Report of Investigation 2021-1A Nunam Iqua

COASTAL FLOOD IMPACT ASSESSMENTS FOR ALASKA COMMUNITIES—NUNAM IQUA

Richard M. Buzard, Jacquelyn R. Overbeck, and Katie Y. Miller

Major flooding during the November 2011 flood. Photo: Alaska Division of Homeland Security & Emergency Management.

Published by
STATE OF ALASKA
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF GEOLOGICAL & GEOPHYSICAL SURVEYS
2021

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Suggested citation:
Buzard, R.M., Overbeck, J.R., and Miller, K.Y., 2021, Coastal flood impact assessments for Alaska communities: Nunam Iqua, *in* Buzard, R.M., Overbeck, J.R., Chriest, Jonathan, Endres, K.L., and Plumb, E.W., Coastal flood impact assessments for Alaska communities: Alaska Division of Geological & Geophysical Surveys Report of Investigation 2021-1A, 31 p.
https://doi.org/10.14509/30675

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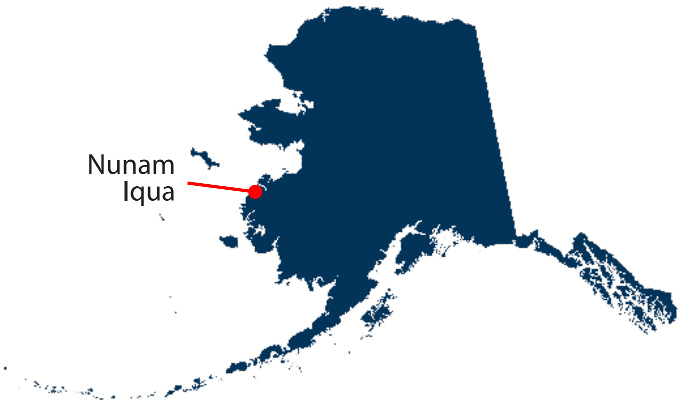
COASTAL FLOOD IMPACT ASSESSMENTS FOR ALASKA COMMUNITIES—NUNAM IQUA

Richard M. Buzard[1], Jacquelyn R. Overbeck[1], and Katie Y. Miller[1]



OVERVIEW

This report is an assessment of the historical flood record and flood impact levels for the community of Nunam Iqua, Alaska. Methods used to evaluate historical floods and designate flood impact elevations (minor, moderate, or major; as defined by the National Weather Service) are described in detail in an overview report (Buzard and others, 2021). This community-specific report has three sections: data description, historical flood record, and flood impact categories. Flood and infrastructure heights are relative to the local mean higher high water (MHHW) datum. All estimate uncertainties are reported to a 95 percent confidence interval. Quoted text from the sources used to estimate flood heights can be found in appendix A. The City of Nunam Iqua was formerly known as Sheldon Point until 1999, so some sources may refer to this previous community name. Appendix B has tables and figures used to determine flood category heights, including relevant results from our global navigation satellite system (GNSS) survey conducted in August 2019.

SUMMARY

Flood categories and related infrastructure heights are listed in table 1, and estimated storm heights are listed in table 2. The 2017 hazard mitigation plan prepared by the Nunam Iqua Advisory Planning Board (NIAPB, 2017) lists three federal disaster declarations for flooding that apply to Nunam Iqua (2004, 2011, and 2013). From 1945 to 2019, Nunam Iqua experienced at least twelve significant coastal flood events. Of these reported events, we estimate the peak still water elevations of ten floods. At the time of occurrence, these floods caused three minor, three moderate, and four major flood events. Homes are built higher now than in the past, and if these events occurred with Nunam Iqua's current infrastructure, they would cause three minor, five moderate, and two major floods. The highest recorded flood occurred on November 5, 2013, reaching a still water height of 8.5 ± 1.0 ft MHHW.

Flood categories as defined by the National Weather Service are modified to reflect observed impacts to the community. Flooding of drinking water resources is normally considered a major impact, but relatively low storm surge heights can cause this issue in Nunam Iqua. The community can turn off the water intake to avoid pumping saltwater into the system (avoiding major flood impacts) until the surge passes and the river returns to freshwater. All other moderate and major flooding indicators are at least 2.3 ft above the drinking water impact height. Therefore, we consider a flood only impacting drinking water to be a moderate event whereas a flood that impacts multiple major categories (such as drinking water and the wastewater facility) is considered a major event. This modification better represents the initial definitions of the flood impact categories as they relate to Nunam Iqua.

[1]Alaska Division of Geological & Geophysical Surveys, 3354 College Rd., Fairbanks, Alaska 99709-3707.

Coastal Flood Impact Map
Nunam Iqua, Alaska

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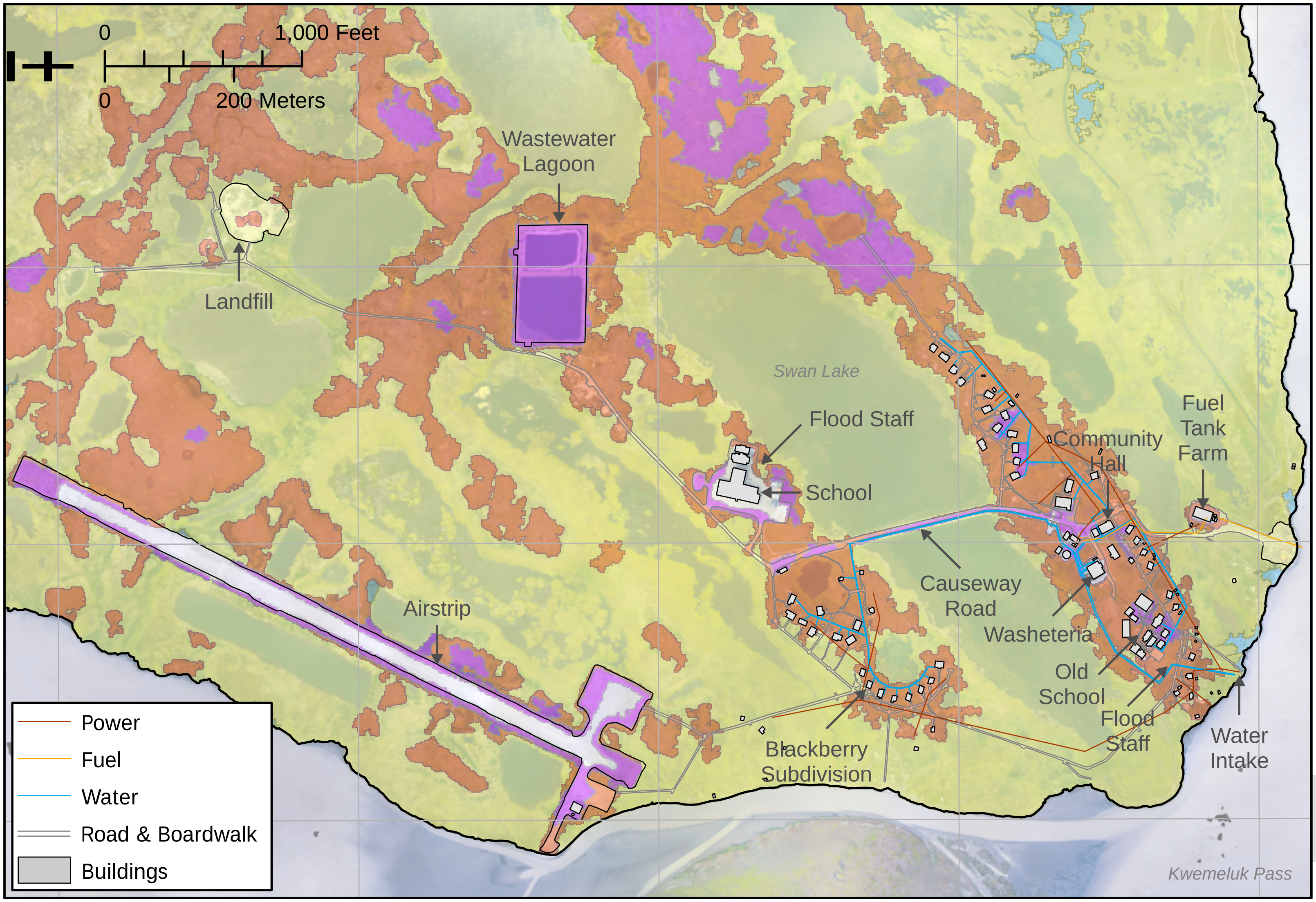
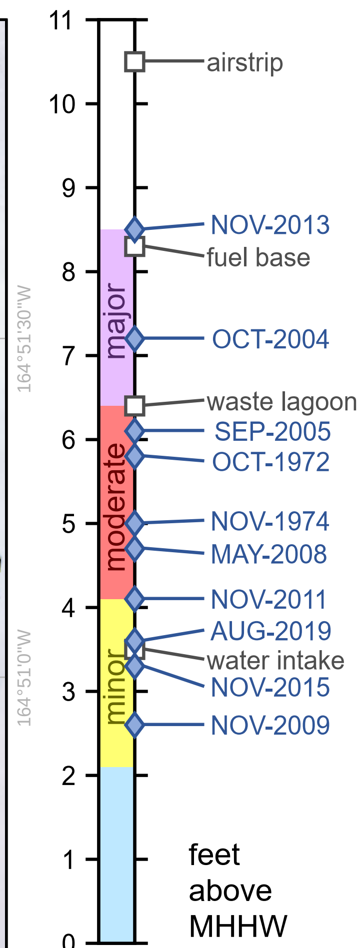
Buzard and others, 2021
NUNAM IQUA





To calculate height above
MLLW: add 2.6 ft
NAVD88: add 6.5 ft

Projection: NAD 1983 UTM Zone 3N
Orthoimage year: 2015
Orthoimagery available from elevation.alaska.gov
Houses or infrastructure may have moved since DCRA linework was completed

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

Moderate Flooding is defined to have some inundation of structures and roads near the water. Some evacuations of people and/or transfer of property to higher elevations may be necessary.

Minor Flooding is defined to have minimal or no property damage, but possibly some public threat.

