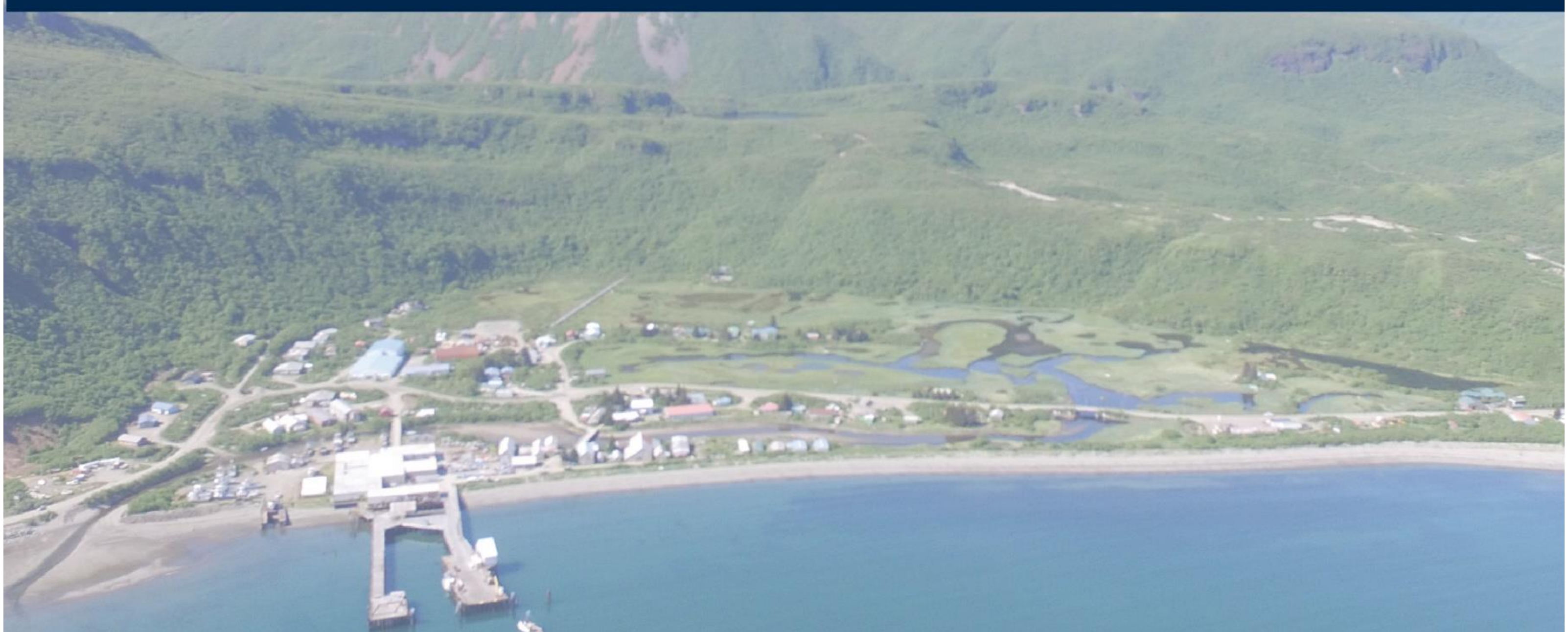
Chignik Bay Coastal Hazard Assessment

Arctic Coastal Geoscience Laboratory (Ver. March 2023)

Jessica Christian, Reyce Bogardus, Harper Baldwin, Richard Buzard, Roberta Glenn, Ed Krauss, Jeanette Carlson, Deb Carlson, and Chris Maio



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STATEMENT OF INTENT

This report is meant to contribute accurate information and high-resolution map and data products to inform erosion and flooding mitigation efforts. It is our goal that this report will aid in local decision making, provide maps and graphics for research funding opportunities, and be an information source for FEMA Hazard Mitigation Plans. We have compiled an assortment of existing data sources (DGGS, UAF-SNAP, etc.) that provide information on current and projected environmental changes. Additionally, numerous datasets have been collected, processed, and analyzed by the ACGL. This work was primarily carried out by undergraduate and graduate students within the ACGL, providing training opportunities for the next generation of geoscientists. Local environmental coordinators have also played a major role in the baseline surveys, operation of erosion monitoring sites, as well as this document. All data and products will be provided by the ACGL upon request. This report is meant to supplement more detailed geotechnical surveys, such as those carried out by contracted engineering firms.

ACKNOWLEDGMENTS

This research has been supported and/or funded through multiple contributors. These include local Tribal Environmental Programs through the Environmental Protection Administration (EPA) Indian General Assistance Program (IGAP), Alaska Sea Grant (ASG), the National Science Foundation (NSF), the Bristol Bay Native Association (BBNA), the Bureau of Indian Affairs (BIA), the University of Alaska Fairbanks (UAF) Geophysical Institute, and the Alaska Division of Geological and Geophysical Surveys Coastal Hazards Program (DGGS). We also thank the long-term contributions made by Susan Flensburg, Gabriel Dunham, and Nicole Kinsman.

We would like to thank the Chignik Bay Tribal Council as well as Jeanette Carlson, Debbie Carlson, and Ed Krauss for their continued efforts to collect monitoring data, their local observations, and assistance during field work. We greatly appreciate your knowledge and support and look forward to our continued collaboration.

DISCLAIMER

The hazard assessments in this report are based on a compilation of data we collected, as well as the data made available to the Arctic Coastal Geoscience Lab (ACGL) through external agencies and bodies. The maps and products within have been created from analysis of this information using modern techniques and based on the best information currently available. However, they do not necessarily show the greatest extent of coastal flooding or erosion suffered in the past, or likely to be suffered in the future. There are also other uncertainties associated with each analysis and mapping product. As such, the ACGL does not warrant or represent that the maps are free from errors or omissions, nor do we accept any liability in relation to the quality or accuracy of the flood and erosion maps. In particular, the ACGL does not warrant that land not shown as being subject to inundation or erosion, is free from flood waters or erosional processes.

The extent of coastal flooding maps is based on the coastal topography at the time of survey. Changes in coastal landform that have occurred since the date of survey, as well as potential future landform change are not reflected in the coastal flood mapping. The maps reflect flooding and erosion associated with coastal processes, and as such do not represent flooding and erosion caused by storm rainfall, including surface run off, storm water network overflow, and river flooding.

We have not assessed or mapped coastal hazards outside of the surveyed areas shown in this report. For areas where only one type of coastal hazard (flooding / erosion) has been mapped, it should be assumed that any unmapped coastal hazard has not been assessed. Where only coastal flood risk has been mapped it should not be assumed that no coastal erosion hazard exists, and vice versa.

