Report of Investigation 2025-5

COASTAL FLOOD IMPACT ASSESSMENT FOR KIVALINA, ALASKA

Keith C. Horen, Jessica E. Christian, and Nora M. Nieminski

View of Kivalina, Alaska, taken with an Uncrewed Aerial Vehicle by Nora Nieminski in 2023.

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

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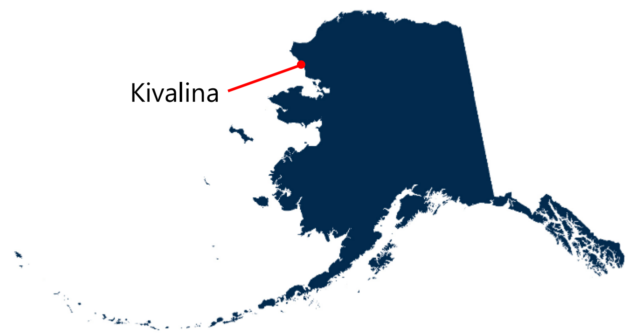
COASTAL FLOOD IMPACT ASSESSMENT FOR KIVALINA, ALASKA

Keith C. Horen[1], Jessica E. Christian[2], and Nora M. Nieminski[1]

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 Kivalina, 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) are defined by the National Weather Service (NWS) and described in detail by Horen 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 Kivalina is located at the southeastern tip of an 8-mile-long barrier island between the Chukchi Sea and Kivalina Lagoon, the latter of which is fed by the Wulik River. According to the 2016 Kivalina Strategic Management Plan (Alaska Division of Community and Regional Affairs [DCRA], 2016), "longer ice-free periods during recent years… has left Kivalina facing significant risks from storms, such as flooding and erosion." Glenn Gray and Associates (2010) found that, while "government agencies are concerned that a '100-year flood' could inundate Kivalina," estimates of this water height vary greatly. A newly constructed evacuation road was completed in 2022, connecting the community to the mainland and providing a safe route to refuge in case of emergency. Although the first-floor heights of many homes are now higher than in the past, floods reaching the height of historical events would still have similar impacts today.

Three disaster declarations (2002, 2004, 2005) have been issued for flooding in Kivalina (Federal Emergency Management Agency [FEMA], 2015; DCRA, 2016). Based on research done for this report, Kivalina experienced at least 12 flood events between 1970 and 2024 (nine from storm surge, one due to rainfall, one associated with blizzard conditions, and one of unknown origin). We estimate the peak still water height for 10 of these flood events, categorizing nine as minor and one as major. The highest recorded flood occurred in September 1970, reaching a still water height of 8.5 ft (2.58 m) MHHW.

DATA

DGGS used geospatial data to assess infrastructure impacts and estimate flood heights from various sources of evidence (e.g. photographs, personal accounts, official reports). We used Esri's ArcGIS Pro version 3.2.0 to map and process 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 four orthoimages (table 2) are available for Kivalina. Aerial imagery was collected in 2016, 2022, and 2023 and used to create digital surface models (DSM) and orthoimagery derived from photogrammetric structure from motion (SfM) processing (Nolan and others, 2022; Horen and Siemsen, 2022; Horen and Nieminski, 2024). In 2017, aerial imagery was collected and orthorectified by the National Geodetic Survey (NGS, 2024). Topographic-bathymetric (topobathy) light detecting and ranging (lidar) data were collected by the U.S. Army Corps of Engineers (USACE) in 2021, from which a topobathy DEM (TBDEM) was derived (Office of Coastal Management [OCM], 2024). Historical aerial imagery collected in 1979 is available from earthexplorer.usgs.gov.

Where first-floor height data were unavailable (e.g., unoccupied buildings, some facility-attached infrastructure, and private property), we extracted heights from the 2023 DSM if discernable from the 2023 SfM model, orthoimagery, or DSM (e.g., decking at entrances to buildings, visible platforms extending from building edges). All DEM and orthoimagery will be referenced in this report by the names assigned in tables 1 and 2.

First-Floor Survey

CRW Engineering Group, LLC completed a field survey of the first-floor heights of occupied buildings in Kivalina in March 2020 (app. A). These data were collected and reported in the North American Vertical Datum 1988 with GEOID12B applied (NAVD88 [GEOID12B]) in U.S. survey feet (usft). The reported vertical accuracy of these data is ± 0.1 ft (0.04 m). DGGS spatially joined these first-floor heights to building footprints digitized from the 2023 orthoimagery. This survey will be referenced in this report as the 2020 first-floor survey.

GNSS Survey

DGGS performed a Global Navigation Satellite System (GNSS) survey between August 21 and August 23, 2023, during a visit to Kivalina (app. B).

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

	2016 DSM	2021 TBDEM	2022 DSM	2023 DSM
Collection date	2016-AUG-29	2021-JUN-27	2022-JUN-07	2023-AUG-21 & 23
Elevation type	Photogrammetric SfM	Topobathy Lidar	Photogrammetric SfM	Photogrammetric SfM
Vertical datum	NAVD88 (GEOID12B)	NAVD88 (GEOID12B)	NAVD88 (GEOID12B)	NAVD88 (GEOID12B)
Ground sample distance	0.7 ft (0.20 m)	3.3 ft (1.00 m)	0.1 ft (0.03 m)	0.1 ft (0.03 m)
Accuracy	1.2 ft (0.38 m)	0.7 ft (0.20 m)	0.3 ft (0.08 m)	0.3 ft (0.08 m)

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

	2016 Orthoimagery	2017 Orthoimagery	2022 Orthoimagery	2023 Orthoimagery
Collection date	2016-AUG-29	2021-JUN-28 to 2021-JUL-14	2022-JUN-07	2023-AUG-21 & 23
Ground sample distance	0.7 ft (0.20 m)	1.1 ft (0.35 m)	0.1 ft (0.03 m)	0.1 ft (0.03 m)

The purpose of this survey was to collect community reports and HWM data related to historical flooding, as well as first-floor heights of buildings constructed after the 2020 first-floor survey was completed (app. A). These data were collected in the NAVD88 (GEOID12B) vertical datum in meters (m) and reported in feet (ft). The vertical accuracy of these data is ± 0.2 ft (0.07 m). This survey will be referenced in this report as the 2023 survey.

Water Level Sensor

DGGS installed a Stilltek (Stillwater Technologies LLC) iGage radar water level sensor in Kivalina on June 7, 2022. The sensor is attached to the bridge over the Kivalina Lagoon that connects the village to the mainland (fig. 1). Data collected by this sensor, updated hourly, are available from Alaska Water Level Watch at portal.aoos.org/#metadata/119626/station/data. The vertical accuracy of these data is ± 0.3 ft (0.09 m).

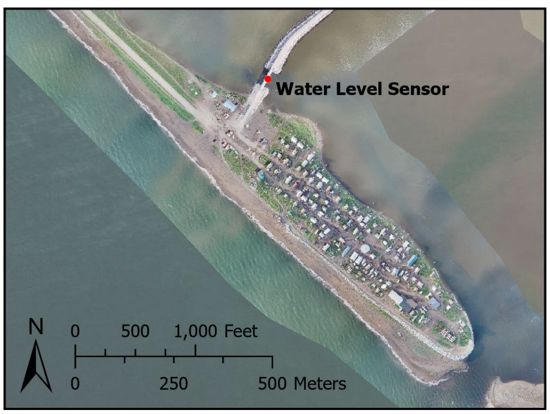


Figure 1. Location of Stilltek iGage radar water level sensor in Kivalina, Alaska.

The National Oceanic and Atmospheric Administration (NOAA) Center for Operational Oceanographic Products and Services (CO-OPS) installed a Water Log H-355 Gas Purge System water level sensor on August 30, 2003, at Red Dog Dock, located approximately 16 miles (26 kilometers [km]) southeast of Kivalina (fig. 2). Data collected by this sensor, updated at 6-minute intervals, are available from tidesandcurrents.noaa.gov/waterlevels.html?id= 9491094. The vertical accuracy of these data is ± 0.1 ft (0.03 m).

DGGS performed a comparative analysis of the water level sensor data at Kivalina and Red Dog Dock during two overlapping periods of time (app. C), allowing us to establish a method of adjustment in order to utilize the Red Dog Dock data to estimate water levels at Kivalina.

Vertical Datums

Local tidal datums (table 3) for Kivalina are described by NOAA CO-OPS tide station 949 1253 available from tidesandcurrents.noaa.gov/stationhome.html?id=9491253. Local tidal datums (table 4) for Red Dog Dock are described by NOAA CO-OPS tide station 949 1094 available from tidesandcurrents.noaa.gov/stationhome.html? id=9491094.

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 minor, moderate, and major (NWS, 2016). Definitions for these categories in the NWS guidance specific to Alaska are provided in the form of statements regarding flooding 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 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 and others, 2024).

Short definitions for each flood impact category are listed below and are explained in greater detail by Horen and others (2024). Table 5 provides a list of key infrastructure heights and the risk categories they

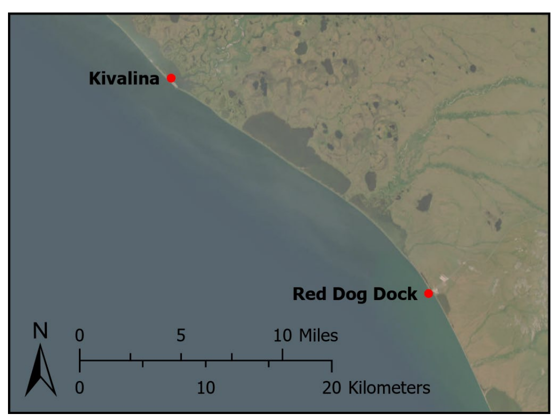


Figure 2. Locations of Kivalina, Alaska, and Red Dog Dock.

Table 3. Local tidal datums for Kivalina, Alaska (NOAA CO-OPS tide station 949 1253).

Tidal Datum	Abbreviation	ft MHHW	m MHHW	ft NAVD88 (GEOID12B)	m NAVD88 (GEOID12B)
Mean Higher High Water	MHHW	0.0	0.00	3.5	1.07
Mean High Water	MHW	-0.1	-0.04	3.4	1.03
Mean Sea Level	MSL	-0.5	-0.14	3.0	0.93
Mean Tide Level	MTL	-0.5	-0.14	3.0	0.93
Mean Low Water	MLW	-0.8	-0.25	2.7	0.82
Mean Lower Low Water	MLLW	-0.9	-0.28	2.6	0.79
North American Vertical Datum 1988 (GEOID12B)	NAVD88 (GEOID12B)	-3.5	-1.07	0.0	0.00

Table 4. Local tidal datums for Red Dog Dock, near Kivalina, Alaska (NOAA CO-OPS tide station 949 1094).