This work is part of the Digital Coast Fellowship project: Bringing Alaska to the Digital Coast. The analysis was paid for by the National Oceanic and Atmospheric Administration Office for Coastal Management, the Alaska Ocean Observing System, and the State of Alaska.

Table 1. Summary of infrastructure heights and flood categories. Purple = major, red = moderate, yellow = minor. Gray represents infrastructure not expected to be flooded, although floodwaters may surround or go underneath them. No infrastructure is considered subject to wave runup because there is no broadly sloping beach.

	Elevation Feature	Elevation (ft MHHW)	Vertical Uncertainty (ft)
Other	School (evacuation center)	13.1	0.1
	*Old school front door grating	13.1	0.1
	Airstrip covered	10.5	1.1
	Several buildings	10.2	1.0
Major	Highest recorded storm	8.5	1.0
	Fuel tank farm	8.3	0.2
	Airstrip use or access	7.5	0.1
	Lowest residence flooded	7.2	0.1
	Access across Causeway Road	6.8	1.3
	*Recommended building height	6.8	0.5
	Wastewater facility	6.4	0.1
	Major	**6.4**	**0.1**
Moderate	Water under lowest building	4.2	0.1
	Drinking water source	4.1	0.5
	Moderate	**4.1**	**0.5**
Minor	Access road threatened	3.2	0.5
	Beach property	2.1	0.1
	Minor	**2.1**	**0.1**

*U.S. Army Corps of Engineers (1993), table 4

Table 2. Summary of estimated historical flood heights. Flood categories are included for reference: purple = major, red = moderate, yellow = minor. The categories are based on current infrastructure conditions, not the conditions when the storm occurred.

Floods Estimated

Flood	Elevation (ft MHHW)	Vertical Uncertainty (ft)
2013-NOV-05	8.5	1.0
2004-OCT-19	7.2	0.5
2005-SEP-25	6.1	0.5
1972-OCT-26	5.8	0.5
1974-NOV-10	5.0	1.3
2008-MAY-24	4.7	0.5
2011-NOV-11	4.1	0.5
2019-AUG-03	3.6	0.5
2015-NOV-09	3.3	1.3
2009-NOV-11	2.6	0.5

Floods Not Estimated

Flood	Elevation (ft MHHW)	Vertical Uncertainty (ft)
1979-NOV-23	—	—
1946-NOV-17	—	—

DATA

Mapped data are used to interpret flood elevations from historical photographs and accounts. This section describes available data used to assess flooding for Nunam Iqua.

Digital Elevation Models and Orthoimagery

High-resolution, high accuracy elevation models are required to measure flood heights. A digital surface model (DSM) and orthoimagery were collected in 2015 for Nunam Iqua (Overbeck and others, 2016; table 3).

Table 3. Specifications of elevation models available for Nunam Iqua.

	Photogrammetric DSM
Collection date	2015-AUG-23
Elevation type	Surface
Ground sample distance	0.20 m
Vertical accuracy	0.19 m
Vertical datum	NAVD88 (GEOID12B)

First Floor and High Water Mark Survey

The U.S. Army Corps of Engineers (USACE) performed a survey of first floor elevations and high water mark estimates using a Temporary Benchmark (TBM) survey in 1993 (USACE, 1993). The grate of the first floor of the high school (now abandoned) is used as the TBM—the local datum to which elevations are measured. In August 2019, we measured the grate using Global Navigation Satellite System (GNSS) positioning to an accuracy of 0.05 m (0.2 ft; fig. B1). This allows the USACE (1993) survey to be referenced relative to the DSM and the local tidal datum (table 4). Since the USACE (1993) survey is reported in decimal feet, but the survey methods are not published and features may have changed over time, a conservative uncertainty of 0.5 ft is assigned to the TBM survey heights. The root-sum-of-squares (RSS) error of this uncertainty and the conversion to orthometric height is 0.5 ft.

Community profile maps created by Alaska Division of Community & Regional Affairs (DCRA, 1979, 1994, 2006) state that the entire

Table 4. U.S. Army Corps of Engineers (1993) Temporary Benchmark (TBM) survey of first floor and high water mark heights relative to the school (assigned a height of 100.0 ft), converted to meters above the North American Vertical Datum of 1988 (NAVD88) and feet above MHHW using GNSS positioning.

	TBM (ft)	ft MHHW	m NAVD88
Estimated 1972 flood height	92.7	5.8	3.73
Recommended building elevation	93.7	6.8	4.04
Lowest tank in the silver tank farm	98.5	11.6	5.50
Runway centerline, downstream end	98.2	11.3	5.41
Lowest tank in the white tank farm	98.0	11.1	5.35
First floor of the church	93.5	6.6	3.98
First floor of the lowest house (old house adjacent to the church)	92.8	5.9	3.76
Lowest tank of the school tank farm	92.4	5.5	3.64
First floor of the log cabin near the lake	92.0	5.1	3.52
First floor of the log cabin nearest the airstrip	91.2	4.3	3.28
Grating at the front door of the high school (1993)	100.0	13.1	5.96

community would be inundated by the 1972 flood based on USACE (1993) report and prior USACE surveys. Our findings indicate that the ground surface of almost the entire community would be covered by still water height reaching approximately the 1972 flood height. This flood has since been exceeded by at least three floods. The still water height of the highest storm did not inundate the land around the washeteria, causeway road, new school, and the airport runway. Modern residences and structures are built high above ground level on post pier foundations resulting in little to no inundation of homes from flooding.

The first-floor height of residences is estimated by NIAPB (2017) using a Garmin GPSmap76. The vertical accuracy of this device is between 10 and 49 ft (3 to 15 m). We use the relative difference between structures for qualitative comparison, but the absolute heights do not have high enough accuracy for this study.

Tidal Datum

The local tidal datum collected for Nunam Iqua is used to convert orthometric heights to MHHW for this report (station 9467551; National Oceanographic and Atmospheric Administration Center for Operational Oceanographic Products and Services [NOAA CO-OPS], 2021; table 5). MHHW is 6.50 ft (1.98 m) above NAVD88.

FLOOD IMPACT CATEGORIES

Flood impact categories are used by the National Weather Service to define and communicate flood risk to the public. The categories are designated as minor, moderate, and major. A flood advisory is issued when a storm is forecast to cause minor flooding, while a flood warning is issued for moderate or major flooding. Definitions of minor, moderate, and major flooding are provided below followed by the information used to establish the elevation thresholds for each category at Nunam Iqua. Elevation thresholds and locations mentioned in the narrative below have been mapped using the DSM (map sheet Nunam Iqua, previous page).

Minor Flooding: Minimal or no property damage, but possibly some public threat.

Moderate Flooding: Some inundation of structures and roads near the water. Some evacuations of people and/or transfer of property to higher elevations may be necessary.

Major Flooding: Extensive inundation of structures and roads. Significant evacuations of people and/or transfer of property to higher elevations are necessary.

Table 5. Tidal datum for Nunam Iqua from the National Oceanic and Atmospheric Administration Center for Operational Oceanographic Products and Services (NOAA CO-OPS, 2021), with reference to NAVD88 using shared solution of tidal benchmark (National Geodetic Survey, 2021).

Tidal Datum	Abbreviation	ft MHHW	m NAVD88
Mean Higher High Water	MHHW	0.00	1.980
Mean High Water	MHW	-0.67	1.776
Mean Tide Level	MTL	-1.57	1.501
Mean Sea Level	MSL	-1.59	1.496
Mean Low Water	MLW	-2.47	1.226
Mean Lower Low Water	MLLW	-2.64	1.176
North American Vertical Datum of 1988	NAVD88	-6.50	0.000

Other Infrastructure

Evacuation center: 13.1 ± 0.1 ft MHHW

The school sits directly on a large, raised gravel pad at 13.1 ± 0.1 ft MHHW (fig. B2). This is the same height as the grate of the old school front door (fig. B1).

Airstrip covered: 10.5 ± 1.1 ft MHHW

The airstrip averages 10.5 ± 1.1 ft MHHW (fig. B3), with the highest point being 10.8 ± 0.1 ft MHHW (fig. B4).

Several buildings (flooded 1 or more ft): 10.2 ± 1.0 ft MHHW

NIAPB (2017) indicates five residences are within 3 ft of the height of the lowest residence (see lowest residences in moderate flooding). To achieve flooding of 1 ft for multiple residences, water must reach at least 10.2 ± 1.0 ft MHHW.

Major flooding: 6.4 ± 0.1 ft MHHW

Fuel tanks: 8.3 ± 0.2 ft MHHW

No sources cite damage to the fuel tanks. The tank farm was remodeled after the 2006 community profile map (DCRA, 2006) and sits on a raised gravel pad. The ground at the four corners averages 8.3 ± 0.2 ft MHHW (fig. B5). The wood barrier is 3.0 ft above the ground. Fuel lines and facilities are on the ground outside the fence, so the average ground height is considered the major flooding indicator.

Wastewater facility: 6.4 ± 0.1 ft MHHW

The wastewater lagoon can be breached by a flood reaching 6.4 ± 0.1 ft MHHW (fig. B6), as was the case during the November 2013 storm.

Moderate flooding: 4.1 ± 0.5 ft MHHW

Airstrip use or access: 7.5 ± 0.1 ft MHHW

The airport apron measured 7.5 ± 0.1 ft MHHW, and the airstrip center 10.8 ± 0.1 ft MHHW (fig. B4). Flooding of the apron would be considered a moderate flood impact.

Lowest residences (flooded 0 to 1 ft): 7.2 ± 0.1 ft MHHW

Residences are raised high above the ground and are recommended to be at least 8 feet above mean sea level (MSL), which is 6.8 ft MHHW (USACE, 1993; table 4). Only one residence was flooded in 2013, the highest estimated flood, when water reached 7.2 ± 0.1 ft MHHW (fig. 6D; table 12). This is identified as the lowest residence by NIAPB (2017).

Access way to larger parts of town: 6.8 ± 1.3 ft MHHW

The Causeway Road connects vital community resources. Its lowest section averages 6.8 ± 1.3 ft MHHW (fig. B8). Part of the road washed out during the November 2013 storm (Carin Finch, oral commun., 2019).