The tsunami inundation map has been completed using the best information available and is believed to be accurate; however, its preparation required many assumptions. Actual conditions during a tsunami may vary from those assumed, so the accuracy cannot be guaranteed. Areas inundated will depend on specifics of the earthquake, any earthquake-triggered landslides, on-land construction, tide level, local ground subsidence, and may differ from the areas shown on the map. Information on this map is intended to permit state and local agencies to plan emergency evacuation and tsunami response actions. The map is not appropriate for site-specific use or for land-use regulation. Interpretation of the tsunami inundation map(s) by qualified experts is strongly recommended.

Finally, this work is preliminary and is subject to revision. It is being provided due to the need for timely "best science" information. Accordingly, these maps should not be relied upon as the sole basis for the making of any decision in relation to potential coastal hazard risk. The assessment is provided on the condition that neither the ACGL nor the University of Alaska Fairbanks may be held liable for any damages resulting from the authorized or unauthorized use of the assessment.

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ACRONYMS AND ABBREVIATIONS

ACCAP	Alaska Center for Climate Assessment and Policy
ACGL	Arctic Coastal Geoscience Laboratory
ADLWD	Alaska Department of Labor and Workforce Development
AHAP	Alaska High Altitude Photography
AIJ	Alaska Institute for Justice
AOOS	Alaska Ocean Observing System
ASOS	Automated Surface Observing System
DCRA	Division of Community and Regional Affairs
DGGS	Division of Geological and Geophysical Surveys
DSAS	Digital Shoreline Analysis System
DSM	Digital Surface Model
ESRI	Environmental Systems Research Institute
GIS	Geographic Information System
GLONASS	Global Orbiting Navigation Satellite System
GNSS	Global Navigational Satellite System
MHHW	Mean Higher High Water
MHW	Mean High Water
MSL	Mean Sea Level
NASA	National Aeronautics and Space Administration
NAVD88	North American Vertical Datum of 1988
NIR	Near infrared
NOAA	National Oceanic and Atmospheric Administration
NSM	Net Shoreline Movement
RGB	Red, Green, Blue
RSLR	Relative Sea Level Rise
RTK	Real-time Kinematic
SECD	Strategic Economic and Community Development
SfM	Structure from Motion
SVTM	Single Value Threshold Map
UAV	Uncrewed Aerial Vehicle
USACE	United States Army Corps of Engineers
USGS	United States Geological Survey
UTM	Universal Transverse Mercator
WCI	Weighted Confidence Interval
WEAR	Waste Erosion Assessment and Review
WIS	Wave Information Study
WLR	Weighted Linear Regression
WMO	World Meteorological Organization
WR2	Weighted R Squared

GLOSSARY

Definitions were pulled from the United Nations Office for Disaster Risk Reduction.

Capacity the combination of all the strengths, attributes and resources available within an organization, community or society to manage and reduce disaster risks and strengthen resilience.

Disaster risk (referred to as risk): the potential loss of life, injury, or destroyed or damaged assets which could occur to a system, society or a community in a specific period of time, determined probabilistically as a function of hazard, exposure, vulnerability and capacity.

Disaster risk assessment (referred to as risk assessment): A qualitative or quantitative approach to determine the nature and extent of disaster risk by analyzing potential hazards and evaluating existing conditions of exposure and vulnerability that together could harm people, property, services, livelihoods and the environment on which they depend.

Exposure the situation of people, infrastructure, housing, production capacities and other tangible human assets located in hazard-prone areas.

Hazard a process, phenomenon or human activity that may cause loss of life, injury or other health impacts, property damage, social and economic disruption or environmental degradation.

Mitigation the lessening or minimizing of the adverse impacts of a hazardous event.

Resilience the ability of a system, community or society exposed to hazards to resist, absorb, accommodate, adapt to, transform and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions through risk management.

Vulnerability the conditions determined by physical, social, economic and environmental factors or processes which increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards.

1. LOCAL NARRATIVE

1.1 LOCAL NARRATIVE

"The community of Chignik 'Anchorage Bay' is located on the south shore of the Pacific side of the Alaska Peninsula. Chignik Bay is the hub community of the Chignik sub-region and provides the residents in our neighboring villages of Chignik Lagoon, Chignik Lake, Perryville, and Ivanof Bay with essential infrastructure, including an airport, three docks, small boat harbor, Trident Seafoods, and the Harris Sub-regional Clinic. Freight is barged from Seattle on Coastal Transportation vessels, and the Alaska State Ferry Tustamena provides more affordable transportation to and from Kodiak, Homer, and Anchorage. Additionally, the Harris Sub-regional Clinic is staffed by a Mid-level Practitioner to provide a higher level of medical care to residents in our region.

"Our community experiences coastal bank erosion and flooding from storm events, which is threatening and damaging infrastructure, (e.g. Harris Sub-regional Clinic, tank farms on the East and West sides of the village, the airport, road culverts, and bridges, tsunami escape road, road to the airport, clinic and power plant. There are invasive plants and alders taking over traditional berry harvesting area. Warming of seawater temperature is affecting salmon runs, and all other species of fish and wildlife, and frequent high levels of PSP has prohibited subsistence clam digging, bidarki picking, and octopus hunting in traditional areas."

Jeanette Carlson
Secretary
Chignik Bay Tribal Council

Debbie Carlson
Treasurer
Chignik Bay Tribal Council

1.2 ADDITIONAL LOCAL OBSERVATIONS

Summary of interview with Chignik Intertribal Coalition, Consultant Hazel Nelson:

This meeting was held through Zoom and began at 10 AM, ending about 11:30 AM. The Chignik Bay Tribal Council (CBTC) was represented by Jeanette 'Chickie' Carlson, CBTC Secretary and Environmental Coordinator; and Debbie Carlson, CBTC Tribal Administrator. The group discussed answers to these questions jointly in a conversation that highlighted old and new information that also helped inform other ongoing efforts towards building resiliency for the Chignik Bay Tribe. They offered their Tribal Hazard Mitigation Plan and Action Plan for additional information to help inform this BIA TRP grant and to help reduce redundancy. The tribal members are very knowledgeable, involved and passionate about building tribal resiliency. They are already working on researching key environmental concerns and furthering mitigation and action plans for the tribe.

What changes in the environment have you observed or that have occurred in the recent past or over your lifetime in your home area?

“When we have high winds now, its higher than ever, the storms seem bigger. The recent 100 mph winds occurred during sub-zero temperatures, it knocked the power out and some people had no electricity.

“The erosion on the beach is very bad. Concerned about the clinic and the East end of the runway. The breakwaters have created two deep holes from eddies, at one end of the harbor and the other by the clinic. They are safety hazards. There’s erosion by the city dock from the big storms. There are a lot of big cracks in the road that goes to the dock.