Tidal Datum	Abbreviation	ft MHHW	m MHHW	ft NAVD88 (GEOID12B)	m NAVD88 (GEOID12B)
Mean Higher High Water	MHHW	0.0	0.00	3.8	1.16
Mean High Water	MHW	-0.1	-0.04	3.7	1.11
Mean Tide Level	MTL	-0.5	-0.15	3.3	1.00
Mean Sea Level	MSL	-0.5	-0.16	3.3	1.00
Mean Low Water	MLW	-0.9	-0.26	2.9	0.90
Mean Lower Low Water	MLLW	-1.0	-0.31	2.8	0.85
North American Vertical Datum 1988 (GEOID12B)	NAVD88 (GEOID12B)	-3.8	-1.16	0.0	0.00

fall within. Additional information about each piece of key infrastructure is detailed in the category blocks that follow table 5. The map 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 evacuation 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).

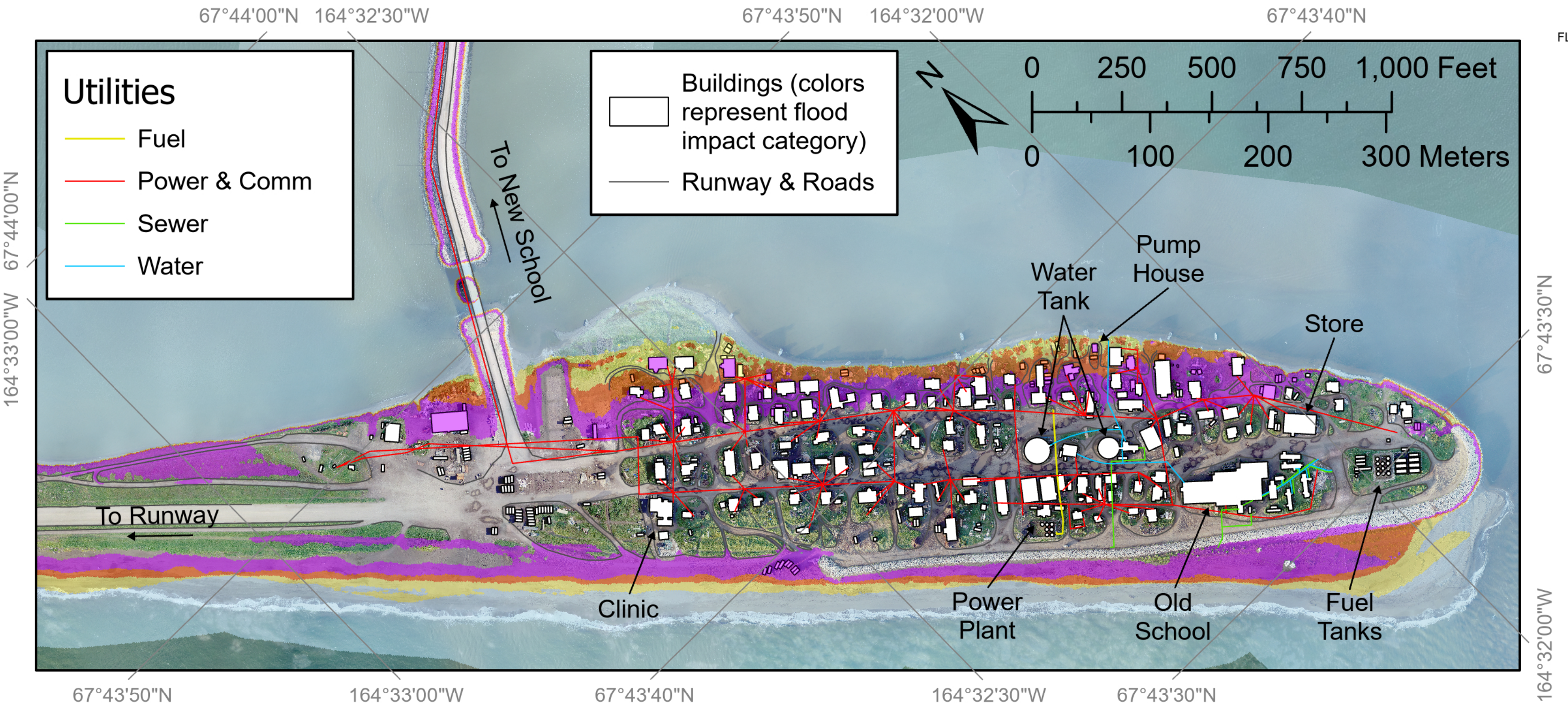
Extreme Flooding: Any flooding that reaches a height above the highest estimated flood height (NWS, 2018) plus the confidence of that estimate (Horen and others, 2024).

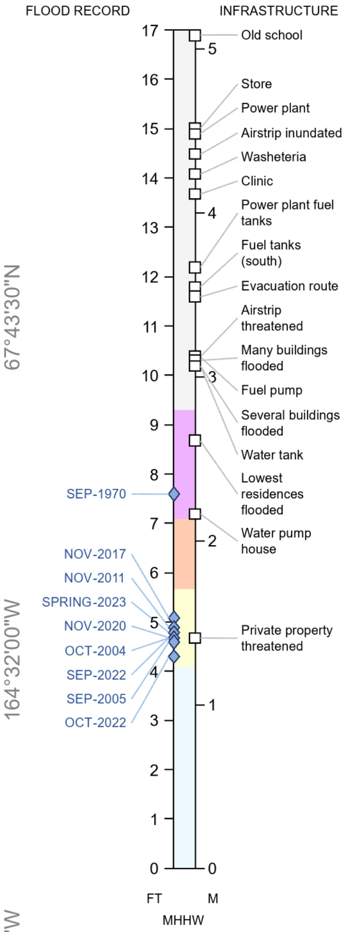
Table 5. Summary of infrastructure heights and flood categories. Gray = extreme, purple = major, red = moderate, yellow = minor. The extreme category represents infrastructure situated at heights above the highest estimated flood height with confidence included. Categories are based on current infrastructure conditions.

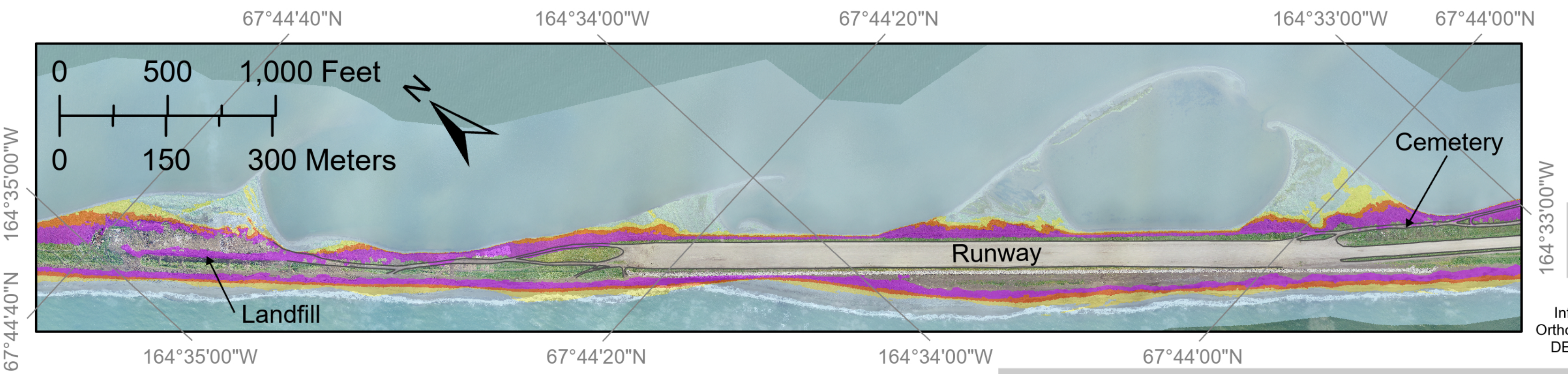
Feature	Height (ft MHHW)	Confidence (ft)	Height (m MHHW)	Confidence (m)
Old school	16.9	0.1	5.16	0.04
Store	15.0	0.1	4.57	0.04
Power plant	14.9	0.1	4.55	0.04
Airstrip inundated	14.5	0.3	4.43	0.08
Washeteria	14.1	0.1	4.28	0.04
Clinic	13.7	0.1	4.16	0.04
Power plant fuel tank barrier	12.2	0.3	3.71	0.08
Fuel tank berm	11.8	0.3	3.59	0.08
Evacuation route cut off	11.6	0.3	3.53	0.08
Extreme	**10.8**		**3.29**	
Airstrip threatened	10.4	0.3	3.18	0.08
Fuel pump	10.4	0.3	3.17	0.08
Many buildings flooded	10.3	0.1	3.15	0.04
Water tank	10.2	0.7	3.12	0.20
Several buildings flooded	10.2	0.1	3.12	0.04
Lowest residences flooded	8.7	0.1	2.64	0.04
Water pump house	7.2	0.1	2.19	0.04
Major	**7.1**		**2.15**	
Normal life disrupted	6.4	0.7	1.94	0.20
Moderate	**5.7**		**1.74**	
Private property threatened	4.7	0.7	1.44	0.20
Minor	**4.1**		**1.24**	

Coastal Flood Impact Map
Kivalina, Alaska

REPORT OF INVESTIGATION 2025-5
Christian and others, 2025
SHEET 1 OF 1







To calculate height above
NAVD88: add 3.51 ft (1.069 m)
MLLW: add 0.90 ft (0.275 m)

Projection: NAD83 (2011) UTM Zone 3N
Infrastructure based on DCRA community map
Orthoimagery available from elevation.alaska.gov
DEM available from coast.noaa.gov/dataviewer

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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Extreme Flooding: Greater than 10.8 ft (3.29 m) MHHW

Old school: 16.9 ± 0.1 ft (5.16 ± 0.04 m) MHHW

The first-floor height of the old school is the highest in the community.

Store: 15.0 ± 0.1 ft (4.57 ± 0.04 m) MHHW

This is the only store in the village.

Power plant: 14.9 ± 0.1 ft (4.55 ± 0.04 m) MHHW

The power plant provides power for the entire village.

Airstrip inundated: 14.5 ± 0.3 ft (4.43 ± 0.08 m) MHHW

Measured from the 2023 DSM, this is the height of the highest point of the airstrip surface.

Washeteria: 14.1 ± 0.1 ft (4.28 ± 0.04 m) MHHW

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

Clinic: 13.7 ± 0.1 ft (4.16 ± 0.04 m) MHHW

The clinic is the only medical provider in the community.

Power plant fuel tank barrier: 12.2 ± 0.3 ft (3.71 ± 0.08 m) MHHW

Measured from the 2023 DSM, this is the height at which flood waters would overtop the barrier surrounding the power plant fuel tanks.

Fuel tank berm: 11.8 ± 0.3 ft (3.59 ± 0.08 m) MHHW

Measured from the 2023 DSM, this is the height at which flood waters would overtop the lowest point on the berm surrounding the fuel tanks at the southern end of the community.