Drinking water source: 4.1 ± 0.5 ft MHHW

The drinking water intake pump platform is at 3.5 ± 0.1 ft MHHW and at risk of erosion (fig. B9; USACE, 2009). Disaster declarations for the 2004 and 2011 storms (7.2 ± 0.5 ft and 4.1 ± 0.5 ft MHHW; table 1) involved loss of drinking water (NIAPB, 2017). Based on observed impacts, the 2011 storm height is used to identify this flooding indicator.

Minor Flooding: 2.1 ± 0.1 ft MHHW

Lowest building: 4.2 ± 0.1 ft MHHW

Most buildings are now elevated above the ground. The ground height at the lowest residence is 4.2 ± 0.1 ft MHHW (fig. 5A).

Access road threatened: 3.2 ± 0.5 ft MHHW

The road to the barge landing averages 3.2 ± 0.5 ft MHHW (fig. B10) and is considered the lowest access road. The road to the airport averages 3.5 ± 1.3 ft MHHW (fig. B11).

Beach property: 2.1 ± 0.1 ft MHHW

The ground near the barge landing and the slough where boats are parked averages 2.1 ± 0.1 ft MHHW (fig. B12). Water reaching this height can flood sheds and impact boats parked on land.

HISTORICAL FLOOD RECORD

The historical flood record for Nunam Iqua, Alaska, is listed here from the earliest recorded event to the most recent (up to November 2019). The sources used in evaluating each flood are listed along with a summary of the relevant information found within. This historical information is used to estimate the flood height where possible. This flood record depends on information that is available to the public and shared with DGGS staff during the August 2019 survey. Relevant survey data is provided in appendix B, table B1. It is possible that storm and flood events have occurred that are not reported here. See appendix A for the direct quotations from each source that are used to evaluate these storms.

The year of the earliest recorded flood is limited to the settlement history of Nunam Iqua. NIAPB (2008) explain, “Buildings first appeared at Nunam Iqua after the 1931 fall flooding wiped out the saltry and store on the other side of Kwemeluk Pass.” Flooding and ivu (ice push) were observed by residents and visitors in the 1800s and early 1900s, but the November 26 and December 8 storms of 1931 caused the community to relocate to the current location NIAPB (2008). For this reason, flood estimates can only be made for events occurring after 1931.

1946-NOV-17 | no water level estimate

Reference	Source information used to estimate flood height
NIAPB (2008)	None

A “major fall flood” is estimated to have occurred around 1946 (NIAPB, 2008). This was likely the November 17, 1946, storm that caused flooding in Nome and other Norton Sound communities (Wise and others, 1981). An estimate cannot be made without more specific information about flood impacts from this storm.

1972-OCT-26 | 5.8 ± 0.5 ft MHHW

Reference	Source information used to estimate flood height
USACE (1993)	USACE survey uses community storm descriptions to estimate storm height relative to old school front door grating (table 4)
NIAPB (2005)	Provides original USACE Floodplain Management document from 1993 survey. No houses were flooded. Water was about 1.5 ft deep in the area of the new school and came to about 6 inches above the ground at the old BIA school.
NIAPB (2008)	Similar information to NIAPB (2005)
NIAPB (2017)	Same as NIAPB (2008)
DCRA (2006)	Published storm height estimate in NAVD88 GEOID96

The 1972 storm surge is considered the flood of record as of 1993 (USACE, 1993). The exact date is not specified, but this was likely the October 26, 1972, storm that caused flooding in Norton Sound (Wise and others, 1981) and Kotzebue (NOAA, 1972). USACE (1993) surveyed the reported flood height using a temporary benchmark that we converted to the current tidal datum (table 4). Our findings are consistent with DCRA (2006) that estimate the height to be 6.59 ft NAVD88 (GEOID96), which is 12.26 ft (3.74 m) NAVD88 (GEOID12B). Using the RSS of the uncertainty of the USACE measurement and the GNSS measurement, the still water estimate is 5.8 ± 0.5 ft MHHW.

1974-NOV-10 | 5.0 ± 1.3 ft MHHW

Reference	Source information used to estimate flood height
Wise and others (1981)	None
NOAA (1974)	Describes significant damage to beach property, and "five houses had minor water damage."

The November 1974 storm damaged many boats and caused minor water damage to five homes (NOAA, 1974). The DCRA (1979) map shows that the community had a similar layout to current day, with fewer homes in total. The first floor of the lowest residence measured by USACE (1993) is higher than the 1972 storm, suggesting that all residences are now elevated higher than they were in 1974. The USACE (1993) survey estimates that the lowest "log cabin" is 4.3 ± 0.6 ft MHHW (table 4). We assume this cabin was a residence in 1974 and use it to determine the minimum possible flood height to cause minor water damage to the homes that were in use at the time. Flooding of 4.1 ft MHHW can reach boats and beach property (table 1), supporting the description by NOAA (1974). The 1974 storm did not reach higher than the 1972 storm (5.8 ± 0.5 ft MHHW) because 1972 is considered the flood of record (USACE, 1993), so this serves as the upper boundary of possible flooding. The still water estimate is 5.0 ± 1.3 ft MHHW (table 6).

Table 6. Flood parameters used to estimate the November 10, 1974, storm. Uncertainty is calculated using the upper-lower bounds method.

Feature	Water between lowest cabin and 1972 flood
Feature represents	Highest water
Water level type	Still water
Estimate of height (ft MHHW)	4.3 to 5.8
Estimate error (ft)	0.6 and 0.5
Lower bound (ft MHHW)	3.7
Upper bound (ft MHHW)	6.3
Mean and uncertainty (ft MHHW)	**5.0 ± 1.3**

1979-NOV-23 | no water level estimate

Reference	Source information used to estimate flood height
DHS&EM (2008)	None

DHS&EM (2008) list Nunam Iqua as being impacted by this storm, but no further information is provided. A flood height estimate could not be made.

2004-OCT-19 | 7.2 ± 0.5 ft MHHW

Reference	Source information used to estimate flood height
NOAA (2004)	Damaged water intake and boardwalks
NIAPB (2005)	Considered a major flood
NIAPB (2008)	"… contaminated traditional sources of drinking water."
NIAPB (2017)	Damaged the water intake station, a boardwalk, and contaminated traditional sources of drinking water.
Carin Finch, oral commun., (2019)	Damaged smokehouses and water under some homes. People drove boats to Community Hall.

The October 2004 storm caused major impacts (NIAPB, 2008; NOAA, 2004). The freshwater source for drinking water was contaminated with saltwater. The pump itself is 3.5 ± 0.1 ft MHHW (fig. B9), but the depth of water needed to salinate the freshwater source is unknown. Water reached under a home at 4.9 ± 0.1 ft MHHW, but the total height above ground is not known (Carin Finch, oral commun., 2019). Residents drove and parked boats at the steps of Community Hall, so we estimate the water depth to be 2.5 ± 0.5 ft above ground level (Carin Finch, oral commun., 2019). The ground height at the base of the steps is 4.7 ± 0.1 ft MHHW (fig. 1; table B1). Only the Community Hall measurement provides an estimate of maximum flooding, so the estimated still water height is 7.2 ± 0.5 ft MHHW (table 7).

Figure 1. Elevation of the ground at Community Hall. Water was high enough to drive boats but did not reach the first floor.

Table 7. Flood parameters used to estimate the October 19, 2004, storm. Uncertainty is calculated using the RSS error.

Feature	Water on road
Feature represents	Highest water
Water level type	Still water
Estimate of height (ft MHHW)	7.2
Uncertainty of estimate (ft)	0.5
Uncertainty of GNSS (ft)	0.1
Mean and uncertainty (ft MHHW)	**7.2 ± 0.5**

2005-SEP-25 | 6.1 ± 0.5 ft MHHW

Reference	Source information used to estimate flood height
NIAPB (2008)	"In September 2005, there was less significant flooding [than in 2004] though water surrounded the tank farm and reached the Community Hall."
NIAPB (2017)	"A similar storm surge in 2005 (September 22-26) did not cause damage. High water that year surrounded the tank farm and reached the Community Hall."
Carin Finch, oral commun. (2019)	Residents had to wade through water to reach Community Hall
NOAA (2005)	None

This storm surge surrounded the tank farm and reached Community Hall but caused fewer impacts than the 2004 storm (NIAPB, 2008). The base of the 2019 tank farm embankment is 2.71 ft MHHW (fig. B5E; table B1). We do not know the height water reached above the base. The road in front of Community Hall is 5.1 ± 0.1 ft MHHW (fig. 2; table B1). We estimate water was between 0.5 and 1.5 feet above the road height because residents felt comfortable wading through it (Carin Finch, oral commun., 2019). This is lower than the 2004 flood, consistent with accounts. The September 2005 flood is estimated to have reached 6.1 ± 0.5 ft MHHW (table 8).

Figure 2. Elevation of the crown of the road in front of Community Hall. Water covered the road but was low enough to wade through in the September 2005 flood.

Table 8. Flood parameters used to estimate the September 25, 2005, storm. Uncertainty is calculated using the RSS error.

Feature	Water on road
Feature represents	Highest water
Water level type	Still water
Estimate of height (ft MHHW)	6.1
Uncertainty of estimate (ft)	0.5
Uncertainty of GNSS (ft)	0.1
Mean and uncertainty (ft MHHW)	**6.1 ± 0.5**

2008-MAY-24 | 4.7 ± 0.5 ft MHHW	
Reference	**Source information used to estimate flood height**
NIAPB (2008)	"In the spring of 2008, an atypical spring flood occurred due to the combination of a broken ice jam on the Yukon River, a south wind, and the high tides that occur after a full moon. The flooding mirrored the preliminary stages of a storm surge. [6 pictures provided of flooding] ... damage primarily to the boardwalk system."
NIAPB (2017)	"Although there was no reported damage, boats and nets stored on the river bank were in potential danger of being swept by the current or hit by ice."
Carin Finch, oral commun., (2019)	Photos provided by community https://maps.dggs.alaska.gov/photodb/search#sort=title%20desc&show=24&search=Nunam%20Iqua%202008%20May

The timing of the spring 2008 flood is considered atypical and thought to be a combination of high tides, setup, and raised river water levels due to ice-jam flooding (NIAPB, 2008). Several images are provided that show the extent of flooding (Carin Finch, oral commun., 2019). The road leading to the tank farm is 4.2 ± 0.1 ft MHHW (table B1) and appeared flooded (fig. 3), whereas the road in front of Community Hall was not flooded (5.1 ± 0.1 ft MHHW; fig. 2). Floodwaters reached the height of the boardwalks on Blackberry Street (fig. 4A). The boardwalks have since been replaced with a higher system, but we measured remnants of the old boardwalks (fig. 4B–D), averaging 2.8 ± 0.1 ft MHHW (table B1). The tank farm was surrounded by water but not flooded. We cannot use the tank farm to estimate the height, because it was replaced before the 2015 DSM. The road to the tank farm serves as the best estimate of a maximum visible still water height. We assume flooding could have reached up to 1 foot (0.5 ± 0.5 ft) above this visible water line to reach 4.7 ± 0.5 ft MHHW (table 9).