“Indian Creek is now so wide that the bridge structures beneath it may collapse, they need to be inspected. The earthquakes and aftershocks have caused all four of the bridges to move and they need inspection for structural safety. If there is a big earthquake and the bridges collapse, then a tsunami, there will be nowhere to go to escape.

“The road to the hill is for tsunami protection and it also goes to the dump. There are steep ditches on both sides of that road along with unstable edges on the corners of the road which are very unsafe. People have already gone off the edge and been medevac’d out with serious injuries.

“The clinic has had damage from the big 8.2 earthquake, the aftershocks and it needs inspection.

“This past summer there were more fish (salmon) up Indian Creek than ever before, Roderick Carlson, CBTC Tribal President caught several silvers in there in October. In the deep creek behind Chickie’s house she saw some salmon and a land otter that was trying to catch them. There are also a lot of sticklebacks there and Kingfishers are catching them.”

All Alaskan tribes rely on key animals, birds, fish and plants and berries – these are key species necessary for food and/or for commercial sale. In the air, lands, or waters that your community relies on please identify the ***key*** *species you are most concerned about.*

“People in Chignik Bay had little to no salmon this summer unless it was brought in from another area.

“This year, there was a good berry harvest, but there is a lot of fireweed, lupine and alders overgrowing traditional berry picking areas. Alder is growing like weeds, it’s so bad that people can’t see each other while they’re berry picking, and are worried about not seeing bears or wolves, and worried about safety. Alder is also growing up all over town and around town.

“There are two wolves that have moved into the local area, and they are seen where people pick berries.

“We used to have ducks that people hunted but they don’t stay over anymore. Very little ptarmigan, it’s been 5, maybe 8 years since someone went ptarmigan hunting because they don’t flock up here anymore. Someone saw two, recently though.”

Have you been thinking about how to protect and strengthen your community’s future? Would you like to create a plan or add to existing plans that define how to live a sustainable life along with the rapid changes happening in your area?

“For the past several years the Chignik Bay tribe and city have been discussing climate change and already made progress in building resilience for the tribe and community. There are several grants that the local government entities have applied for and are in different stages of completion and award. They are already working on a BIA Tribal Climate Resilience Planning grant with Bristol Engineering Services, Danielle Dance as a consultant to complete the work. Chignik Bay’s IGAP grant has Bristol Bay Heritage Land Trust Executive Director, Tim Troll as a consultant, along with his partner, UAA Research Geographer, Marcus Geist working on the development of a watershed plan to identify and map areas important for the survival and harvest of local subsistence resources, places of cultural and historical significance, and other values in the Chignik, and which includes the communities of Chignik Bay, Chignik Lagoon, Chignik Lake, Perryville, and Ivanof Bay. Chignik Bay’s IGAP grant also has UAF Arctic Geoscience Lab Director, Chris Maio of UAF as a consultant conducting baseline coastal erosion assessment studies, which include time-lapse photos/digital mapping for annual coastal hazard assessment reports. He will also provide technical support to write a QAPP-Site Specific Sampling Plan.”

Hazel Nelson
Consultant
Chignik Intertribal Coalition

2. GEOGRAPHIC OVERVIEW

2.1 WESTERN GULF OF ALASKA REGION

The Gulf of Alaska encompasses all water from the east shore of the Alaska Peninsula to southeast Alaska. The Gulf is a semi-enclosed basin with circulation dominated by the Alaska Coastal Current and the subarctic Alaska Gyre. The current is characterized by its relatively warm water, low salinity, and freshwater core from freshwater runoff from the mountains surrounding the Gulf of Alaska (Stabeno et al. 2004; Stabeno et al. 2016). The western region includes the area of several megathrust earthquake ruptures, including the southwestern extent of the M9.2 1964 rupture—the second largest earthquake ever recorded (Zimmermann et al. 2019). The landscape of this region has been sculpted by subduction zone tectonics and multiple glaciations (Zimmermann et al. 2019).

2.2 CHIGNIK BAY

Chignik Bay is one of seventeen communities in the Lake and Peninsula Borough. It lies 724 km (450 mi) southwest of Anchorage and 418 km (260 mi) southwest of Kodiak (DCCED 2018) (**Figure 1**). The city comprises 11.7 square miles of land and 4.3 square miles of water (Chignik Bay Tribal Council 2019). Kalwak, the original village of the current land of Chignik Bay, was destroyed in the late 1700s during the Russian fur boom (Chignik Bay Tribal Council 2019). The word “Chignik” is a Sugpiak word for “big wind,” and the village of Chignik Bay was named after the body of water it overlooks. The community was established in the late 1800s as a fishing community and became an incorporated city in 1983 (DCCED 2018). Coal mining occurred from 1899 to 1915. The city is located at the head of Anchorage Bay, which itself is in the larger Chignik Bay.