Evacuation route cut off: 11.6 ± 0.3 ft (3.53 ± 0.08 m) MHHW

Measured from the 2023 DSM, at this height flood waters would render the evacuation route to the new school dangerous to travel upon. 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 portions of the community cut off: 11.5 ± 0.3 ft (3.52 ± 0.08 m) MHHW

Measured from the 2023 DSM, at this height roads within the village would become potentially dangerous to traverse and access may become limited in some areas.

Major Flooding: 7.1 to 10.8 ft (2.15 to 3.29 m) MHHW

Airstrip threatened: 10.4 ± 0.3 ft (3.18 ± 0.08 m) MHHW

Measured from the 2023 DSM, this is the height at which flood waters would first reach any part of the airstrip.

Fuel pump: 10.4 ± 0.3 ft (3.17 ± 0.08 m) MHHW

Measured from the 2023 DSM, this is the height at which flood waters would reach the only fuel pump in the community.

Many buildings flooded 1.0 ft (0.30 m) or more: 10.3 ± 0.1 ft (3.15 ± 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.

Water tank: 10.2 ± 0.7 ft (3.12 ± 0.20 m) MHHW

Measured from the 2021 TBDEM, this is the ground height of the lower of the two water tanks in the community.

Several buildings flooded less than 1.0 ft (0.30 m): 10.2 ± 0.1 ft (3.12 ± 0.04 m) MHHW

We consider "several" buildings to describe more than one but fewer than six occupied buildings.

Lowest residences flooded 1.0 ft (0.30 m) or more: 8.7 ± 0.1 ft (2.64 ± 0.04 m) MHHW

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

Water pump house: 7.2 ± 0.1 ft (2.19 ± 0.04 m) MHHW

This is the height at which flood waters would reach the community's water pump house. Accounting for uncertainty, this height forms the basis for the lower limit of the major flood category.

Moderate Flooding: 5.7 to 7.1 ft (1.74 to 2.15 m) MHHW

Normal life disrupted: 6.4 ± 0.7 ft (1.94 ± 0.20 m) MHHW

Measured from the 2021 TBDEM, this is the height at which critical subsistence materials, equipment, or structures are at risk of being washed away or damaged. Accounting for uncertainty, this height forms the basis for the lower limit of the moderate flood category.

Minor Flooding: 4.1 to 5.7 ft (1.24 to 1.74 m) MHHW

Private property threatened: 4.7 ± 0.7 ft (1.44 ± 0.20 m) MHHW

Measured from the 2021 TBDEM, this is the height at which flood waters would reach private property and enter areas beneath buildings. Private property may include storage sheds, boats, fishing equipment, vehicles, and other property at ground level outside of occupied structures.

HISTORICAL FLOOD RECORD

The historical flood record for Kivalina 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 the August 2023 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 and others (2024). As described by Horen and others (2024), each estimate is accompanied by two confidence metrics, an estimate of 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 (*) in the Flood Event Summaries 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 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 estimation, where relevant. Each flood height estimate is classified into a single flood impact category but estimate confidences may span more than one category. Table 6 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 6. Summary of historical floods in Kivalina, 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	1970-SEP	Storm Surge	8.5	± 1.3	± 1.0*	2.58	± 0.40	± 0.30*
Minor	2024-OCT-20	Storm Surge	5.2	± 0.3	± 0.0	1.57	± 0.10	± 0.00
	2013-NOV-11	Storm Surge	5.0	± 0.3	± 0.0	1.53	± 0.10	± 0.00
	2023-MAY-24	Unknown	4.9	± 0.4	± 0.0	1.49	± 0.13	± 0.00
	2011-NOV-10	Storm Surge	4.8	± 0.3	± 0.0	1.48	± 0.10	± 0.00
	2005-SEP-24	Storm Surge	4.8	± 0.3	± 0.0	1.47	± 0.10	± 0.00
	2022-SEP-18	Storm Surge	4.8	± 0.3	± 0.0	1.45	± 0.09	± 0.00
	2004-OCT-20	Storm Surge	4.7	± 0.3	± 0.0	1.42	± 0.10	± 0.00
	2020-NOV-07	Blizzard	4.7	± 0.3	± 0.0	1.42	± 0.10	± 0.00
	2022-OCT-07	Storm Surge	4.3	± 0.3	± 0.0	1.30	± 0.09	± 0.00

Floods Not Estimated

Date	Type
2002-OCT-08	Storm Surge
2012-AUG-13	Rainfall

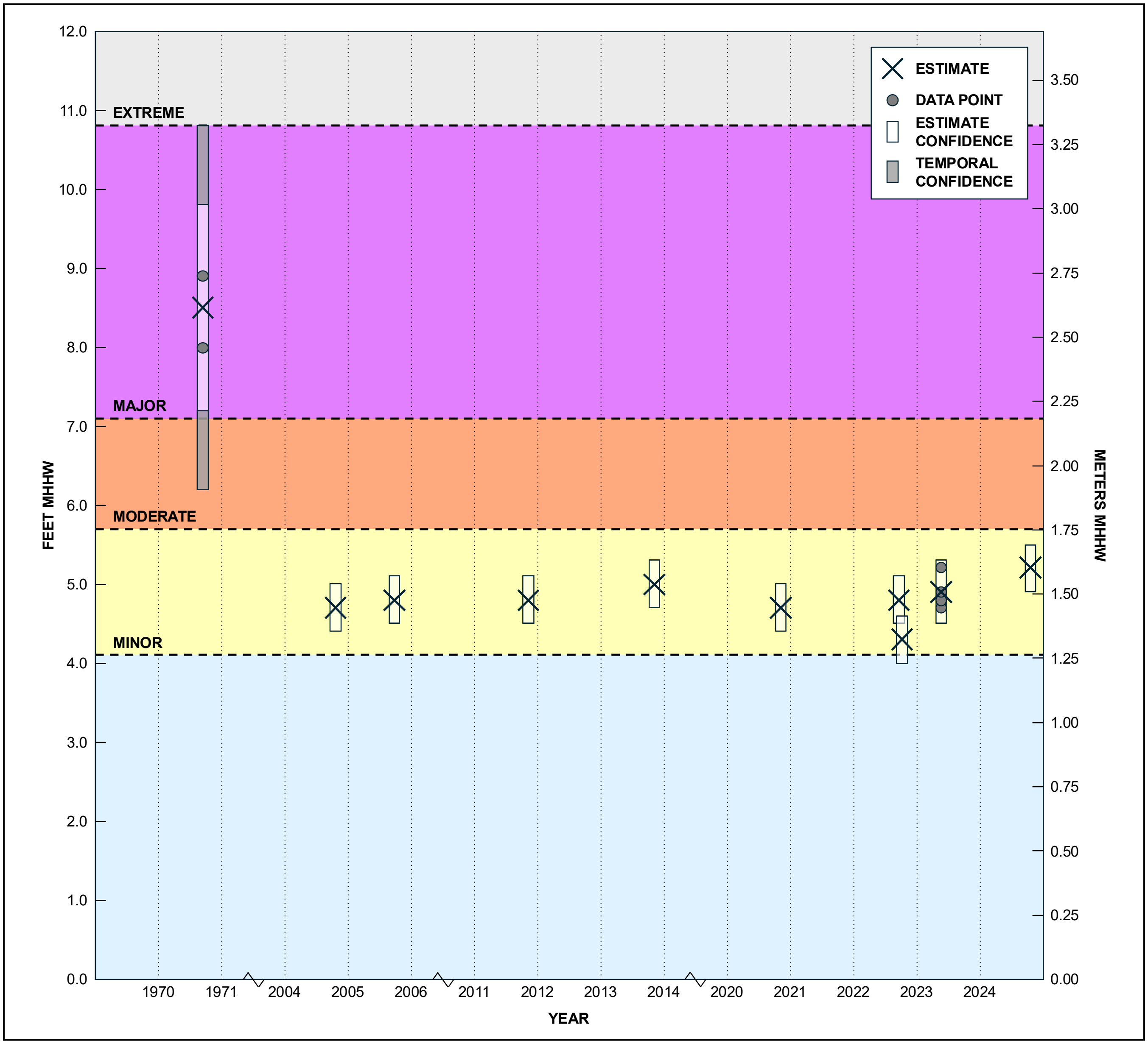

Figure 3. Timeline of estimated flood events and visual representation of flood height estimates and confidences for Kivalina, Alaska. Flood height estimates were calculated following the methods developed by Horen and others (2024). Estimates are denoted by black X symbols. Data points used during estimation 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 confidence 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
1970-SEP	8.5	± 1.3	± 1.0*	2.58	± 0.40	± 0.30*	Major

A USACE floodplain management file details the 1970 storm of record resulted in 20–30 percent of Kivalina flooded with water reaching the southern end of the old airstrip (USACE, 1970).

To estimate this flood, we compared the 1976 Alaska DCRA community profile map (DCRA, 1976) with historical aerial imagery collected in 1979 to confirm building locations. We then overlaid the 1979 aerial imagery with a simple bathtub model applied to the 2016 DSM to simulate the flooding scenarios described (fig. 4). At 20 percent inundation the water height would have reached approximately 8.0 ft (2.45 m) MHHW, while at 30 percent inundation the water height would have reached approximately 8.9 ft (2.71 m) MHHW. We averaged these results to determine a flood height estimate of 8.5 ft (2.58 m) MHHW.

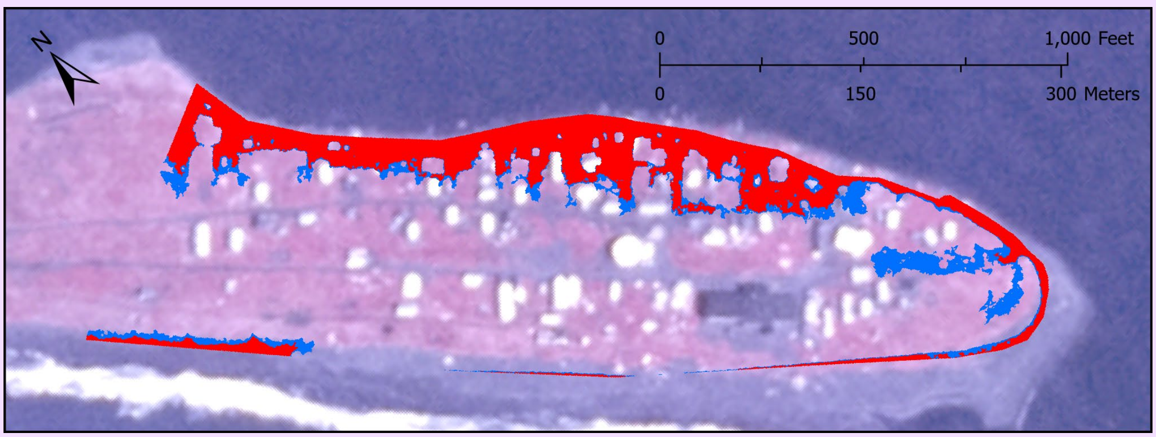

Figure 4. Map of a simple bathtub model applied to the 2016 DSM to simulate the extents of 20 (red) and 30 percent (blue) inundation overlaid on the 1979 aerial imagery of Kivalina, Alaska.