Figure 3. A. Road to tank farm partially flooded during the spring 2008 flood. Photo: Carin Finch. **B.** Elevation measurement at road crest in 2019. The photos are taken facing opposite directions.

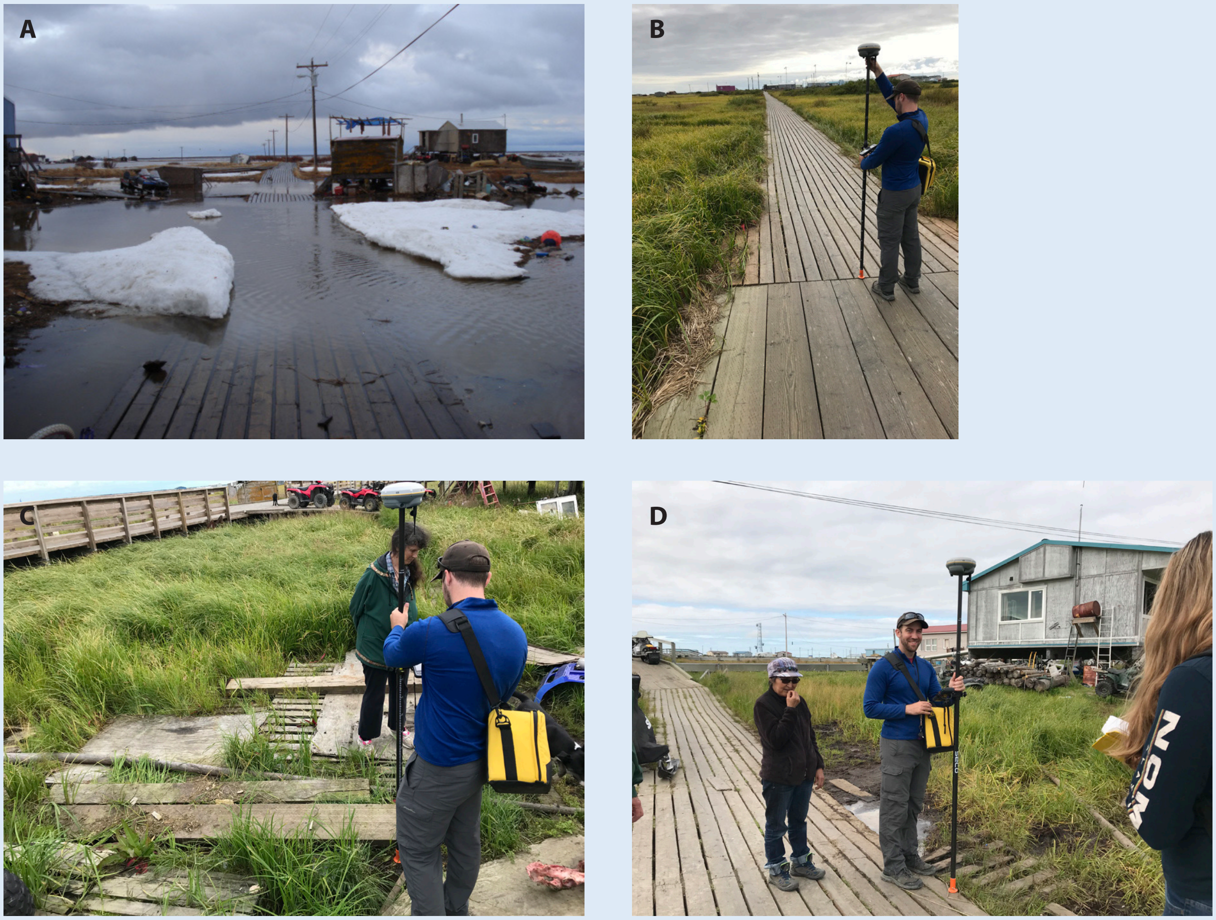

Figure 4. A. Flooding of the boardwalks in the Blackberry Subdivision in 2008. Photo: Carin Finch. **B.** Elevation measurement of the old boardwalk north of the subdivision (photo in opposite direction to A). **C, D.** Elevation measurement of old boardwalk in the subdivision.

Table 9. Flood parameters used to estimate the May 24, 2008, flood. Uncertainty is calculated using the RSS error.

Feature	Flooding of boardwalk
Feature represents	Highest water
Water level type	Still water
Estimate of height (ft MHHW)	4.7
Uncertainty of estimate (ft)	0.5
Uncertainty of GNSS (ft)	0.1
Mean and uncertainty (ft MHHW)	**4.7 ± 0.5**

2009-NOV-11 | 2.6 ± 0.5 ft MHHW

Reference	Source information used to estimate flood height
Janie (2009)	"... fall flood in Nunam Iqua on November 11 [2009]. You can see from the pictures that this flooding wreaked havoc on the Yukon River ice. The flooding brought in massive amounts of sea ice from the Bering Sea that unfortunately is still clogging the Yukon. Several people lost their fishing nets they had set under the ice and a couple of families even lost their boats during the flood."

This fall storm brought sea ice and river ice to the shore, destroying nets and boats. The damage may have been due to ivu (ice push) more than from high water. Only beach property was damaged, so we use the height of beach property (table 1) and consider that water could have reached up to 1 foot (0.5 ± 0.5 ft) higher to reach 2.6 ± 0.5 ft MHHW (table 10).

Table 10. Flood parameters used to estimate the November 11, 2009, flood. Uncertainty is calculated using the RSS error.

Feature	Flooding of beach property
Feature represents	Highest water
Water level type	Still water
Estimate of height (ft MHHW)	2.6
Uncertainty of estimate (ft)	0.5
Uncertainty of GNSS (ft)	0.1
Mean and uncertainty (ft MHHW)	**2.6 ± 0.5**

2011-NOV-09 | 4.1 ± 0.5 ft MHHW

Reference	Source information used to estimate flood height
NIAPB (2017)	Damage to water intake hose for water sewer system due to ivu
DHS&EM, unpub. data (2019)	Photos from storm https://maps.dggs.alaska.gov/photodb/#show=96&search=Nunam%20Iqua%202011
NOAA (2011)	Water exceeded bank, covered road to airport

The 2011 storm caused widespread flooding throughout Nunam Iqua, peaking at 3:15 pm local time on November 9th (NOAA, 2011). DHS&EM (unpub. data, 2019) took photos from an airplane that are date-stamped at November 9, 2011, at around 4:45 pm. Given the timing, we assume the photos represent peak flood levels. We compare three GNSS points taken near the visible high water line to estimate the height (fig. 5; table 11). We increase the uncertainty to 0.5 ft to consider that the observation may not be at peak flooding and the GNSS locations may not be directly on the water line. We estimate the November 2011 flood reached 4.1 ± 0.5 ft MHHW.

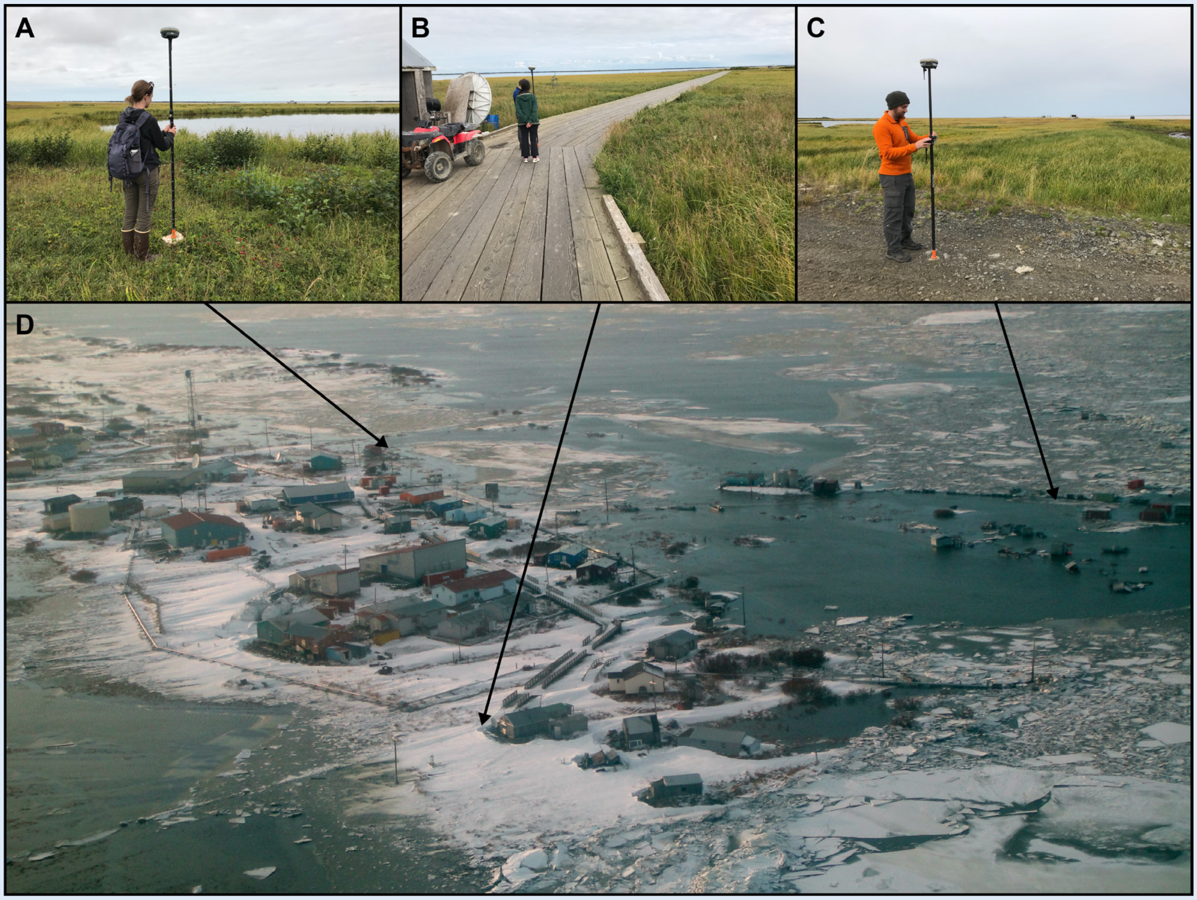

Figure 5. GNSS measurements (**A**, **B**, and **C**) used to estimate highest water from the November 2011 flood (**D**). A and C are taken at the high water line, while B is above the water. The aerial photo is taken around peak flooding by DHS&EM.