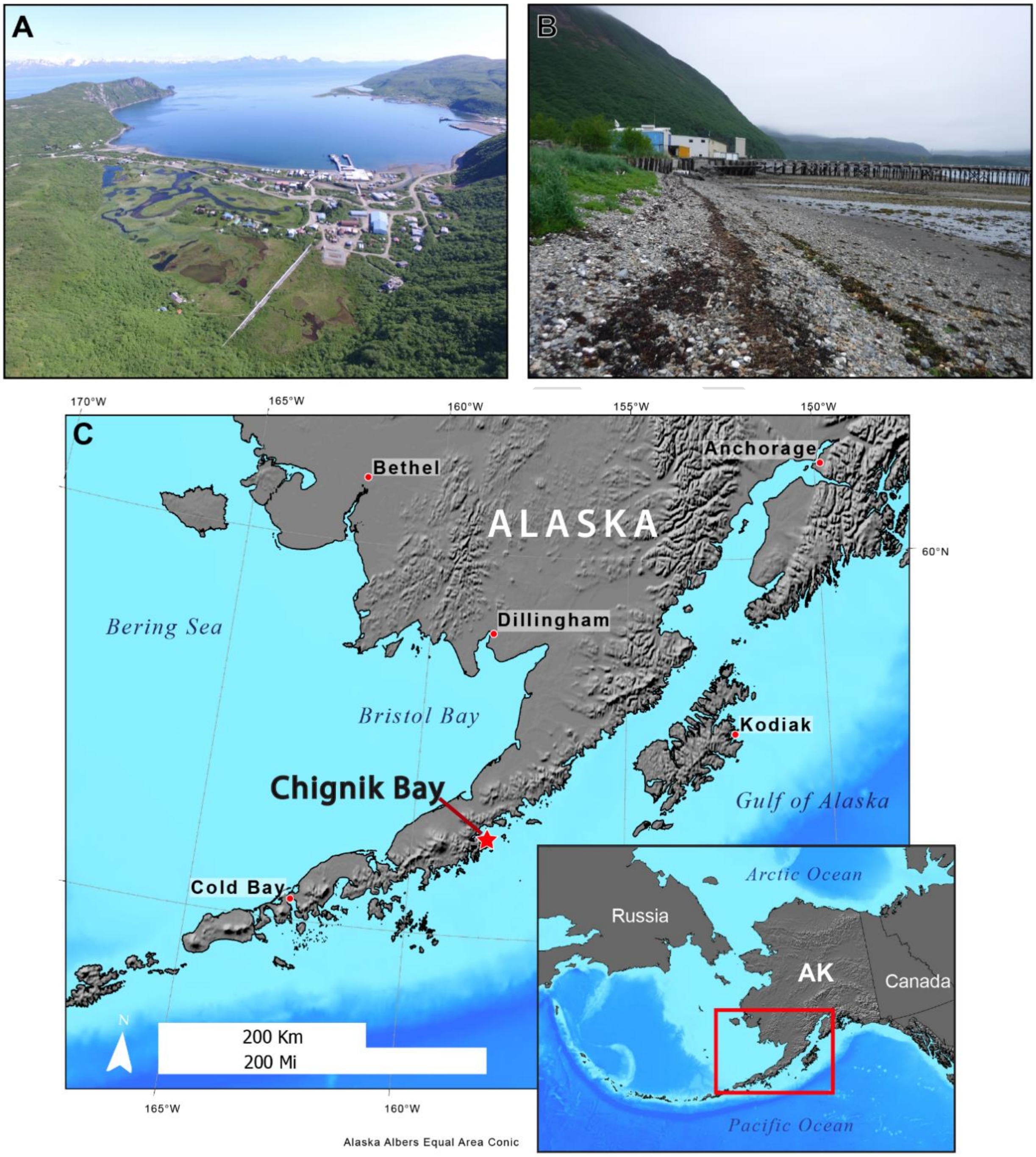

Figure 1. Regional context of the Chignik Bay, AK study site. (A) Aerial view of Chignik Bay. (B) Beach and cannery. (C) Regional map showing Chignik Bay's location in Alaska.

2.3 COMMUNITY INFORMATION

According to the 2017 State of Alaska Department of Commerce, Community, and Economic Development, Chignik Bay has a population of 96 – down from 188 as reported in the 1990 Census. The majority (57.14%) of the population is Alaska Native. The 2010 census reported 41 households with an average household size of three people (DCCED 2018).

2.3.1 Infrastructure Description

The community of Chignik Bay spans approximately 2.5 miles long with a state road connecting the main community with the airstrip and dock system. According to the 2010 census, 41 of 105 housing units are occupied (note: some of these may be seasonal homes not built to be lived in year-round).

There are several tank farms located around the community. There are three active tank farms: the east power plant tank farm, Trident tank farm, and the school tank farm. The east power plant tank farm contains six fuel tanks and is located 165 ft from Anchorage Bay (CIAP WEAR Trip Report, 2014). It acts as a fuel station for the community, and it supplies fuel to the east side power plant. The Trident tank farm contains eight fuel tanks and is located 60 ft from Anchorage Bay. It provides fuel for the Trident Seafoods Corporation (CIAP WEAR Trip Report, 2014). The school tank farm, located behind the school, provides fuel for the school. The site is located 1,200 ft from Anchorage Bay (CIAP WEAR Trip Report, 2014).

The city landfill has been in operation since 1996. It is unpermitted and only accepts municipal waste (CIAP WEAR Trip Report, 2014). This site is 1,000 ft from the west side of Anchorage Bay and 2,000 north of the main residential area (CIAP WEAR Trip Report, 2014). Indian creek holds a dam and a reservoir that treats water for all homes and the school. Piped sewage is held in community tanks and discharged through ocean outfall lines (CIAP WEAR Trip Report, 2014).

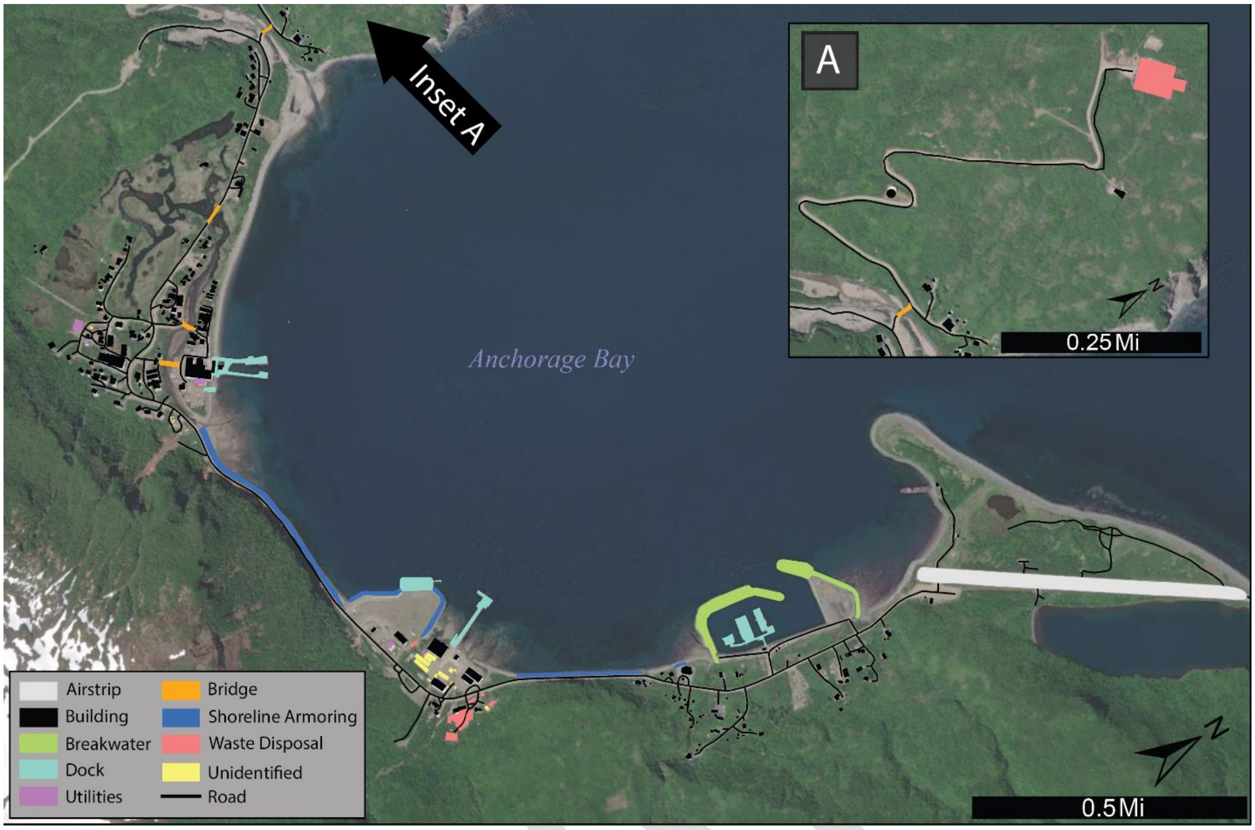

Figure 2. Map showing the building and utility infrastructure of Chignik Bay. (A) The extent of the community, (B) The waste disposal site. Data are displayed over ArcGIS base imagery provided by Esri.