This flood height estimate, with estimate and temporal confidences added, constitutes the upper limit of the major flooding category and the lower limit of the extreme flooding category.

Flood Date	Height (ft MHHW)	Estimate Confidence (ft)	Temporal Confidence (ft)	Height (m MHHW)	Estimate Confidence (m)	Temporal Confidence (m)	Category
2002-OCT-08	—	—	—	—	—	—	No flood height estimate

The Alaska Division of Homeland Security & Emergency Management (DHS&EM) reports "coastal storm surge flooding occurred in communities on the Northwestern coast of Alaska commencing on October 8, 2002," noting "widespread damage and coastal flooding, including damage to public roads and other public real property" prompted the Governor to declare "a disaster for the cities of Kotzebue and Kivalina in the Northwest Arctic Borough" (DHS&EM, 2008).

A flood height could not be estimated for this event because the evidence provided neither flood height nor infrastructure impact information.

Flood Date	Height (ft MHHW)	Estimate Confidence (ft)	Temporal Confidence (ft)	Height (m MHHW)	Estimate Confidence (m)	Temporal Confidence (m)	Category
2004-OCT-20	4.7	± 0.3	± 0.0	1.42	± 0.10	± 0.00	Minor

A National Centers for Environmental Information (NCEI) storm report notes coastal flooding was observed in Kivalina from storm surge October 19–20, 2004, with "power poles and lines damaged," the washateria drain field destroyed and leaking raw sewage, and erosion beneath the school principal's residence (NCEI, 2004). A DHS&EM (2008) report indicates both the Governor and FEMA issued disaster declarations for this event.

To estimate this flood, we gathered water level data from the Red Dog Dock water level sensor during the relevant time period. As described in appendix C, these data were adjusted to estimate local water levels in Kivalina (fig. 5).

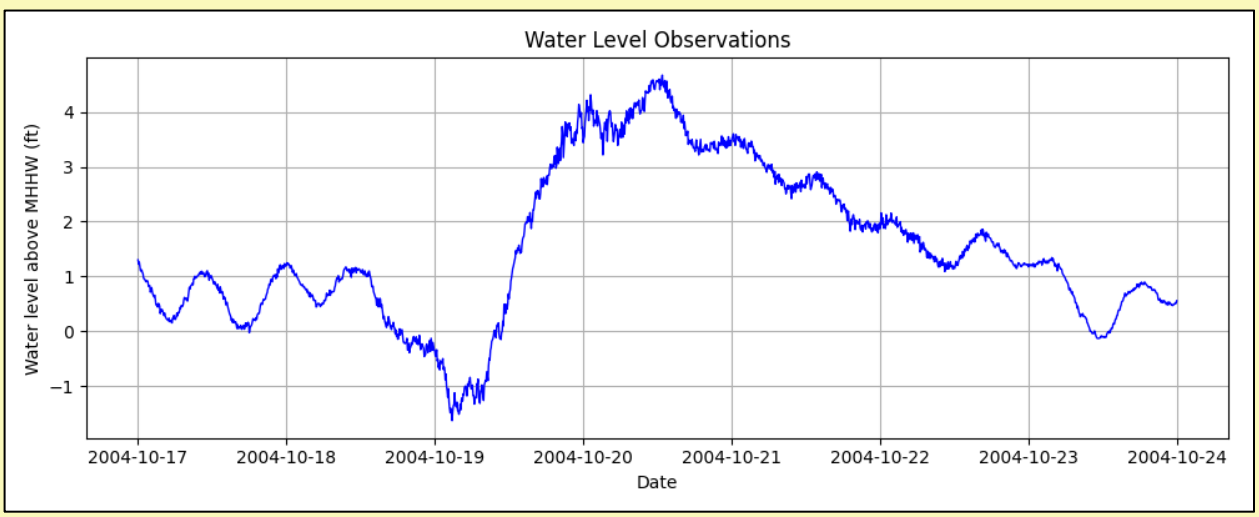

Figure 5. Red Dog Dock water level sensor readings with Kivalina adjustment applied, October 17–24, 2004.

Flood Date	Height (ft MHHW)	Estimate Confidence (ft)	Temporal Confidence (ft)	Height (m MHHW)	Estimate Confidence (m)	Temporal Confidence (m)	Category
2005-SEP-24	4.8	± 0.3	± 0.0	1.47	± 0.10	± 0.00	Minor

An NCEI storm report details a storm on September 23–24, 2005, that resulted in "25–30 feet of beach erosion, along a 500 foot length of shoreline, at the southeast end of" Kivalina, as well as "20 feet of beach erosion toward the airstrip, encroaching on the taxiway," with "several telephone poles near the edge of shore… toppled due to erosion underneath," and the school principal and their family evacuated their home during the storm "as water moved right to the edge of the structure" (NCEI, 2005).

Figure 6. Photograph of flooding and erosion near the school principal's residence on September 23, 2005, in Kivalina, Alaska. Credit: Jim Evak.

To estimate this flood, we gathered water level data from the Red Dog Dock water level sensor during the relevant time period. As described in appendix C, these data were adjusted to estimate local water levels in Kivalina (fig. 7).

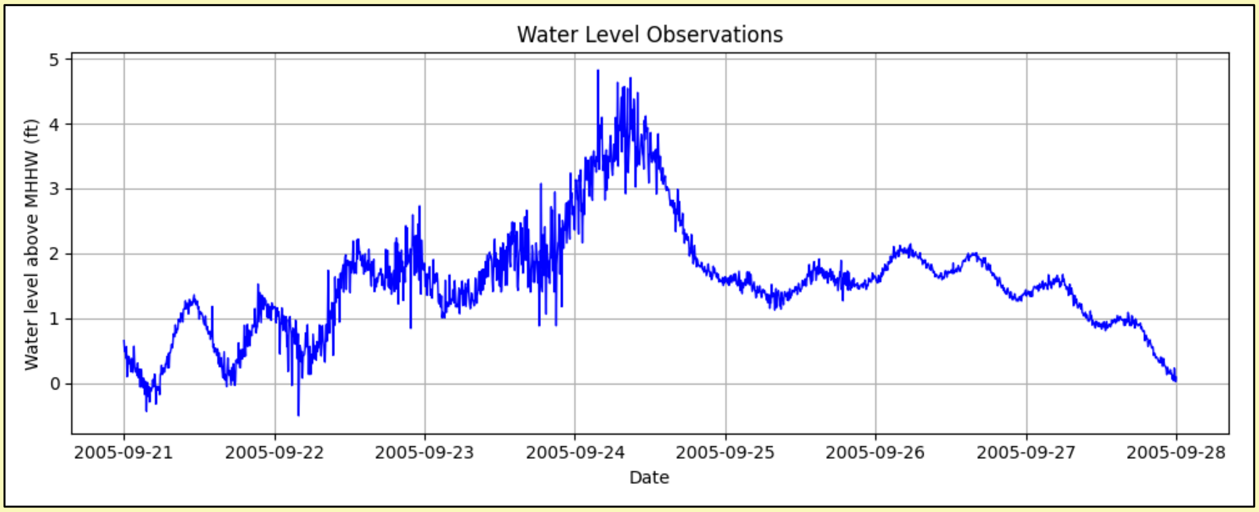

Figure 7. Red Dog Dock water level sensor readings with Kivalina adjustment applied, September 21–28, 2005.

Flood Date	Height (ft MHHW)	Estimate Confidence (ft)	Temporal Confidence (ft)	Height (m MHHW)	Estimate Confidence (m)	Temporal Confidence (m)	Category
2011-NOV-10	4.8	± 0.3	± 0.0	1.48	± 0.10	± 0.00	Minor

A National Centers for Environmental Information (NCEI) storm report details coastal flooding along the Chukchi Sea coast November 9–10, 2011, noting "at Kivalina, water flooded the lowest lying areas of the village, with flooding reported at the village dump site between the ocean and lagoon… no homes or structures were flooded" (NCEI, 2011).

To estimate this flood, we gathered water level data from the Red Dog Dock water level sensor during the relevant time period. As described in appendix C, these data were adjusted to estimate local water levels in Kivalina (fig. 8).

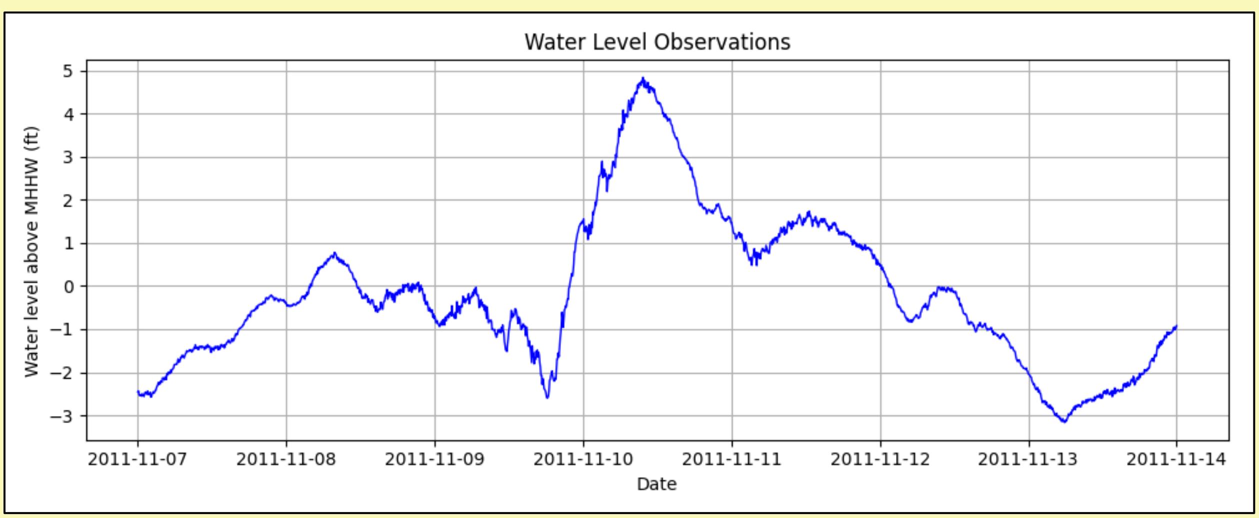

Figure 8. Red Dog Dock water level sensor readings with Kivalina adjustment applied, November 7–14, 2011.