Table 11. Flood parameters used to estimate the November 9, 2011, flood. Uncertainty is calculated using the upper and lower bounds of the highest water estimates A and C.

Feature	Figure 5A	Figure 5B	Figure 5C
Feature represents	Highest water	Above flooding	Highest water
Water level type	Still water	Still water	Still water
Estimate of height (ft MHHW)	4.2	4.4	4.0
Uncertainty of estimate (ft)	0.1	0.1	0.1
Mean and uncertainty of highest water (ft MHHW)		**4.1 ± 0.2**	

2013-NOV-09 | 8.5 ± 1.0 ft MHHW

Reference	Source information used to estimate flood height
NIAPB (2017)	Highest water in memory, no homes flooded or sustained damage, four boardwalks washed away, as well as part of river access road. Water scattered dumpsite debris around dump.
Carin Finch, oral commun., (2019)	GPS survey where residents identified flood heights

The 2013 storm reached the highest water level in memory, possibly even higher than in 1972 (NIAPB, 2017). Floodwaters washed away four major boardwalks, portions of the road to the barge landing, and displaced solid waste from the dump site (NIAPB, 2017). We spoke with residents and measured observed peak flood heights with GNSS (table 12; fig. 6). The highest flood estimate is 8.5 ± 1.0 ft MHHW. Flooding reached between 7 and 8.5 ft MHHW along the north section of the community closest to the coast. Flood water indicators were at least 5.5 ft MHHW in all other parts of town. The November 2013 storm is estimated to have reached 8.5 ± 1.0 ft MHHW. See Other Flood Information section for a discussion on this storm surge flood event.

Table 12. Flood parameters used to estimate the November 9, 2013, flood. Uncertainty is calculated using the RSS of the estimate uncertainty and GNSS accuracy (0.1 ft).

Feature	Figure 6	Water Level Type	Height (ft MHHW)	Uncertainty (ft)
flood height above boardwalk	B	Still water	8.5	1.0
flood about 3 ft above ground	C	Still water	7.4	1.0
water entered hole	D	Still water	7.2	0.1
flood inside house	E	Still water	7.0	1.0
flood here was 2 ft above ground	F	Still water	6.6	1.0
flood height at porch step	G	Still water	6.1	0.5
flood height at porch step	H	Still water	5.9	0.5
flood height at porch step	I	Still water	5.8	0.5
flood crossed Causeway Road	J	Still water	5.5	0.5
flood height at porch step	K	Still water	5.5	0.5
flood height at boardwalk	L	Still water	5.5	0.5

Figure 6. GNSS measurements used to estimate highest water from the November 2013 storm. Panel A shows a map where the GNSS points (B to L) are collected, along with the estimated flood height. The flood was between 7 and 9 ft MHHW in the north (B to D) and 5 to 7 ft MHHW elsewhere.

2015-NOV-09 | 3.3 ± 1.3 ft MHHW

Reference	Source information used to estimate flood height
NIAPB (2017)	In 2015, there were 5 storm surge warnings during the fall freeze-up resulting in minor flooding but no significant damage.
NOAA (2015)	None

The November 2015 storm raised water levels 5 to 7 feet in Scammon Bay, about 50 miles south of Nunam Iqua (NOAA, 2015). NIAPB (2017) describe the flooding seen in Nunam Iqua as minor (NIAPB, 2017). We estimate that the flood reached between the minor and moderate flood category thresholds (table 1). The November 2015 storm is estimated to have reached 3.3 ± 1.3 ft MHHW (table 13).

Table 13. Flood parameters used to estimate the November 09, 2015, storm. Uncertainty is calculated using the upper-lower bounds method.

Feature	Flooding between minor and moderate levels
Feature represents	Highest water
Water level type	Still water
Estimate of height (ft MHHW)	2.1 to 4.1
Estimate error (ft)	0.1 to 0.5
Lower bound (ft MHHW)	2.0
Upper bound (ft MHHW)	4.6
Mean and uncertainty (ft MHHW)	**3.3 ± 1.3**

2019-AUG-03 | 3.6 ± 0.5 ft MHHW

Reference	Source information used to estimate flood height
Carin Finch, oral commun., (2019)	GPS survey where residents identified flood heights

The unusual timing of the August 2019 storm led to minor flood impacts because low-lying property was not secured for a storm surge (Carin Finch, oral commun., 2019). We surveyed storm height observations and indicators one week after the flood occurred (table 14; fig. 7). We consider these observations to have at least 0.5 ft uncertainty. The flood reached its highest point near the utilidor on the north side of the community (fig. 7C). Flooding was about 1 foot lower on the south side. We estimate the maximum still water height of the August 2019 flood is 3.6 ± 0.5 ft MHHW.

Table 14. Flood parameters used to estimate the August 3, 2019, flood. Uncertainty is calculated using the RSS of the estimate uncertainty and GNSS accuracy (0.1 ft).

Feature	Figure	Feature Represents	Water Level Type	Height (ft MHHW)	Uncertainty (ft)
Observed flooding at Blackberry Subd.	4C	Max.	Still water	2.6	0.5
Observed flooding at Blackberry Subd.	4D	Max.	Still water	2.7	0.5
Mud on marker	7A	Min.	still water	2.6	1.0
Wrack line	7B	Min.	still water	2.5	0.5
Ground at utilidor	7C	Max.	still water	3.6	0.5

Figure 7. GNSS measurements used to estimate highest water from the August 2019 flood. **A**. This aerial marker is nailed into the ground and was not disturbed by flooding, but mud was deposited onto it. **B**. A wrack line was left near the airport runway and river access road. **C**. Water reached the ground at this utilidor but did not go beyond.

OTHER FLOOD INFORMATION

DGGS installed two flood staffs in Nunam Iqua in August 2019. One is on a power pole between the old school grounds and residences on the northeast coast (fig. 8). The second staff is on a power pole on the northwest side of the school, between the building and Swan Lake (fig. 9). We can use a photo of the staff in floodwater to estimate the height of floods.

The results of the November 2013 storm survey show the storm setup component reached up to 3 feet above other peak flood level observations (table 12; fig. 6). When water is pushed onshore, its leading edge slows down due to friction with the ground and the elevation it must climb. Behind this slowdown, more water is still surging inland, causing a “pileup” of water. This is called setup and is what we estimate when we observe "still water" heights. Incoming waves can temporarily bring water further up a beach, resulting in "wave runup." However, Nunam Iqua is very flat, so the peak observed water height is likely not runup, just still water. Still water appears relatively flat, but it can have a broad "bubble" or ridge across the flooded area. The peak is where the pileup is greatest. Areas nearest the coast tend to experience greater setup, but the peak can occur further inland than the coastline. We choose to use the highest observation to communicate the storm height (rather than a mean or other statistic) for two reasons: (1) Most storms in this study have few data points and these points represent the highest observed flooding, so using the highest observation allows an equal comparison. (2) The peak setup location can occur elsewhere depending on many factors including storm direction, duration, intensity, friction with the ground surface, and overland flow paths. While we understand the 2013 storm did not reach 8.5 ft MHHW everywhere, we do not know whether a similar storm could reach this peak anywhere in the community. One elder said this was the highest storm ever observed at her house (Maggie Stronghart, oral commun., 2019). Water reached 5.5 ft MHHW, consistent with nearby observations. However, multiple observations within 300 feet reached at least 7 ft MHHW. This example shows the dynamic nature of storm surge that makes height estimates and forecasts less certain and more challenging to communicate.

ACKNOWLEDGMENTS

This work was funded in part by the National Oceanic & Atmospheric Administration Office of Coastal Management through the Digital Coast Fellowship, the State of Alaska, and the Alaska Ocean Observation Systems. Significant contributions to this work came from the observations of individuals in the community of Nunam Iqua. We thank Carin Finch and Maggie Strongheart for generous support and assistance in collecting this flood information.

Figure 8. Flood staff on power pole northeast of the old school, in a field by the old basketball court. The 0 mark on the staff is 3.9 ft MHHW (table B1).

Figure 9. Flood staff on power pole northwest of the current school, between the school and Swan Lake. The 0 mark on the staff is 5.0 ft MHHW (table B1).

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APPENDIX A: STORM-RELATED ACCOUNTS

There are many written reports that contain information pertaining to storm-driven flooding in Nunam Iqua. Reports may be difficult to find in the future as their online linked location can change. This appendix provides the exact relevant text from each source used in this report to preserve the information. Any added commentary or summary information is enclosed by brackets.

Alaska Division of Community & Regional Affairs (DCRA), 2006, Community profile map, Nunam Iqua: Department of Commerce, Community, and Economic Development.

Flood Data - The U.S. Army Corps of Engineers (USACE) report "Alaska Communities Flood Hazard Data 1993", has published flood of record which occured [sic] in 1972 with a flood elevation of 92.7 feet (6.59 feet based upon this maps vertical control).

