" N	164° 01' 51.98288" W	15.16	FF HOME
4219	59° 56' 32.46593" N	164° 01' 51.21311" W	14.5	FF HOME
4220	59° 56' 31.85290" N	164° 01' 48.85399" W	16.81	FF HOME
4221	59° 56' 28.73091" N	164° 01' 58.95692" W	14.12	FF HOME
4222	59° 56' 29.14884" N	164° 02' 00.70557" W	14.31	FF HOME
4223	59° 56' 28.70787" N	164° 02' 02.53356" W	13.6	FF HOME
4224	59° 56' 25.49980" N	164° 02' 13.25931" W	14.96	FF GENERATOR BLDG
4225	59° 56' 24.67504" N	164° 02' 13.00611" W	18.19	FF OLD GENERATOR BLDG
4226	59° 56' 27.00440" N	164° 02' 11.94195" W	16.54	FF FUEL CONTAINMENT TOP
4227	59° 56' 27.23172" N	164° 02' 11.97082" W	14.07	FF FUEL CONTAINMENT BOTTOM
4228	59° 56' 25.67285" N	164° 02' 09.94934" W	14.18	FF APPROX BOTTOM OF FUEL TANKS
4229	59° 56' 30.75048" N	164° 02' 00.76064" W	12.17	FF HOME
4230	59° 56' 33.85447" N	164° 02' 00.77319" W	13.88	FF HOME
4231	59° 56' 34.25743" N	164° 02' 01.64898" W	12.46	FF HOME
4232	59° 56' 33.25053" N	164° 02' 03.66489" W	14.5	FF HOME
4233	59° 56' 34.53091" N	164° 02' 05.53834" W	14.53	FF ABANDONDED DOPLAR RADAR BLDG
4234	59° 56' 35.02098" N	164° 02' 08.73753" W	13.61	FF HOME
4235	59° 56' 38.36369" N	164° 02' 07.50773" W	13.82	FF HOME
4236	59° 56' 34.93862" N	164° 02' 12.30306" W	14.02	FF HOME
4237	59° 56' 35.26649" N	164° 02' 17.05098" W	13.65	FF HOME
4238	59° 56' 31.27629" N	164° 02' 15.78699" W	14.62	FF HOME
4239	59° 56' 26.24679" N	164° 02' 21.56562" W	13.23	FF GAS PUMP
4240	59° 56' 25.79259" N	164° 02' 22.63624" W	13.23	FF GAS STATION

4241	59° 56' 25.20387" N	164° 02' 22.48325" W	14.36	FF STORAGE BLDG
4242	59° 56' 25.18672" N	164° 02' 21.93889" W	11.79	FF STORAGE BLDG
4243	59° 56' 24.74481" N	164° 02' 21.20211" W	12.27	FF STORAGE BLDG
4244	59° 56' 24.62996" N	164° 02' 21.74924" W	13.88	FF HARDWARE STORE
4245	59° 56' 25.38545" N	164° 02' 17.59251" W	13.63	FF HOME

APPENDIX B: FIELD INVESTIGATION FLOOD HEIGHT DATA COLLECTION

Ground Survey Details

DGGS visited Kipnuk on June 21, 2022, to collect historical high-water mark (HWM) and flood elevation data. A Trimble R10 receiver was temporarily installed as a GNSS base station over an existing stainless-steel rod in a lidded case stamped "AIRPORT GEODETIC CONTROL MARK LS11797 2015 IIK-A" (table B1). Points were surveyed with a Trimble R8s receiver as a GNSS rover, between 8:01 AM and 8:09 PM AKDT. DGGS measured 10 flood elevation points (table B2) identified through local accounts or from photographic evidence.

Data Processing

The base station position was corrected using an Online Positioning User Service (OPUS) solution and NOAA's Vertical Datum Transformation (VDatum) software. The corrected base station position was used to update the ground rover positions through post-processed kinematic (PPK) adjustments in Trimble Business Center (Version 5.51) software with default settings applied.

Coordinate System and Datum

All data were processed and are delivered in meters in the NAD83 (2011) UTM Zone 3N horizontal coordinate system and NAVD88 (Geoid 12B) vertical datum.

Horizontal Accuracy

DGGS quantified the horizontal accuracy of the base station GNSS position data using the latitudinal and longitudinal peak-to-peak errors provided by OPUS (table B1). The horizontal accuracy of the rover GNSS position data was quantified using Trimble Business Center and reflects the root-mean-square (RMS) of latitudinal and longitudinal errors, which does not include propagated error from the corrected base station position (table B2). Consistent with OPUS shared solution requirements (https://geodesy.noaa.gov/OPUS/about.jsp), DGGS considers high-quality GNSS solutions to have latitudinal and longitudinal errors less than or equal to 0.040 m.

Vertical Accuracy

DGGS quantified the vertical accuracy of the base station GNSS position data using the combined NAD83 (2011) ellipsoidal height peak-to-peak error provided by OPUS and orthometric height (RMS) error provided by VDatum (table B1). The vertical accuracy of the rover GNSS position data was quantified using Trimble Business Center, which does not include propagated error from the corrected base station position (table B2). Consistent with OPUS shared solutions requirements, DGGS considers high-quality GNSS solutions to have vertical errors less than or equal to 0.080 m.

Table B1. Base station coordinates and GNSS errors.

Northing	Easting	Elevation	Northing Error	Easting Error	Vertical Error
6644568.574	554135.137	4.451	0.011	0.008	0.077

Table B2. Rover coordinates and GNSS errors.

Point ID	Northing	Easting	Elevation	Horizontal Error	Vertical Error	Description
3001	6645074.998	553809.828	3.540	0.011	0.012	Reported height of 2015 flooding at first step of council building.
3002	6645319.556	553961.471	2.710	0.008	0.010	Estimated location of reported boardwalk floating 1.0 m above ground during 2016 flooding.
3003	6645439.449	553984.589	3.498	0.009	0.011	Reported height of 2016 flooding at fourth step of home.
3004	6644721.651	553458.099	3.745	0.006	0.008	Reported height of 2016 flooding reaching top of porch of home.
3005	6644625.405	553379.642	2.695	0.005	0.007	Estimated location of reported ATV submerged by water 1.0 m above ground during 2016 flooding.
3006	6644958.493	553589.033	3.245	0.006	0.008	Reported location of water 0.37 m above ground during 2015 flooding.
3007	6644957.784	553590.225	3.254	0.006	0.008	Reported location of water 0.55 m above ground during 2016 flooding.
3012	6644758.807	553602.525	4.049	0.007	0.009	Reported height of 2016 flooding at top step of home.
3013	6644476.251	553629.524	2.839	0.013	0.020	Estimated location depicted in photographic evidence of 2016 flooding.
3014	6645267.702	553972.962	3.406	0.008	0.011	Reported height of 2016 flooding 0.18 m above second step of home.