2.3.2 Transportation

The primary methods of transportation within the community are four-wheel drive vehicles followed by all-terrain vehicles. Skiffs and air transportation are typically used to travel to surrounding communities. The unpaved road system consists primarily of sands. There is a 1.2km long by 23m wide gravel airstrip in the community with regular air traffic typically scheduled three days a week (HDR, 2011). There is an 80m long dock in the eastern section of the community with berthing areas large enough to receive commercial barges as well as a smaller boat loading ramp for smaller watercraft (HDR, 2011).

2.3.3 Economy

The main source of employment comes from the local government and health services with other manufacturing, construction, information, professional and business services, trade, transportation, and utilities (ALARI, 2018). The primary source of food for the community comes from a subsistence lifestyle (DCCED, 2018). The median household income in the community was $75,417per the Alaska Demographics 2021 report.

2.4 GEOLOGIC SETTING

Chignik is built on the Pacific side of the Alaska Peninsula, a volcanic arc formed by subduction zone processes. The city is approximately 30 miles east of Mount Veniaminof and 40 miles southwest of Mount Aniakchak, two historically active volcanoes (**Figure 3**). The U-shaped Anchorage Bay comprises sedimentary and volcanic rock formations with regions covered by unconsolidated alluvium. Three major sedimentary rock formations make up the bulk of the bay. The small dome of volcanic rock found in Anchorage Bay is an intrusive rock. The volcanic rocks covering the sedimentary formations south of Chignik are an unconformity from the Meshik Formation. Most of the surficial geology is hard rock, promoting a stable shoreline. Much of the city is built atop unconsolidated alluvium (silt, sand, and gravel) deposited by streams. There are several faults identified in the area.

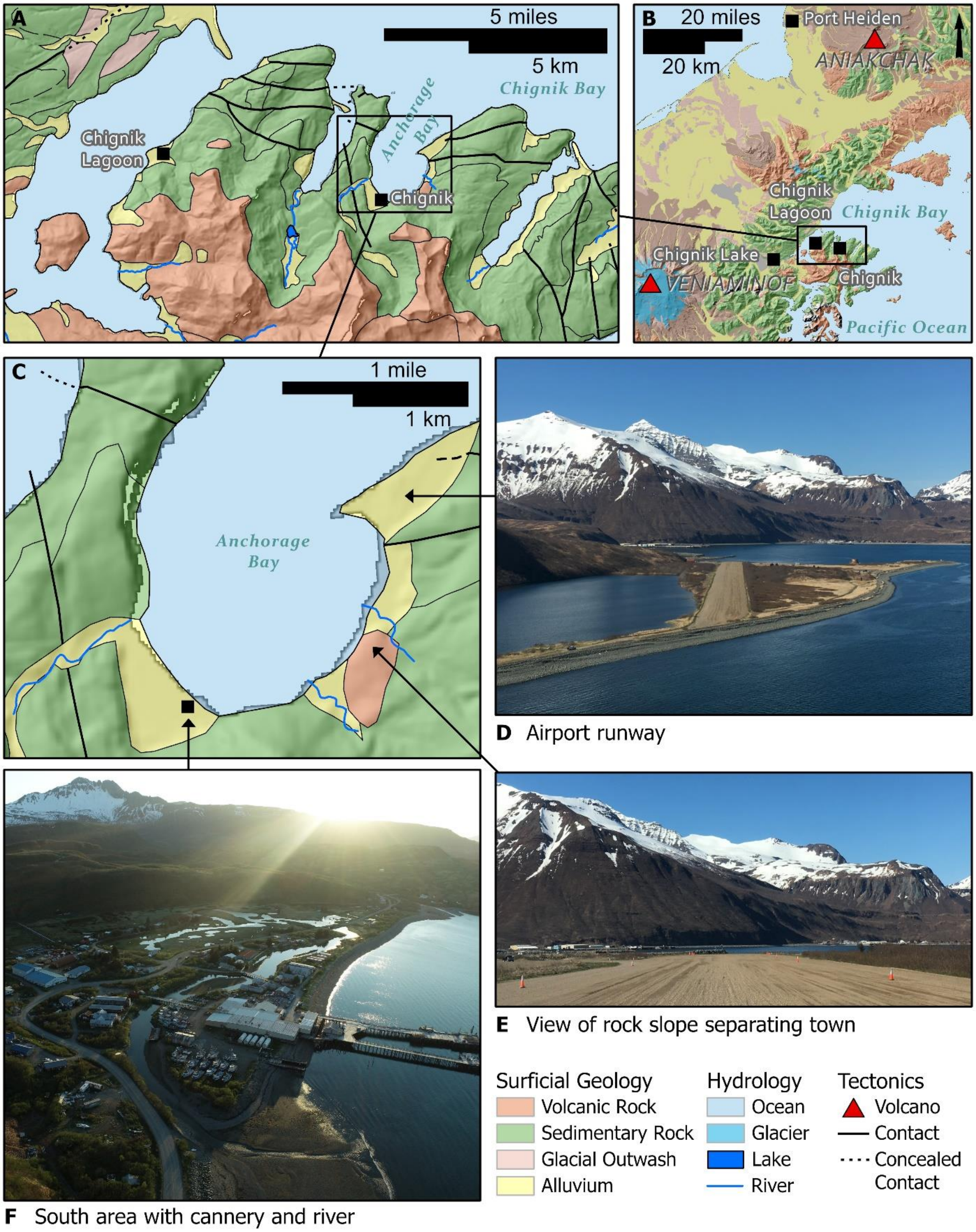

Figure 3. Surficial geology of Chignik (from Detterman et al., 1981). (A) The Chignik Bay area comprises sedimentary and volcanic rock with scattered alluvium deposits. Numerous faults exist. (B) This region is near two historically active volcanoes. (C) Anchorage Bay has mountainous hard-rock formations with three zones of unconsolidated sediments where Chignik is built. (D, E, F) Examples of Chignik in relation to surficial geology.