CE2 Engineers, Inc., 2002, Feasibility study for the construction of a traffic conveyance structure across Swan Lake: CE2 Engineers, Inc., Anchorage, Alaska, 67 p.

[Boardwalk was only mode of transport to airport, flooded by spring melt and by fall high water. Boardwalk runs on coast-side of Swan Lake]

Division of Homeland Security & Emergency Management (DHS&EM), 2008, Alaska weather-related disasters 1978 – 2008: State of Alaska Department of Military and Veteran Affairs, 62 p.

80-06. West Coast Storm, November 23, 1979 – A major sea storm on the west coast of Alaska caused extensive damage in 14 villages in the area. The governor proclaimed a disaster emergency effective from Sheldon Point to Togiak….

Janie, 2009, Fall flood = help needed in Nunam Iqua again this winter: Anonymous Bloggers [website]: found at https://anonymousbloggers.wordpress.com/2009/11/26/ann-strongheart-fall-flood-help-needed-in-nunam-iqua-again-this-winter/

… fall flood in Nunam Iqua on November 11 [2009]. You can see from the pictures that this flooding wreaked havoc on the Yukon River ice. The flooding brought in massive amounts of sea ice from the Bering Sea that unfortunately is still clogging the Yukon. Several people lost their fishing nets they had set under the ice and a couple of families even lost their boats during the flood.

NOAA Storm Data Reports:

November, 1974:

Sheldon Point: Nets, thirteen boats, three motors, drums of gasoline, and five houses had minor water damage. Estimate approximately 17 claims for unmet losses.

October, 2004:

Nunam Iqua: Boardwalks were damaged and water pipeline serving the village's water needs was damaged; holding tank was emptied by early December creating a water crisis due to lack of fresh water.

September, 2005:

Damage amounts include $1000 claimed by Nunam Iqua under Public Assistance…

November 8–10, 2011:

Water levels also rose significantly at Nunam Iqua and at 1515AKST [on the 9th] the water level crested at the top of the river bank. There were reports of over flow covering the roadway to the airport that cut off the village from the airport.

Nunam Iqua Advisory Planning Board (NIAPB), 2005, Nunam Iqua Strategic Plan for Comprehensive Community Development: Nunam Iqua Advisory Planning Board, 643 p.

5.1 History … There was a Northern Commercial Company (NC) store across the river and a fishery on Munsen Island. After the big flood, the NC store moved to Nunam Iqua on higher ground.

5.7 Flood – FEMA does not list a flood of record for Nunam Iqua, but does make note of a flood in 1972, in which water was reported to be about 1.5 feet deep in some areas of the community. Although these floodwaters covered much of the ground, no houses were reported flooded. … The danger of fall flooding is significantly increased if ice is present. … The Corps of Engineers established the 100-year flood elevation as 92.7 ft during a 1993 survey, using the grating at the front door of the Lower Yukon School District High School (which is at 14.3' Mean Sea Level). The first floor of any building constructed would need to be elevated to 8 feet MSL to be the required 1 foot above the flood of record (the 1972 flood).

10.1.10 NITP Tank Farm

…The [fuel] dispenser location blocks the gravel road traffic and is subject to flooding.

10.6.2 Disaster Plans

… A major flood occurred in October 2004 causing damage in the community.

…Recently constructed buildings have been elevated four feet above the ground surface.

[Provides original USACE Floodplain Management document from 2000 that includes TBM survey data] Water was reported to be about 1.5 ft deep in the area of the new school and came to about 6 inches below the skirting of the old BIA school during the 1972 flood. (The school was reported to be settling, and the skirting on September, 1993, was about 1 foot above the ground.) Water covered the [sic] much of the land, but no houses were reported flooded. The floodplain is extremely broad so that a large increase in flood flow would result in a small increase in flood elevation.

Nunam Iqua Advisory Planning Board (NIAPB), 2008, Nunam Iqua Hazard Mitigation Plan 2008: Nunam Iqua Advisory Planning Board, 47 p.

[Airport was improved in 2005]

Historical disasters – Eugene Pete Sr., a well respected elder, talked about a fall flood that happened many years ago with high winds in the black River area. An Ivu [ice push] pushed the ground up into high mounds now covered with willows. It was so windy it was necessary to crawl. Flooding stopped when the winds died. …

6.4.1 Severe Weather

During a Storm Surge, the high water in Kwemeluk Pass flows over the river bank, into the village as shown by the red arrows in the Fall Storm Surge Flooding Map. Low lands are subsequently filled similar to Nunam Iqua Spring Flooding Map. Once the lowlands fill, the water flows back into Swan Lake as shown by the blue arrows. … The potential exists that the entire community could flood from a storm surge of extreme magnitude.

[Fall Storm Surge Flooding Map]

[Discusses saltwater contamination at water source, Kwemeluk Pass, which causes water to be untreatable at the water plant]

Previous occurrences: … [discusses general storm surge factors] Fox (catholic missionary) described major flooding on Thanksgiving and again on December 8, 1931, at Akulurak on Kwemeluk Pass. … Buildings first appeared at Nunam Iqua after the 1931 fall flooding wiped out the saltry and store on the other side of Kwemeluk Pass. … Another major fall flood was reported by an elder and estimated to have taken place in 1946. The flood of record used by the US Army Corps of Engineers occurred in 1972. Data from this flood was used to determine that to meet federal standards, all structures must be elevated to 8' MSL. In October 2004 a storm surge brought water into the village and contaminated traditional sources of drinking water. In September 2005, there was less significant flooding though water surrounded the tank farm and reached the Community Hall.

6.5.2 Flooding

Previous Occurrences: … In the spring of 2008, an atypical spring flood occurred due to the combination of a broken ice jam on the Yukon River, a south wind, and the high tides that occur after a full moon. The flooding mirrored the preliminary stages of a storm surge. [6 pictures provided of flooding] … damage primarily to the boardwalk system.

9.5 Flood and Erosion Vulnerability for Housing and Facilities

… Elevations [of structures in town, including the MSL value used to discuss the USACE survey for 1972 flood] were determined using a Garmin GPSmap76 and extrapolating from the COE school measurement. [Table of elevations of a few structures]

Nunam Iqua Advisory Planning Board (NIAPB), 2017, Nunam Iqua Hazard Mitigation Plan Update—2017: Nunam Iqua Advisory Planning Board, 52 p.

Hazards that threaten Nunam Iqua

1. Severe Weather- Coastal Storms, Storm Surge, Ice Override, High Winds, and Ice Storms are particularly hazardous to travelers and contribute to infrastructure failure. Federal Disasters in 2004, 2011, and 2013 have noted specific damage done by high winds and over the bank flooding during the fall.

5.1.1 Severe Weather

Previous Occurrences: [same info as from 2008 HMP]

A Federal Declaration of Disaster (DR-1571-AK-2004) occurred after a 2004 (October 18-24) storm surge that brought water into the village damaging the water intake station, a boardwalk, and contaminating traditional sources of drinking water. Water was flown in for residents. A similar storm surge in 2005 (September 22–26) did not cause damage. High water that year surrounded the tank farm and reached the Community Hall.

In 2011 (November 8–13), … a storm surge was accompanied by an ice override which damaged the water intake hose and piled up on the water intake station. A glycol leak at that site caused the community water [and] sewer to freeze. Accompanying high winds caused damaged to the power distribution line.

[November 5–14, 2013] … was due to severe storm, straight line winds and flooding due to a storm surge. High water and ice inundated the village washing away four major boardwalks, portions of the river access road, and knocking out power to the airport runway and waterplant. Debris was scattered throughout the village blocking transportation routes. Water flushed over the dumpsite and displaced the solid waste outside the designated site. In 2015 there were 5 storm surge warnings during the fall freeze-up resulting in minor flooding but no significant damage.

[Photos from 2013 storm]

10.1 Progress on 2008 Mitigation Projects

[From NIAPB, 2008] Houses not on piling and potentially vulnerable to first floor flooding include: Houses #38 #40 #41-#42 #43 and all houses designated X in the listing for a total of 8 houses. Assist residents in applying for alternative housing. [Progress since 2008] 2 houses have been torn down. The other houses did not sustain damage during the 2013 flood which had the highest water in memory.

U.S. Army Corps of Engineers, 1993, High water elevation identification: Alaska District Corps of Engineers—Flood Plain Management Services, 2 p.

Date of Visit: 24 September 1993

Historical Record of High Water: The town is a relatively new town, as there is no record of it prior to the 1950 U.S. Census. The flood of record is the 1972 flood. Flood water was said to be about 1.5 feet deep in the area of the new school and came to about 6 inches below the skirting of the old BIA school. (The school was said to be settling, and the skirting is now about 1 foot above the ground.) Water covered much of the land, but it was said that no houses were flooded. The flood plain is extremely broad so that a large increase in flood flow would result in a small increase in flood elevation. The 1972 flood represents the 100-year flood, or Base Flood Elevation.

[Lists temporary benchmark survey that we copied to table 4]

U.S. Army Corps of Engineers, 2009, Erosion information paper—Nunam Iqua (Sheldon Point), Alaska: Alaska Baseline Erosion Assessment, 4 p.

Potential Damages: Active erosion is occurring less than 100 feet from the community water intake pump. Other structures and facilities between 100 and 500 feet from erosion include some homes, water lines, food storage areas, drying racks, smoke houses, public buildings, the marine header, fuel dispenser, tank farm, the airport runway and airport facilities. The city has an FEMA approved Hazard Mitigation Plan for the community. The Northern Commercial Company and Alaska Commercial Company had a store in Nunam Iqua that was destroyed by erosion.

Wise, J.L., Comiskey, A.L., and Becker, R., Jr., 1981, Storm surge climatology and forecasting in Alaska: Anchorage, Alaska, Arctic Environmental Information and Data Center, University of Alaska, 32 p.