Flood Date	Height (ft MHHW)	Estimate Confidence (ft)	Temporal Confidence (ft)	Height (m MHHW)	Estimate Confidence (m)	Temporal Confidence (m)	Category
2012-AUG-13	—	—	—	—	—	—	No flood height estimate

The City of Kivalina Hazard Mitigation Plan (FEMA, 2015) lists flooding on August 13, 2012, due to "record flows on the Wulik River" resulting from "a week of record rainfall," noting "the high water washed several sections of the surface water piping into the river and overtopped the city's landfill, washing landfill debris into the community."

Figure 9. Photographs of flood waters encroaching residences on the lagoon side of Kivalina, Alaska, in August 2012. Credit: Unknown.

While it is possible to determine a minimum height at which water would begin flooding the landfill, approximately 3.3 ft (1.00 m) MHHW as measured from the 2016 DSM, it is not possible to determine a maximum flood height from the description provided.

Flood Date	Height (ft MHHW)	Estimate Confidence (ft)	Temporal Confidence (ft)	Height (m MHHW)	Estimate Confidence (m)	Temporal Confidence (m)	Category
2013-NOV-11	5.0	± 0.3	± 0.0	1.53	± 0.10	± 0.00	Minor

Although Kivalina was not named directly, an NCEI (2013) storm report details a series of "very strong low pressure systems" that impacted western and northern Alaska "from the 6th to the 14th of November," causing "storm surge rang[ing] from 2 to 6 feet along the Chukchi Sea coast."

To estimate this flood, we gathered water level data from the Red Dog Dock water level sensor during the relevant time period. As described in appendix C, these data were adjusted to estimate local water levels in Kivalina (fig. 10).

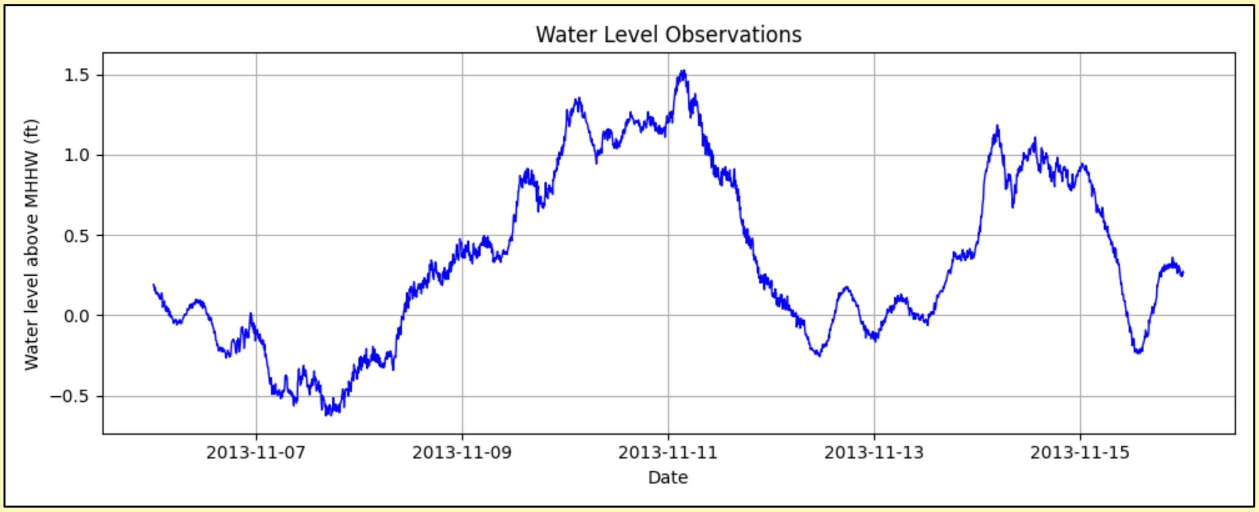

Figure 10. Red Dog Dock water level sensor readings with Kivalina adjustment applied, November 6–16, 2013.

Flood Date	Height (ft MHHW)	Estimate Confidence (ft)	Temporal Confidence (ft)	Height (m MHHW)	Estimate Confidence (m)	Temporal Confidence (m)	Category
2020-NOV-07	4.7	± 0.3	± 0.0	1.42	± 0.10	± 0.00	Minor

An NCEI (2020) storm report details “strong winds and blizzard conditions [for] much of the west coast [of Alaska] from November 4th into the 5th,” the storm stretching from Wales to Point Hope.

To estimate this flood, we gathered water level data from the Red Dog Dock water level sensor during the relevant time period. As described in appendix C, these data were adjusted to estimate local water levels in Kivalina (fig. 11).

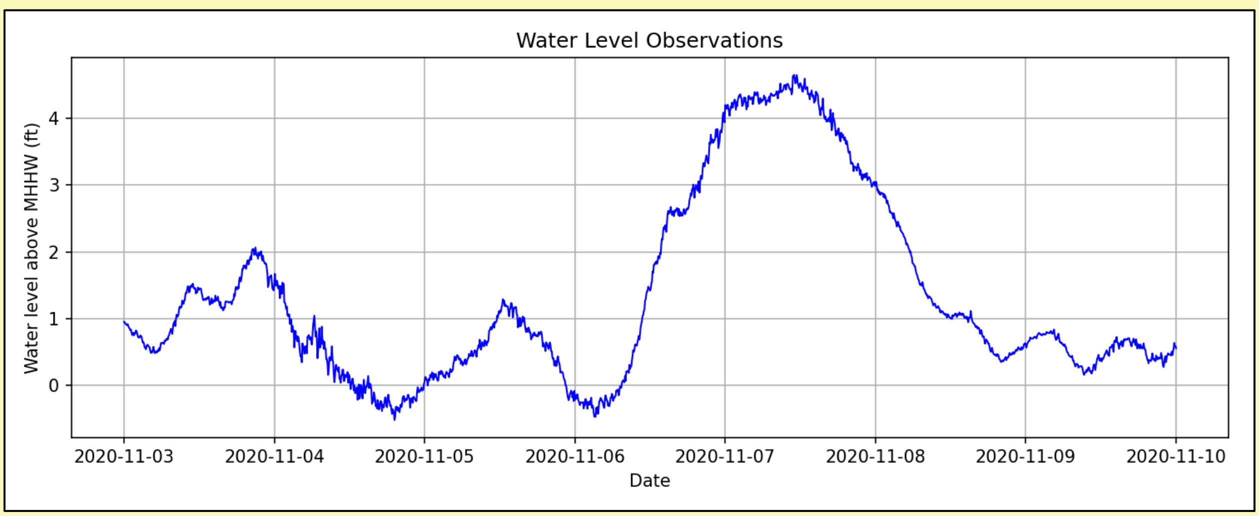

Figure 11. Red Dog Dock water level sensor readings with Kivalina adjustment applied, November 3–10, 2020.

Flood Date	Height (ft MHHW)	Estimate Confidence (ft)	Temporal Confidence (ft)	Height (m MHHW)	Estimate Confidence (m)	Temporal Confidence (m)	Category
2022-SEP-18	4.8	± 0.3	± 0.0	1.45	± 0.09	± 0.00	Minor

An NCEI (2022a) storm report notes "the remnants of Typhoon Merbok in the northern Pacific Ocean began approaching the Bering Sea on Thursday, September 15, 2022... The storm continued to move northeast into the Chukchi Sea Saturday afternoon, September 17th" with "minor flooding of low lying areas and erosion from wave runup" observed in Kivalina.

Figure 12. Photographs of flood waters encroaching residences on the lagoon side of Kivalina, Alaska, during Ex-typhoon Merbok, in September 2022. Credit: Unknown.

To estimate this flood, we gathered water level data from the Kivalina water level sensor during the relevant time period (fig. 13).

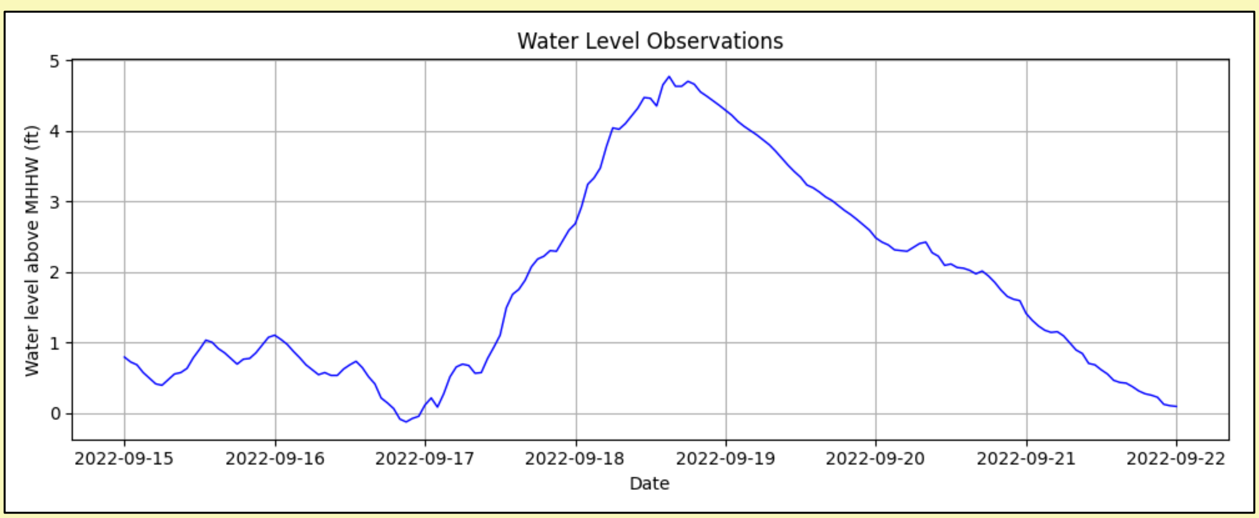

Figure 13. Kivalina, Alaska, water level sensor readings, September 15–22, 2022.

Flood Date	Height (ft MHHW)	Estimate Confidence (ft)	Temporal Confidence (ft)	Height (m MHHW)	Estimate Confidence (m)	Temporal Confidence (m)	Category
2022-OCT-07	4.3	± 0.3	± 0.0	1.30	± 0.09	± 0.00	Minor

An NCEI (2022b) storm report details a coastal flood event resulting from strong winds "causing water levels to rise from the Seward Peninsula to Utqiagvik," the highest water in Kivalina occurring on the morning of October 7, 2022, with "minor flooding… of low lying [areas]."

Figure 14. Photograph of flood waters encroaching residences on the lagoon side of Kivalina, Alaska, in October 2022. Credit: Unknown.

To estimate this flood, we gathered water level data from the Kivalina water level sensor during the relevant time period (fig. 15).