2.5 CLIMATE AND METEOROLOGY

2.5.1 Temperature Regime

Temperatures across Alaska have increased between 1970 and 2019. Southwestern Alaska and the Aleutian Island chain have observed temperature increases of between 2 and 5 °F over this period which could have significant ecological and physical impacts (**Figures 4, 5, 6**). Seasonal trends show an increase in temperatures, especially in regard to fall (**Figures 7 & 8**). The four warmest falls have all occurred within recent years and the warmest year exceeding the warmest summer temps (**Figures 7 & 8**).

Chignik Bay is located within the southwest maritime climate zone, characterized by persistently overcast skies, high winds, and frequent cyclonic storms (DCCED, 2018). Annual precipitation averages 127 inches, with an average annual snowfall of 58 inches (NOAA, November 2013). The average winter temperatures range from 21 to 50°F, and the average summer temperatures range from 39 to 60°F. Extreme temperatures range from as high as 76°F to as low as -12°F have been recorded (NOAA, November 2013).

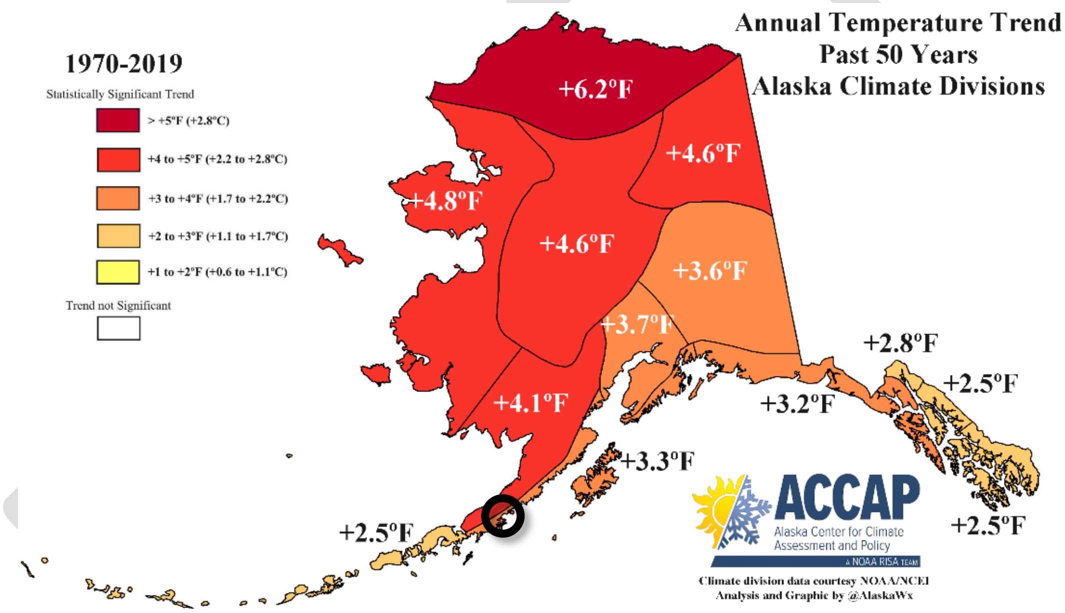

Figure 4. Annual temperature increase in Alaska between 1970 and 2019. Chignik Bay (black circle) has a 1.2°C (3.7°F) increase in temperatures over 49 years. Figure courtesy of Rick Thoman and ACCAP (URL: https://uaf-accap.org/air-temperature/).

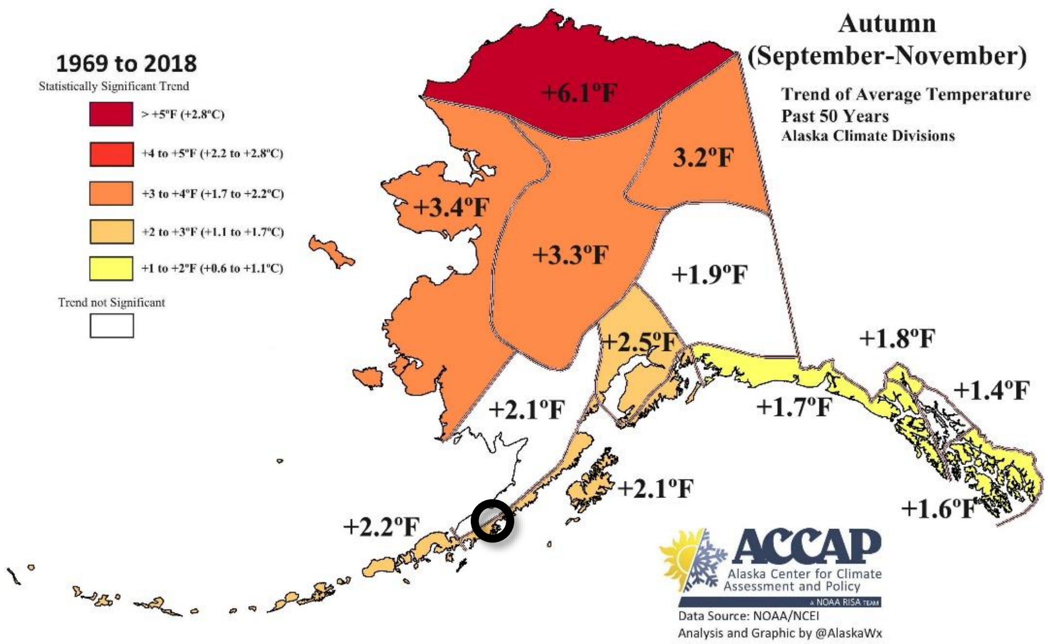

Figure 5. Autumn temperature increase in Alaska between 1969 and 2018. Chignik Bay (black circle) has a 1.2°C (2.2°F) increase in temperatures over 49 years. Figure courtesy of Rick Thoman and ACCAP (URL: https://uaf-accap.org/air-temperature/).