[November 10–12, 1974 caused $20,000 in damages to Sheldon Point]

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APPENDIX B: FLOOD CATEGORY CALCULATION FIGURES

DGGS staff visited Nunam Iqua in August 2019 and surveyed points relevant to the flood history and category study. The Trimble R10 base station was installed over the benchmark near the airport apron stamped SXP A 2015 (NGS, 2021). Points were surveyed with the Trimble R8s receiver between August 10 to 12, 2019. Horizontal coordinates are provided in WGS84 latitude and longitude and NAD83 (2011) UTM Zone 3N easting and northing. Elevations are provided in orthometric height (meters above NAVD88 [GEOID12B]) and converted to feet above local MHHW using the tidal datum by NOAA CO-OPS (2021). MHHW is 6.50 ft (1.98 m) above NAVD88. Uncertainty is expressed using ± accuracy at a 95 percent confidence interval.

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Table B1. Coordinates and heights of surveyed features. Latitude and longitude are in decimal degrees WGS84. Northing and easting are in meters NAD83 (2011) UTM Zone 3N. Orthometric heights are in meters above NAVD88 (GEOID12B).

Feature	Figure	Latitude	Longitude	Northing	Easting	Ortho. Height (m)	Height above MHHW (ft)
Ground at old school	B1	62.52638904	-164.8511936	6933418.373	507822.888	3.63	5.41
Old school grating	B1	—	—	—	—	5.96	13.05
School NE corner	B2	62.52638904	-164.8511936	6932831.578	507660.445	5.957	13.05
Runway	B4	62.51898982	-164.8491212	6932007.484	507769.041	5.269	10.79
Tank farm SE corner	B5A	62.53241341	-164.8508110	6933502.794	507678.590	4.493	8.24
Tank farm SW corner	B5B	62.53245933	-164.8510961	6933507.876	507663.904	4.527	8.36
Tank farm NW corner	B5C	62.53270671	-164.8509026	6933535.460	507673.800	4.526	8.35
Tank farm NE corner	B5D	62.53265863	-164.8506182	6933530.137	507688.445	4.506	8.29
Tank farm pad base	B5E	62.53235893	-164.8507793	6933496.729	507680.235	2.807	2.71
Wastewater lagoon	B6	62.52322123	-164.8561211	6932478.080	507407.607	3.923	6.37
Airport apron	B7	62.52411956	-164.8457112	6932579.399	507943.236	4.236	7.40
Water intake platform	B9	62.53299950	-164.8460122	6933568.670	507925.386	3.060	3.54
Ground near riverbank	B12A	62.52789766	-164.8427140	6933000.686	508096.492	2.621	2.10
Ground near riverbank	B12B	62.53337473	-164.8481165	6933610.218	507817.000	2.626	2.12
Community Hall ground	1	62.53122792	-164.8507284	6933370.730	507683.143	3.419	4.72
Community Hall road center	2	62.53128241	-164.8508608	6933376.784	507676.319	3.543	5.13
Road to barge landing	3	62.53212780	-164.8502158	6933471.045	507709.295	3.269	4.23
Blackberry Sub. boardwalks	4B	62.53052535	-164.8435415	6933293.332	508053.192	2.851	2.86
Blackberry Sub. boardwalks	4C	62.52865261	-164.8454053	6933084.460	507957.776	2.782	2.62
Blackberry Sub. boardwalks	4D	62.52726559	-164.8471851	6932929.716	507866.540	2.799	2.69
Ground near home	5A	62.53115555	-164.8530309	6933362.395	507564.669	3.271	4.24
Barge landing	5B	62.53212472	-164.8455740	6933471.265	507948.167	3.315	4.38

Table B1, continued. Coordinates and heights of surveyed features.

Feature	Figure	Latitude	Longitude	Northing	Easting	Ortho. Height (m)	Height above MHHW (ft)
Boardwalk	5C	62.53331484	-164.8502658	6933603.287	507706.411	3.205	4.02
Water above boardwalk	6B	62.53216697	-164.8460930	6933475.908	507921.449	4.560	8.5
3 ft of water at house	6C	62.53154052	-164.8502578	6933405.613	507707.283	4.240	7.4
Heater exhaust	6D	62.53113738	-164.8528003	6933360.398	507576.540	4.160	7.2
House platform	6E	62.52994516	-164.8513562	6933227.743	507651.166	4.110	7.0
2 ft of water by home	6F	62.52951532	-164.8541506	6933179.528	507507.459	3.990	6.6
Porch step of 2013 flood	6G	62.52719523	-164.8472900	6932921.864	507861.158	3.848	6.1
Porch step of 2013 flood	6H	62.52905216	-164.8557210	6933127.746	507426.755	3.770	5.9
Porch step of 2013 flood	6I	62.52964062	-164.8534313	6933193.571	507544.448	3.735	5.8
Causeway Road	6J	62.52758020	-164.8500313	6932964.423	507719.964	3.664	5.5
Porch step of 2013 flood	6K	62.52865031	-164.8454600	6933084.198	507954.959	3.660	5.5
Boardwalk	6L	62.52981988	-164.8528800	6933213.607	507572.776	3.643	5.5
Mud on marker	7A	62.52365865	-164.8412100	6932528.611	508175.065	2.775	2.61
Wrack line	7B	62.52340088	-164.8411520	6932499.901	508178.119	2.727	2.45
Ground at utilidor	7C	62.53002427	-164.8540351	6933236.243	507513.277	3.079	3.61
Flood staff by old school	8	62.53210201	-164.8468305	6933468.581	507883.512	3.162	3.87
Flood staff near new school	9	62.52635211	-164.8522507	6932827.338	507606.047	3.500	4.99

Figure B1. The elevation of the abandoned high school grate is measured to compare with the survey by USACE (1993). The GNSS receiver could not get adequate satellite coverage at the grating, so the height of this level pipe above is measured, and the height between the pipe and the grating is added to get the height of the grating. The elevation of the ground surveyed in the photo is 5.41 ft MHHW (3.63 ± 0.04 m NAVD88). The top of the pipe is 4.20 ft (1.28 m) above the ground. The grating is 3.44 ft (1.05 m) above the pipe. We estimate this method has a vertical uncertainty of 0.13 ft (0.04 cm) in addition to the 0.10 ft (0.03 m) uncertainty from GNSS. Using the RSS, this makes the height of the grating 13.1 ± 0.1 ft MHHW (5.96 ± 0.05 m NAVD88).

Figure B2. Elevation point measured at the northeast corner of the school.

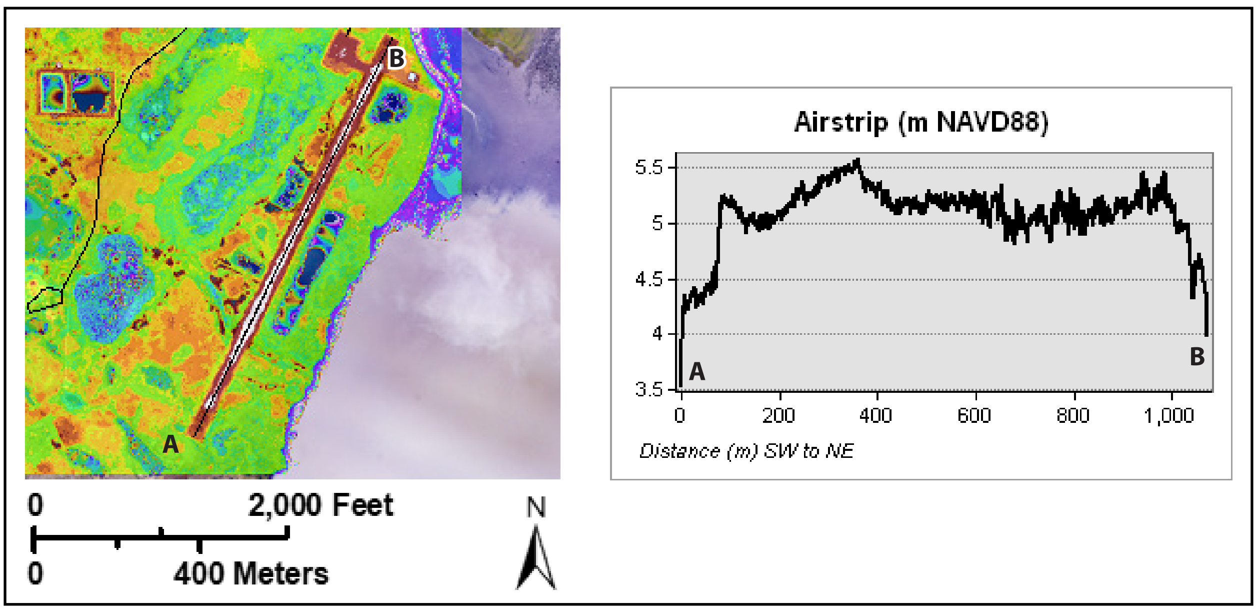

Figure B3. (Left) Elevation map of airstrip with cold colors representing low elevation and hot colors high elevation displayed over imagery. The long brown and white feature is the airport runway with a black elevation profile line drawn down the center. (Right) Elevation profile of airstrip shows mean height of 10.5 ± 1.1 ft MHHW (5.17 ± 0.33 m NAVD88) in the section before the drop-offs at either end.

Figure B4. Elevation of highest visible point on airport runway.