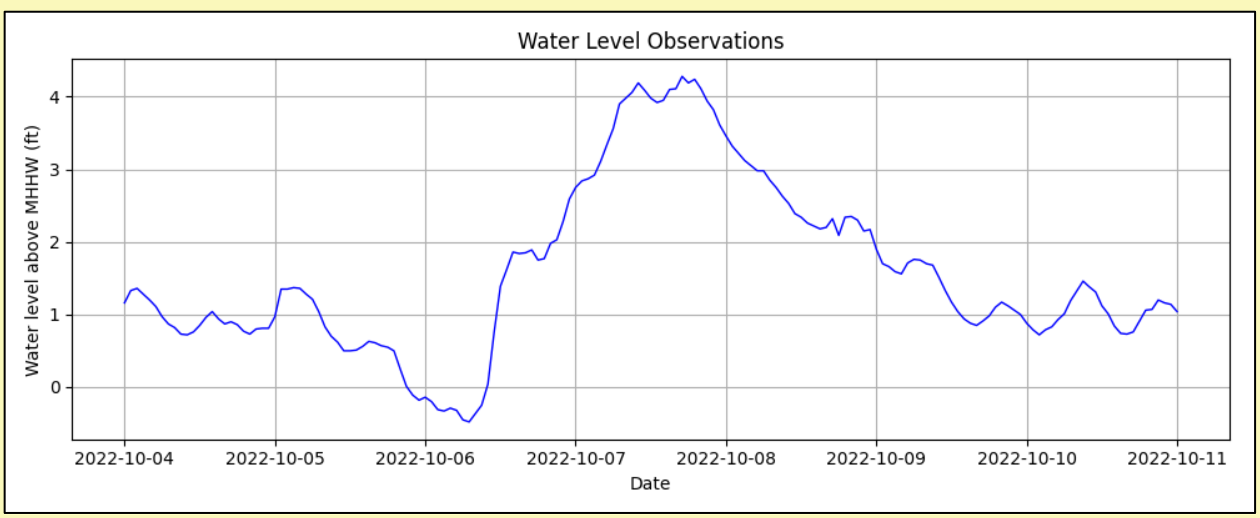

Figure 15. Kivalina, Alaska, water level sensor readings, October 4–11, 2022.

Flood Date	Height (ft MHHW)	Estimate Confidence (ft)	Temporal Confidence (ft)	Height (m MHHW)	Estimate Confidence (m)	Temporal Confidence (m)	Category
2023-MAY-24	4.9	± 0.4	± 0.0	1.49	± 0.13	± 0.00	Minor

During the 2023 survey, residents described a recent flood event that impacted Kivalina during the spring of that year. Although there was a potential flood event identified in the Kivalina water level sensor data in late May 2023, with a maximum water height of 5.7 ft (1.75 m) MHHW (fig. 16), the veracity of these water level readings is suspect for periods during which ice was likely present, so we have sought additional evidence and HWM data. DGGS collected five GNSS observations in August 2023 (app. B) identified as areas of flooding during this event. These 6 GNSS observations measured 4.7 ft (1.44 m), 4.8 ft (1.46 m), 4.8 ft (1.46 m), 4.9 ft (1.49 m), and 5.2 ft (1.59 m) MHHW. We used the average of these five heights to estimate a flood height of 4.9 ft (1.49 m) MHHW.

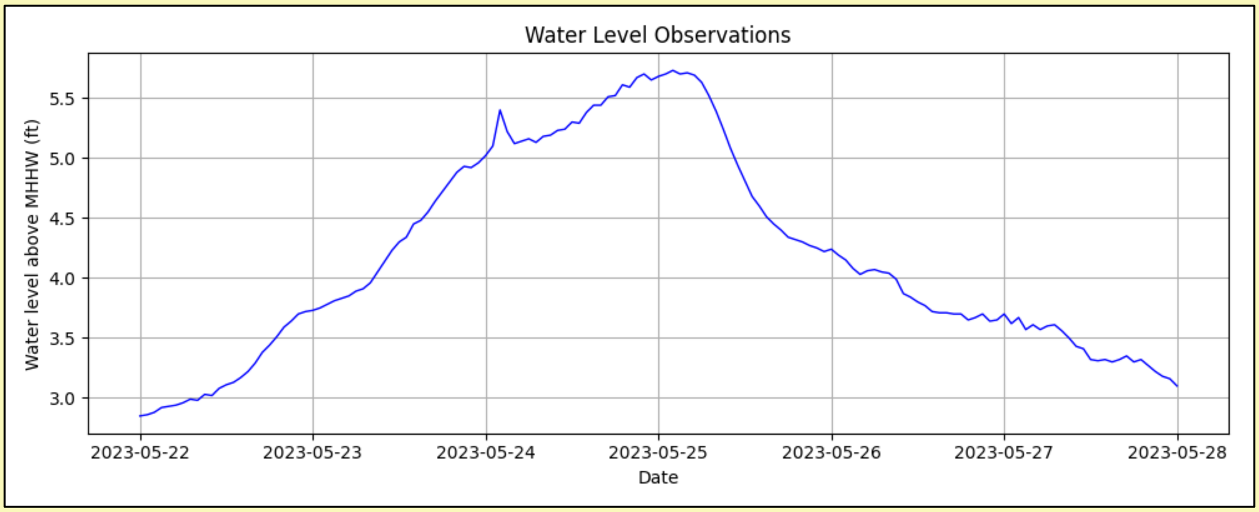

Figure 16. Kivalina, Alaska, water level sensor readings, May 22–28, 2023.

Flood Date	Height (ft MHHW)	Estimate Confidence (ft)	Temporal Confidence (ft)	Height (m MHHW)	Estimate Confidence (m)	Temporal Confidence (m)	Category
2024-OCT-23	5.2	± 0.3	± 0.0	1.57	± 0.10	± 0.00	Minor

An NCEI (2024) storm report details “a major fall storm [that] quickly pushed across northern Alaska between October 20th and 23rd,” bringing “coastal flooding, high winds, heavy precipitation, and a mix of precipitation, including a rain-snow mix and freezing rain,” with a “surge of water all along the West Coast [of Alaska].”

To estimate this flood, we gathered water level data from the Red Dog Dock water level sensor during the relevant time period. As described in appendix C, these data were adjusted to estimate local water levels in Kivalina (fig. 17).

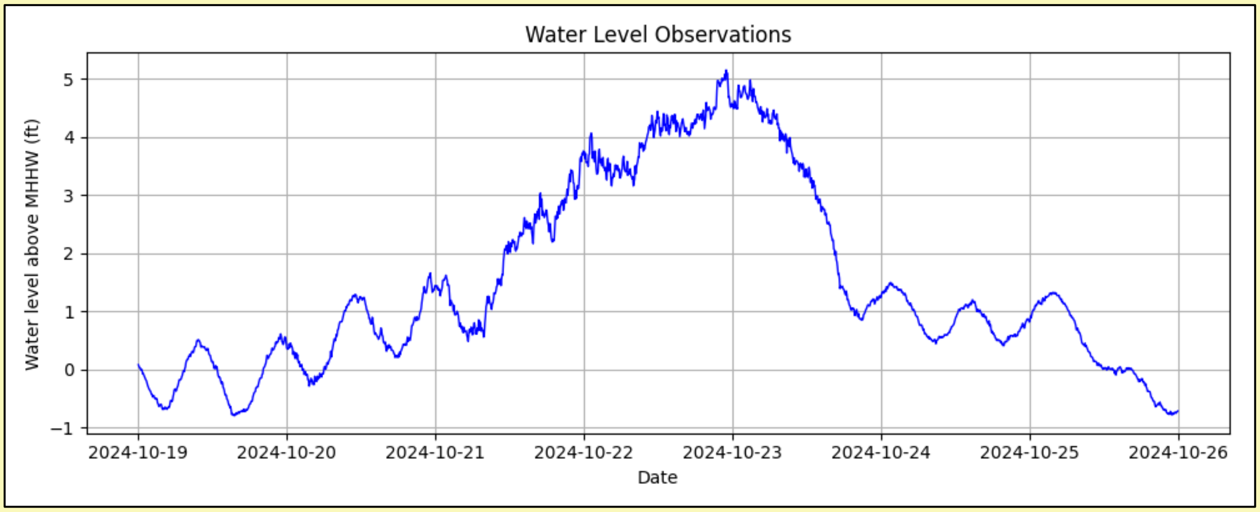

Figure 17. Red Dog Dock water level sensor readings with Kivalina adjustment applied, October 19–26, 2024.

ACKNOWLEDGMENTS

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Appendix A: First-floor height survey, Kivalina, Alaska

Ground Survey Details

The data provided are from a field survey completed by CRW Engineering Group, LLC in March 2020. Project heights were collected and are reported in the North American Vertical Datum 1988 with GEOID12B applied (NAVD88 [GEOID12B]) in U.S. survey feet (usft) and were measured using a Trimble R10 global positioning system (GPS) receiver utilizing real-time kinematic adjustments from a Trimble R10 GPS base station.

Basis of Horizontal Control

The basis of Horizontal Control for this survey is tidal benchmark 949 1253 E (CRW control point 601), National Geodetic Survey (NGS) PID BBBH52, as observed on October 5, 2003, a stainless-steel rod encased in an uncovered 0.4-ft diameter PVC pipe. This station has the following recorded horizontal coordinates in the North American Datum 1983 (2011) (NAD83[2011]):

NAD83(2011) (EPOCH 2010.0000) Geodetic Coordinates

Latitude:	67° 43′ 29.08061″ N	± 0.006 m
Longitude:	164° 31′ 58.04079″ W	± 0.007 m

NAD83(2011) (EPOCH 2010.0000) Alaska State Plane Zone 8

Northing:	5,019,179.54	± 0.02 usft
Easting:	1,844,084.79	± 0.02 usft

Basis of Vertical Control

The basis of Vertical Control for this survey is tidal benchmark 949 1253 E (CRW control point 601), NGS PID BBBH52. This station has the following recorded vertical height in the NAVD88 (GEOID12B):