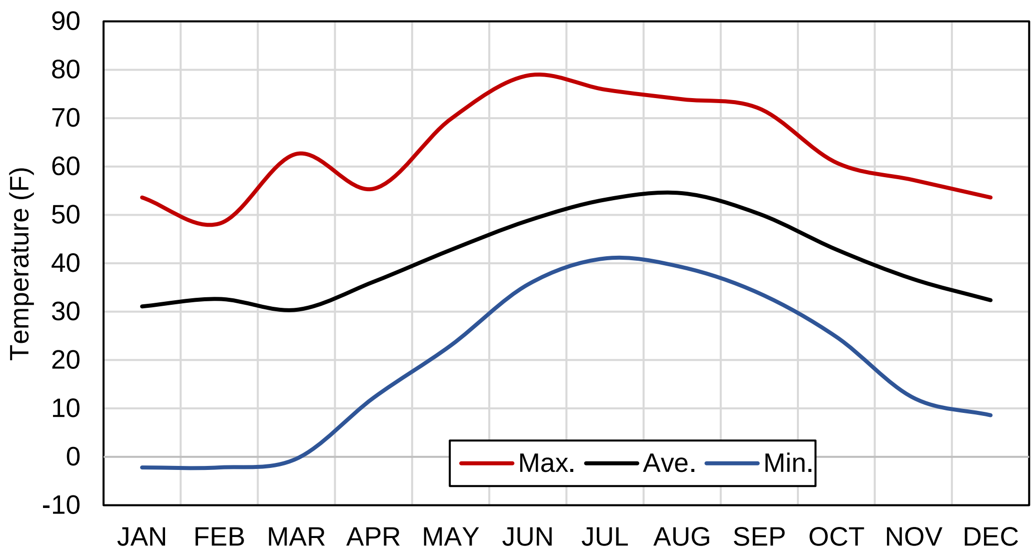

Figure 6. Temperature trends in Chignik Bay between 1997 and 2022 based on a local airport temperature gauge. Temperature data is from ASOS (URL: https://mesonet.agron.iastate.edu/request/download.phtml?network=AK_ASOS).

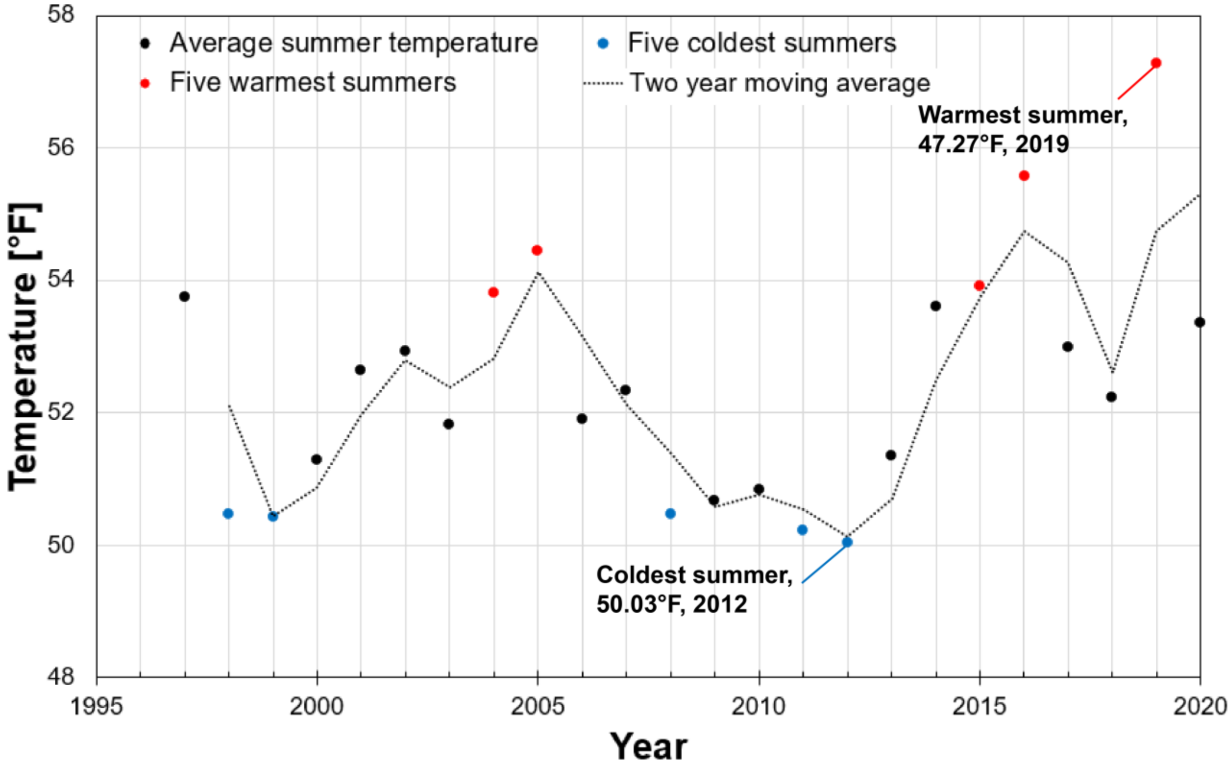

Figure 7. Mean summer (June-August) temperatures in Chignik Bay between 1997 and 2020 based on a local airport temperature gauge. The average summer temperature is 11.4°C (52.4°F). 2019 had the highest average temperature of 14.0°C (57.3°F), while 2012 had the lowest average temperature, at 10.0°C (50.0°F). Temperature data is from ASOS (URL: https://mesonet.agron.iastate.edu/request/download.phtml?network=AK_ASOS).