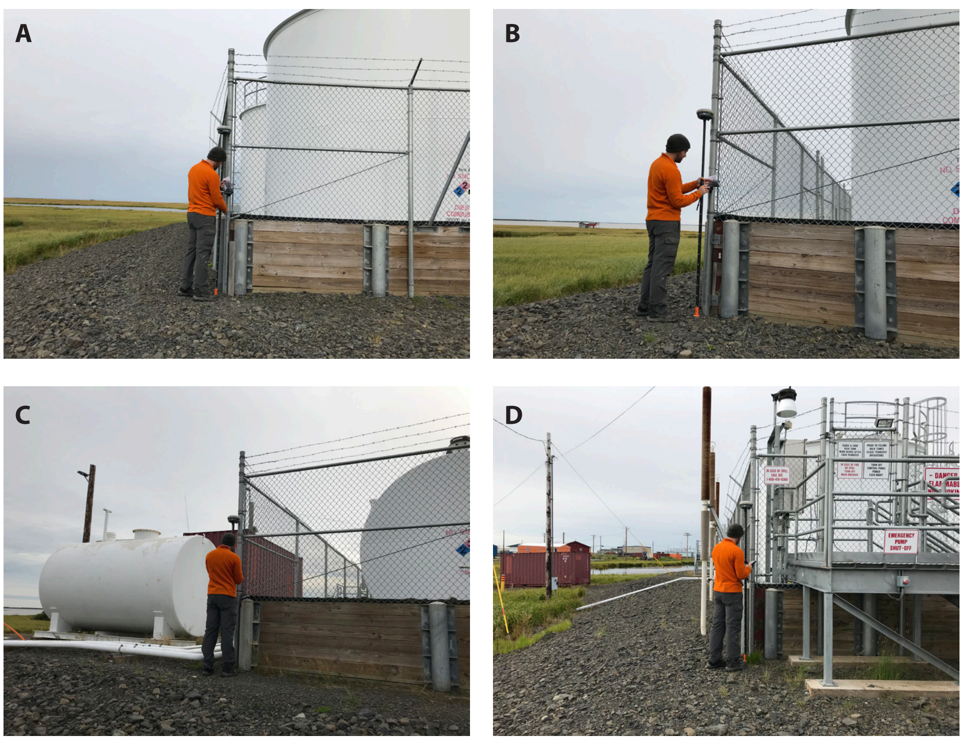

Figure B5. The base of the tank farm fence is measured at the (**A**) southeast, (**B**) southwest, (**C**) northwest, and (**D**) northeast corners. The average height is 8.3 ± 0.2 ft MHHW (4.51 ± 0.05 m) NAVD88. The gravel pad (**E**) is about 5.6 ft tall. The top of the wood wall is 3.0 ft above the gravel pad.

Figure B6. The low point on the east side of the wastewater lagoon boundary where water can travel into the lagoon.

Figure B7. GNSS base station on airport apron.

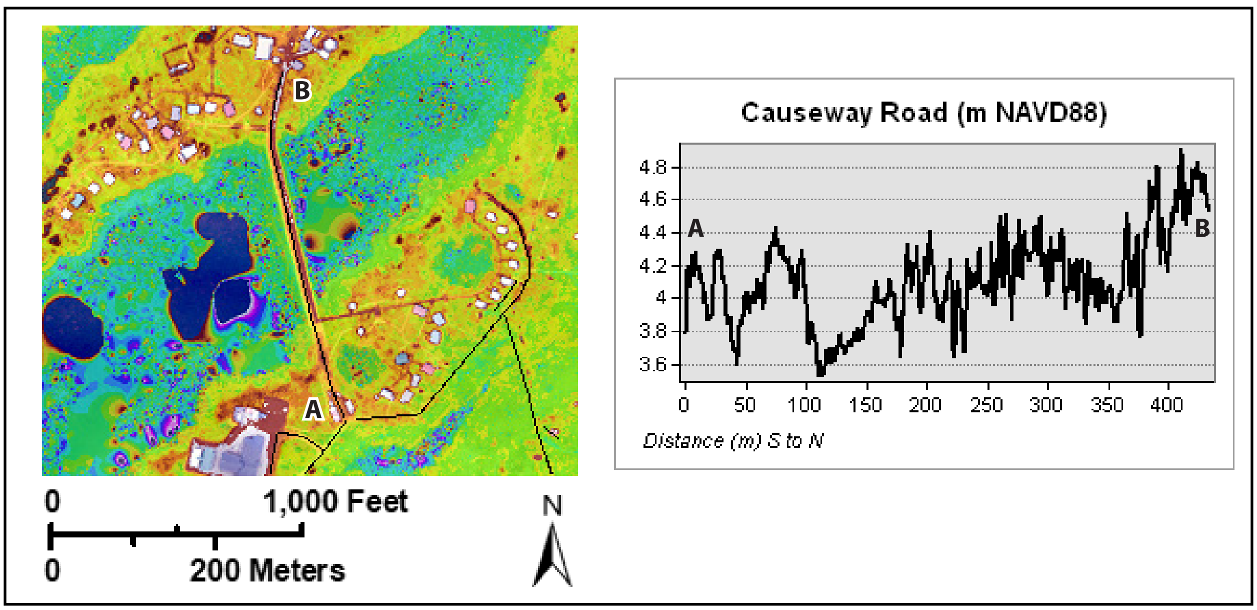

Figure B8. (Left) Elevation map of Causeway Road shows lower section in the south. The raised portion on the east side of the road is a water line. (Right) Elevation profile of the road shows that the majority of the road is 6.8 ± 1.3 ft MHHW (4.04 ± 0.41 m NAVD88).

Figure B9. The water intake pump platform is 3.5 ± 0.1 ft above MHHW (4.04 ± 0.04 m NAVD88).

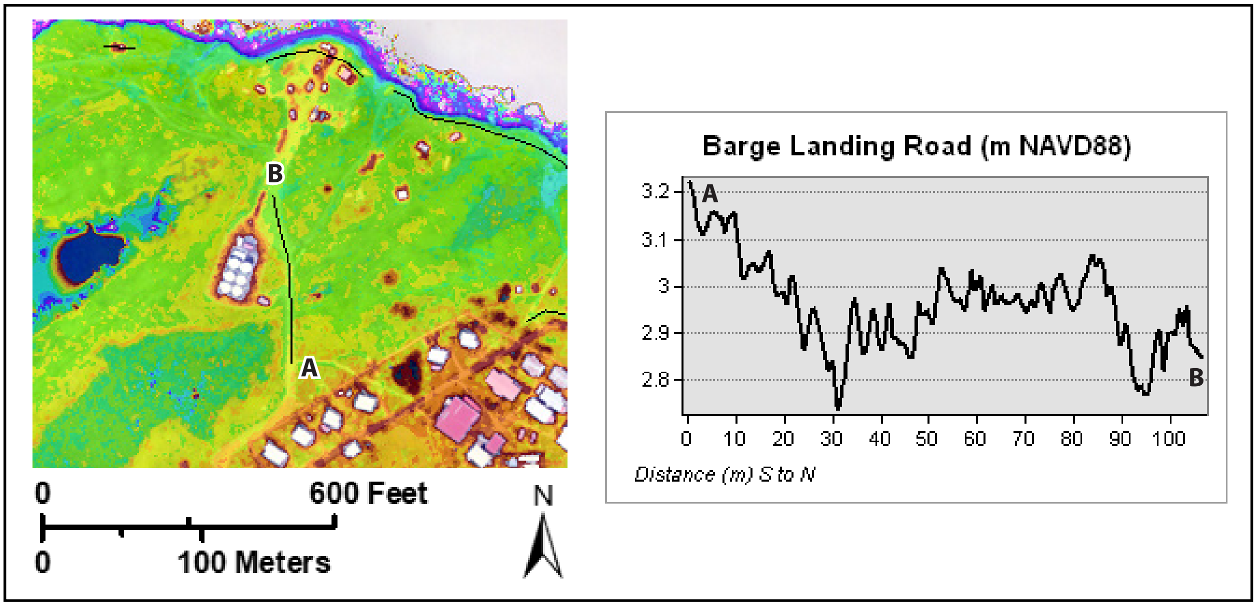

Figure B10. (Left) Elevation model showing lowest section of only road to barge landing and fuel tanks in green. (Right) Elevation profile of road averages 3.2 ± 0.5 ft MHHW (2.94 ± 0.15 m NAVD88).

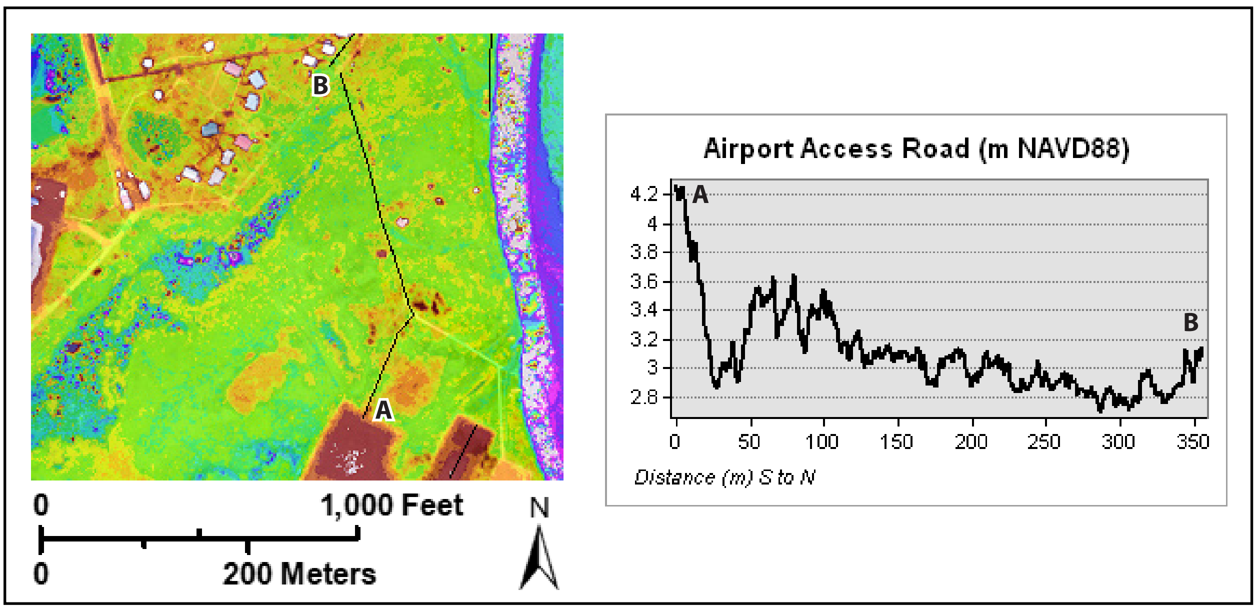

Figure B11. (Left) elevation map with access boardwalk to airstrip annotated in black. (Right) elevation profile shows that the boardwalk is 3.5 ± 1.3 ft MHHW (3.1 ± 0.4 m NAVD88).

Figure B12. Ground elevations near the riverbank on the north shore (**A**) and the east slough (**B**) average 2.1 ± 0.1 ft MHHW (2.61 ± 0.04 m NAVD88).