NAVD88(GEOID12B) Elevation

4.640	± 0.043 m
15.22	± 0.14 usft

POINT	NORTHING	EASTING	HEIGHT	DESCRIPTION
4002	5019447.04	1843840.49	16.42	BLDFF 220 SCHOOL SHOP
4003	5019389.49	1843787.44	16.33	BLDFF 221B TEACHER HOUSING
4004	5019438.55	1843768.37	17.96	BLDFF 220A SCHOOL SHOP
4005	5019448.27	1843747.96	20.42	BLDFF 219 SCHOOL
4006	5019411.44	1843863.15	17.82	BLDFF 221C TEACHER HOUSING
4007	5019335.20	1843880.63	18.01	BLDFF 92A
4008	5019344.18	1843947.84	16.42	BLDFF 92
4009	5019350.46	1843906.28	16.84	BLDFF 221D TEACHER HOUSING
4010	5019434.77	1843965.72	16.94	BLDFF 93
4011	5019425.75	1843977.95	16.03	BLDFF 93A
4012	5019354.82	1844194.15	19.26	BLDFF 91
4015	5019387.92	1844122.07	16.80	BLDFF 90 NOT HAPPY
4016	5019506.33	1844082.36	16.53	BLDFF 89
4017	5019521.38	1844107.65	17.39	BLDFF 88
4018	5019509.74	1844016.20	18.51	BLDFF 223 STORE
4019	5019464.24	1843891.77	16.41	BLDFF 221 TEACHER HOUSING
4020	5019482.50	1843862.41	17.43	BLDFF 221ATEACHER HOUSING
4021	5019562.21	1843821.91	15.65	BLDFF 219A SCHOOL
4022	5019580.14	1843897.78	16.06	BLDFF 222 STORE WAREHOUSE
4023	5019757.11	1843966.91	14.43	BLDFF 87
4024	5019700.83	1843854.96	15.58	BLDFF 85
4025	5019715.64	1843820.13	13.56	BLDFF 84
4026	5019649.14	1843802.54	18.94	BLDFF 86
4027	5019607.68	1843849.08	17.92	BLDFF 86A
4028	5019614.13	1843687.35	15.85	BLDFF 219B SCHOOL
4029	5019729.38	1843748.84	16.20	BLDFF 94
4030	5019786.08	1843799.26	15.86	BLDFF 83
4031	5019840.95	1843746.65	15.17	BLDFF 217 FRIENDS CHURCH
4032	5019754.48	1843675.63	16.49	BLDFF 95
4033	5019764.82	1843663.15	18.51	BLDFF 218 WTP/W
4034	5019826.93	1843584.37	17.56	BLDFF 218A WTP/W (WST)
4035	5019876.56	1843651.13	13.98	BLDFF 216 NANA
4036	5019888.91	1843704.32	14.31	BLDFF 68A
4037	5019914.71	1843674.46	14.86	BLDFF 69
4038	5019917.64	1843700.39	12.58	BLDFF 68
4039	5019958.78	1843731.77	12.83	BLDFF 66
4040	5019991.15	1843734.43	13.68	BLDFF 65
4041	5019957.08	1843656.58	17.34	BLDFF 67
4042	5020081.60	1843707.73	10.70	BLDFF 15

4043	5019710.12	1843679.31	13.83	BLDFF 96
4044	5019655.89	1843477.03	15.00	BLDFF 79
4045	5019641.74	1843488.68	19.83	BLDFF 80
4046	5019651.19	1843526.16	17.07	BLDFF 81
4047	5019701.24	1843566.21	15.84	BLDFF 82
4048	5019708.23	1843539.03	15.25	BLDFF 78
4049	5019774.31	1843503.23	15.67	BLDFF 75
4050	5019804.88	1843465.28	14.95	BLDFF 74
4051	5019811.32	1843429.66	19.20	BLDFF 72
4052	5019726.94	1843442.11	16.35	BLDFF 76
4053	5019710.42	1843390.87	17.47	BLDFF 77
4054	5019754.57	1843357.40	16.63	BLDFF 210B AVEC
4055	5019783.83	1843385.83	15.15	BLDFF 73A
4056	5019810.36	1843338.00	15.12	BLDFF 210A AVEC
4057	5019850.40	1843286.73	18.43	BLDFF 210 AVEC
4058	5019840.75	1843362.50	15.78	BLDFF 70
4059	5019851.05	1843400.46	16.02	BLDFF 71
4060	5019889.33	1843451.20	15.55	BLDFF 211A HOME NOW
4061	5019909.82	1843343.91	16.89	BLDFF 209 BINGO HALL
4062	5019923.65	1843333.27	18.09	BLDFF 208 COMMUNIYT HALL
4063	5020416.25	1843230.45	9.88	BLDFF 8
4065	5021214.34	1842085.93	14.82	BLDFF 201A Garage
4066	5021258.20	1842057.17	13.72	BLDFF
4067	5021235.91	1841958.14	15.72	BLDFF
4068	5021121.96	1842292.93	12.17	BLDFF 201B
4070	5020658.91	1842607.02	17.89	BLDFF House 9
5002	5020323.08	1843208.51	16.91	BLDFF House 44
5003	5020381.49	1843137.51	16.92	BLDFF House 42
5004	5020403.79	1843120.63	14.97	BLDFF House 41
5005	5020344.83	1843080.35	16.45	BLDFF House 39
5006	5020263.59	1843128.73	16.81	BLDFF House 46
5007	5020208.88	1843142.59	16.95	BLDFF House 47
5008	5020280.11	1843051.37	18.79	BLDFF House 38
5009	5020246.21	1843033.44	15.48	BLDFF House 37
5010	5020242.96	1843019.62	15.84	BLDFF House 36
5011	5020219.31	1842976.95	17.71	BLDFF House 35
5012	5020154.69	1842860.44	19.46	BLDFF House 34
5013	5020147.05	1843046.55	18.18	BLDFF House 50
5014	5020146.41	1843070.39	15.38	BLDFF House 203 FIRE EQUIPTMENT
5015	5020079.83	1843046.45	16.41	BLDFF House 206 SAR

5016	5020111.46	1843094.31	15.36	BLDFF House 204 IRA/CITY
5017	5020106.42	1843116.05	16.49	BLDFF House 205 POST OFFICE
5018	5020133.55	1843220.14	17.49	BLDFF House 49
5019	5020163.65	1843251.74	16.84	BLDFF House 48
5020	5020256.52	1843265.39	14.95	BLDFF House 45
5021	5020290.29	1843297.95	17.12	BLDFF House 43
5022	5020236.63	1843324.20	18.27	BLDFF House 53
5023	5020229.65	1843379.04	15.38	BLDFF House 54
5024	5020163.01	1843376.53	15.88	BLDFF House 55
5025	5020138.08	1843326.31	16.65	BLDFF House 56
5026	5020021.95	1843216.59	16.16	BLDFF House 51
5027	5020010.17	1843180.34	16.70	BLDFF House 52
5028	5019958.88	1843254.58	15.67	BLDFF House 207 CHURCH
5029	5020268.92	1842880.71	19.18	BLDFF House 32
5030	5020346.16	1842948.66	15.76	BLDFF House 29
5031	5020368.84	1842856.80	18.61	BLDFF House 28
5032	5020399.96	1842995.15	16.19	BLDFF House 26
5033	5020487.92	1843096.26	13.55	BLDFF House 40
5034	5020451.45	1843109.10	14.53	BLDFF House 41CONNECTED TO 40 SHOT AT SEAM
5035	5020526.73	1843024.30	14.80	BLDFF House 22
5036	5020566.53	1842976.04	15.29	BLDFF House 21
5037	5020499.06	1842962.89	14.66	BLDFF House 23A BUILDING NEW HOME
5038	5020476.44	1843012.06	16.32	BLDFF House 24
5039	5020537.69	1842955.82	14.85	BLDFF House 23 BURIED ABANDONED MAYBE
5040	5020628.02	1842975.88	12.23	BLDFF Garage 20
5041	5020586.61	1842933.30	14.11	BLDFF Garage 20
5042	5020470.32	1842863.26	14.62	BLDFF House 25 ABANDONED
5043	5020297.73	1842971.75	19.18	BLDFF House 30
5044	5020331.33	1842818.19	18.91	BLDFF House 31
5045	5020265.81	1842742.44	17.55	BLDFF House 33
5046	5020394.93	1842732.47	16.75	BLDFF House 13
5047	5020437.50	1842817.43	18.57	BLDFF House 27
5048	5020497.54	1842827.69	16.38	BLDFF House 15
5049	5020591.98	1842862.39	14.69	BLDFF House 17
5050	5020688.44	1842923.38	7.76	BLDFF 19 SHED
5051	5020743.78	1842903.34	11.17	BLDFF House 19
5052	5020698.03	1842861.76	12.90	BLDFF House 18
5053	5020632.28	1842807.24	13.16	BLDFF House 16
5054	5020503.73	1842715.20	14.08	BLDFF House 14
5055	5020448.71	1842688.03	16.75	BLDFF House 12

5056	5020497.73	1842569.94	14.10	BLDFF House 11
5057	5020573.68	1842544.66	17.17	BLDFF House 202 CLINIC
5058	5020613.06	1842513.79	17.51	BLDFF Garage 202A CLINIC GARAGE
5059	5020526.00	1842467.64	17.19	BLDFF Garage 202B CLINIC GARAGE
5060	5020588.70	1842649.22	18.27	BLDFF House 10
5061	5020665.49	1842746.85	15.06	BLDFF House 8
5062	5020684.95	1842696.18	17.17	BLDFF House 8
5063	5020733.50	1842622.98	15.41	BLDFF House 6
5064	5020728.57	1842644.24	17.02	BLDFF House 7
5065	5020839.65	1842677.96	13.34	BLDFF House 3
5066	5020815.76	1842710.93	14.69	BLDFF House 4
5067	5020772.45	1842770.96	14.94	BLDFF House 5
5068	5020857.75	1842759.27	12.75	BLDFF House 1
5069	5020813.01	1842812.83	13.14	BLDFF House 2
5071	5020083.82	1843511.54	14.96	BLDFF House 213 BOYS AND GIRLS CLUB
5072	5020123.98	1843551.53	15.22	BLDFF House 214 ARMORY
5073	5020078.41	1843621.87	12.26	BLDFF House 60
5074	5020062.02	1843631.54	10.96	BLDFF House 61
5075	5020055.65	1843587.73	11.95	BLDFF House 62 UNABLE TO CLEARLY SEE FF GUESS
5076	5020037.93	1843538.05	15.49	BLDFF House 63
5077	5019945.03	1843578.44	15.09	BLDFF House 64
5078	5020127.89	1843436.68	14.70	BLDFF House 58
5079	5020155.53	1843461.34	15.62	BLDFF House 59
5080	5020416.21	1843230.44	9.86	BLDFF House 59

APPENDIX B: FIELD INVESTIGATION DATA, KIVALINA, ALASKA, COLLECTED AUGUST 21–23, 2023

Ground Survey Details

The Alaska Division of Geological & Geophysical Surveys (DGGS) visited Kivalina, Alaska, between August 21 and 23, 2023, to collect historical high-water mark (HWM), first-floor heights of infrastructure constructed after 2020, and flood height information. A Trimble R10 receiver was temporarily installed as a global navigation satellite system (GNSS) base station over a found, R&M Consultants, Inc., aluminum cap monument stamped "RM2 ADL 420984" (table B1). Observations were surveyed using a Trimble R8s receiver as a GNSS rover. DGGS measured six points (table B2), consisting of one first-floor height, three HWM identified by residents, and two HWM identified by the field team.

Data Processing

The base station position was corrected using Online Positioning User Service (OPUS) solutions and the National Oceanic and Atmospheric Administration (NOAA) Vertical Datum Transformation (VDatum) software (version 4.6.1). The corrected base station position was used to update the rover positions through post-processed kinematic (PPK) adjustments in Trimble Business Center software (version 5.51) with default settings applied.

Coordinate System and Datum

All data were collected, processed, and are delivered in the North American Datum 1983 (2011) Universal Transverse Mercator Zone 3 North (NAD83[2011] UTM 3N) horizontal coordinate system and the North American Vertical Datum 1988 with GEOID12B applied (NAVD88[GEOID12B]) 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 during baseline processing, which does not include propagated error from the corrected base station position (table B2). Consistent with OPUS shared solution requirements (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 errors provided by OPUS and the orthometric height (RMS) errors provided by VDatum (table B1). The vertical accuracy of the rover GNSS position data was quantified using Trimble Business Center and reflects vertical errors during baseline processing, which does not include propagated error from the corrected base station position (table B2). Consistent with OPUS shared solution 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, in meters NAD83(2011) UTM 3N / NAVD88(GEOID12B).

Northing	Easting	Height	Northing Error	Easting Error	Vertical Error
7512860.285	519265.295	6.673	± 0.009	± 0.004	± 0.075
7512860.285	519265.294	6.659	± 0.006	± 0.008	± 0.070
7512860.284	519265.292	6.661	± 0.006	± 0.008	± 0.074

Table B2. Rover coordinates and GNSS errors, in meters NAD83(2011) UTM 3N / NAVD88(GEOID12B).

Point ID	Northing	Easting	Height	Horizontal Error	Vertical Error	Description
3012	7512527.473	519652.421	2.663	± 0.010	± 0.016	HWM – ID
3014	7512649.373	519372.645	6.068	± 0.008	± 0.013	First-floor
3016	7512759.947	519397.646	2.563	± 0.008	± 0.016	HWM – ID
3017	7512776.131	519380.154	2.512	± 0.007	± 0.013	HWM – ID
3179	7514295.449	517803.514	2.528	± 0.007	± 0.010	HWM – snag
3180	7514288.606	517797.466	2.529	± 0.007	± 0.010	HWM - snag

APPENDIX C: WATER LEVEL SENSOR COMPARATIVE ANALYSIS AND ADJUSTMENT FOR RED DOG DOCK, NEAR KIVALINA, ALASKA

The National Oceanic and Atmospheric Administration (NOAA) Center for Operational Oceanographic Products and Services (CO-OPS) installed a Water Log H-355 Gas Purge System water level sensor on August 30, 2003, at Red Dog Dock, located approximately 16 miles (26 kilometers [km]) southeast of Kivalina, Alaska. Data collected by this sensor, updated in 6-minute intervals, are available from tidesandcurrents.noaa.gov/waterlevels.html?id=9491094. The vertical accuracy of these data is ± 0.1 ft (0.03 m).

The Alaska Division of Geological & Geophysical Surveys (DGGS) installed a Stilltek iGage radar water level sensor in Kivalina on June 7, 2022. This sensor is attached to a bridge over the Kivalina Lagoon. Data collected by this sensor, updated hourly, are available from the Alaska Water Level Watch at portal.aoos.org/#metadata/119626/station/data. The vertical accuracy of these data is ± 0.3 ft (0.09 m).

An overlap of consistent, high-quality data is available for both Kivalina and Red Dog Dock between June 7–October 31, 2022, and May 29–October 5, 2023. DGGS performed a comparative analysis of these data to determine what relationship, if any, exists between the water levels recorded at these locations. We first cross-correlated the datasets using the direct method (by sums) to identify any temporal lag, finding a 93.6 percent signal match after applying shifts of -3 hours ± 6-minutes and -2 hours ± 6-minutes to the 2022 and 2023 Kivalina data, respectively. This discrepancy appears to be related to incorrectly applied time zone adjustments to the Kivalina data when downloading from the Alaska Water Level Watch portal. After lag-adjustment, the average difference between readings was -0.163 m, with a root mean square error (RMSE) of ± 0.187 m. We next performed a linear regression on these data (fig. C1), calculating a slope (scale-factor) of 0.974 and an intercept (vertical offset) of 0.165 m, resulting in an R^2 of 0.877 and residual RMSE of ± 0.092 m.

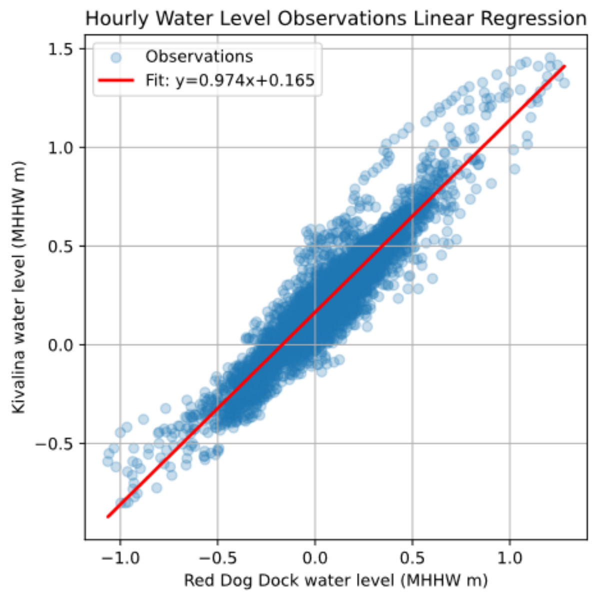

Figure C1. Linear regression fit for hourly water level observations recorded at Red Dog Dock and Kivalina, Alaska between June 7–October 31, 2022, and May 29–October 5, 2023.

Although the lengths of the data overlaps are short, the agreement within the linear regression model suggests a strong correlation between water level readings at these two locations. Nonetheless, the vertical offset is not insignificant, especially given the relatively small tidal ranges at these closely situated locations. As part of our installation of the iGage radar water level sensor in Kivalina in 2022, DGGS collected three global navigation satellite system (GNSS) water level heights aligned to the sensor recording interval. After post-processing, these GNSS observations deviated from the sensor readings an average of 0.001 ± 0.068 m; for this reason, we have adjusted the Red Dog Dock data to comport with the water level heights in Kivalina (fig. C2 and C3).

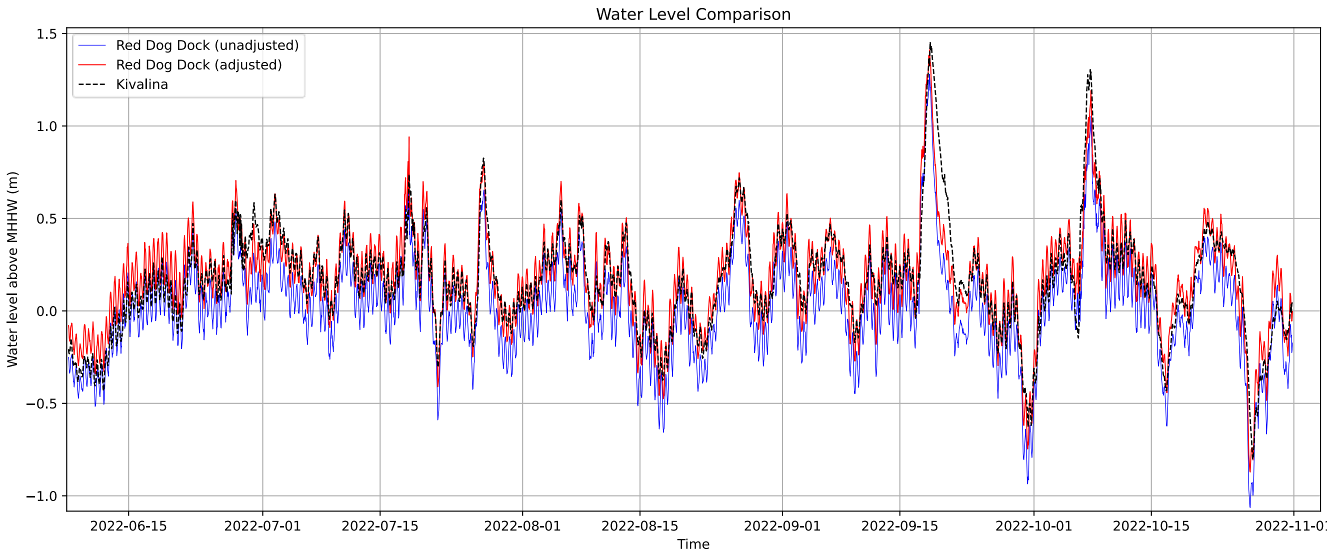

Figure C2. Comparison of Kivalina (black dashed line) to pre- (blue line) and post-adjusted (red line) Red Dog Dock water level readings from June 7 to October 31, 2022.

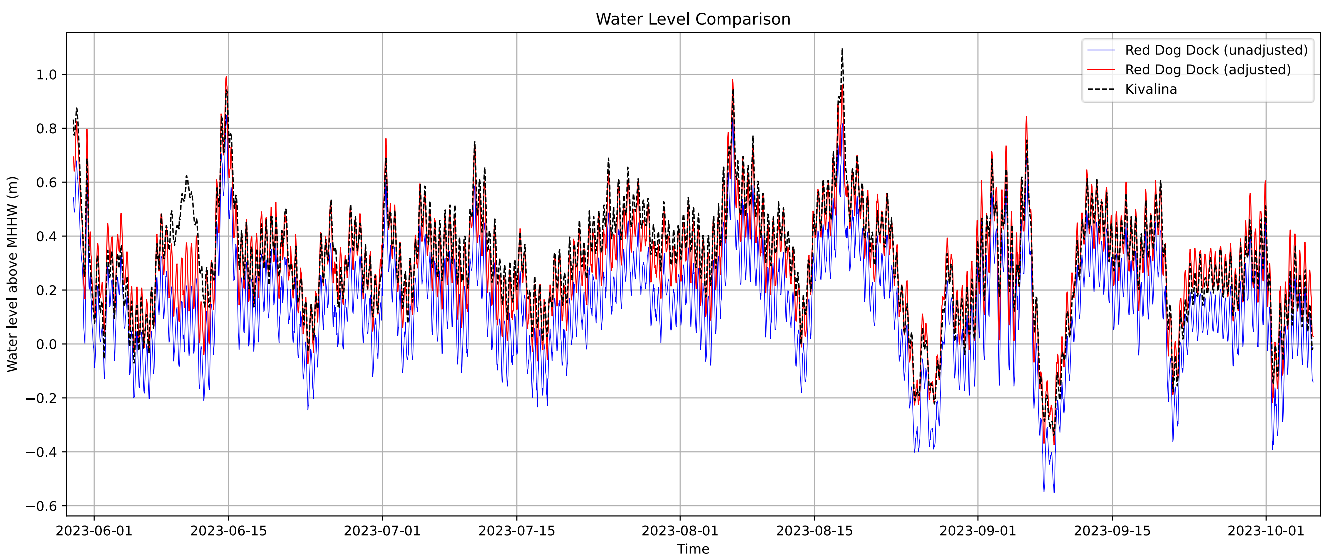

Figure C3. Comparison of Kivalina (black dashed line) to pre- (blue line) and post-adjusted (red line) Red Dog Dock water level readings from May 29 to October 5, 2023.