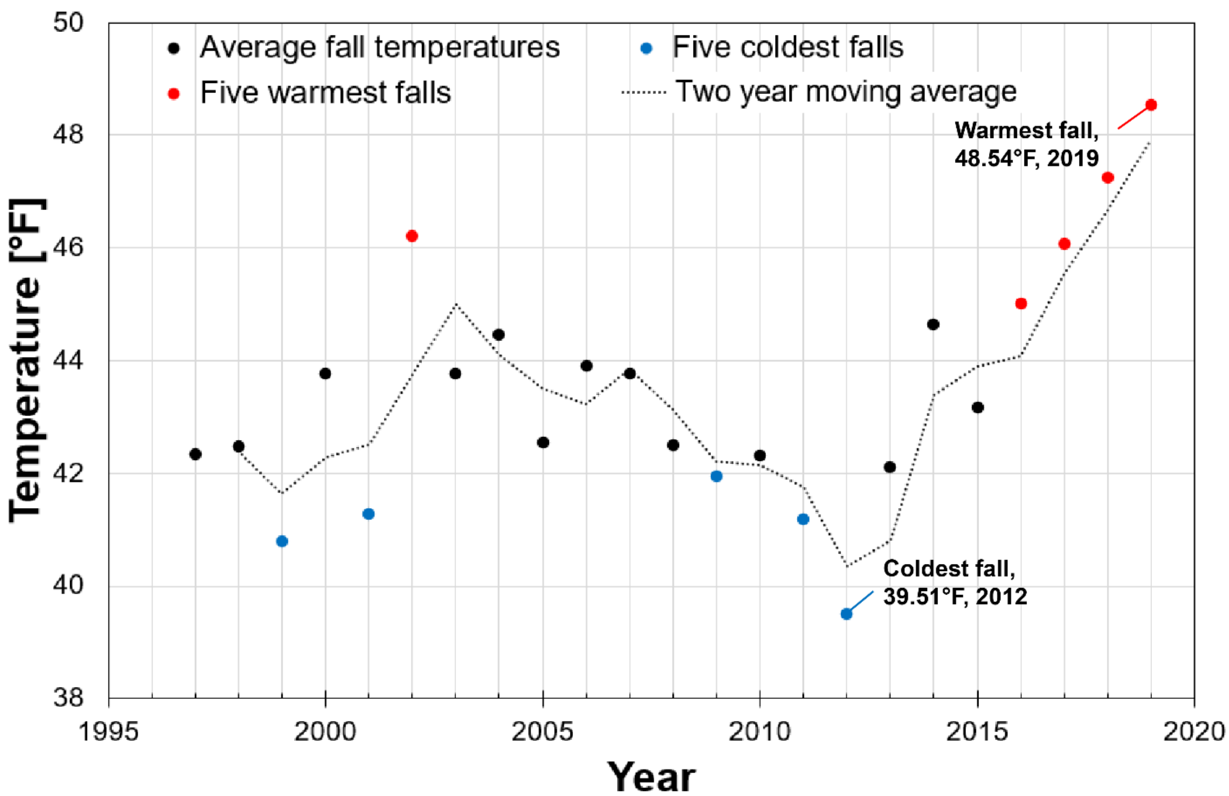

Figure 8. Mean fall (September-November) temperatures in Chignik Bay between 1997 and 2020 based on local airport temperature gauge. The average fall temperature was 6.4°C (43.5°F). The highest average fall temperature was 9.2°C (48.5°F) in 2019, while the lowest average temperature was 4.2°C (39.5°F) in 2012. Temperature data is from ASOS (URL: https://mesonet.agron.iastate.edu/request/download.phtml?network=AK_ASOS).

2.5.2 Wind Regime

Records of wind strength and direction at Chignik Bay were compiled from ASOS via the Iowa State University Environmental Mesonet (**Figure 9**). The dataset was recorded at the Chignik Bay airport (SID: PAJC) and spans 27 years. The plotted data show that winds predominantly prevail from the northwest and are strongest during the winter months, whereas prevailing wind direction is more variable during the summer months.

Chignik wind measurements from 1996 through 2023 shows winds average 9.3 mph and most commonly blow from the northwest (**Figure 9**). Winds are strongest during the winter months (**Figure 10**). The windier part of the year is from October to April, with average wind speeds of more than 10.3 mph. December is the windiest month of the year, with an average hourly wind speed of 11.1 mph. The calmer time of year is from May to September, with average wind speeds of 7.9 mph. The calmest month of the year is July, with an average hourly wind speed of 6.7 mph. Prevailing wind direction is more variable during the summer months.

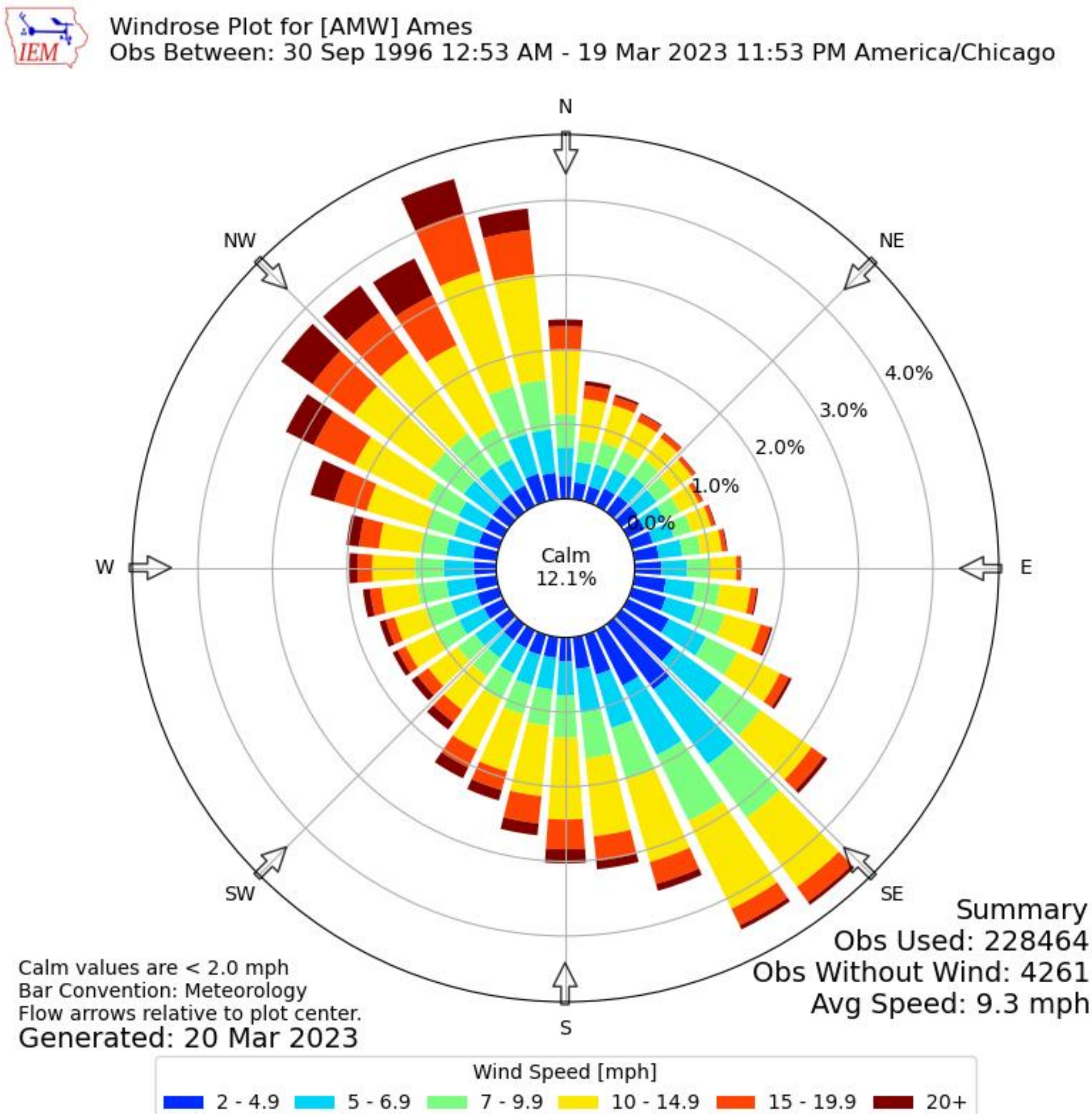

Figure 9. Average yearly wind rose for Chignik Bay computed from 1996 through 2022. Spokes point in the compass direction from which winds traveled. Colors within each spoke denote wind speed bins and the length of the spokes denote the frequency of occurrence. Wind is most frequent from the northwest and can exceed 20 mph (URL: https://mesonet.agron.iastate.edu/ASOS/).

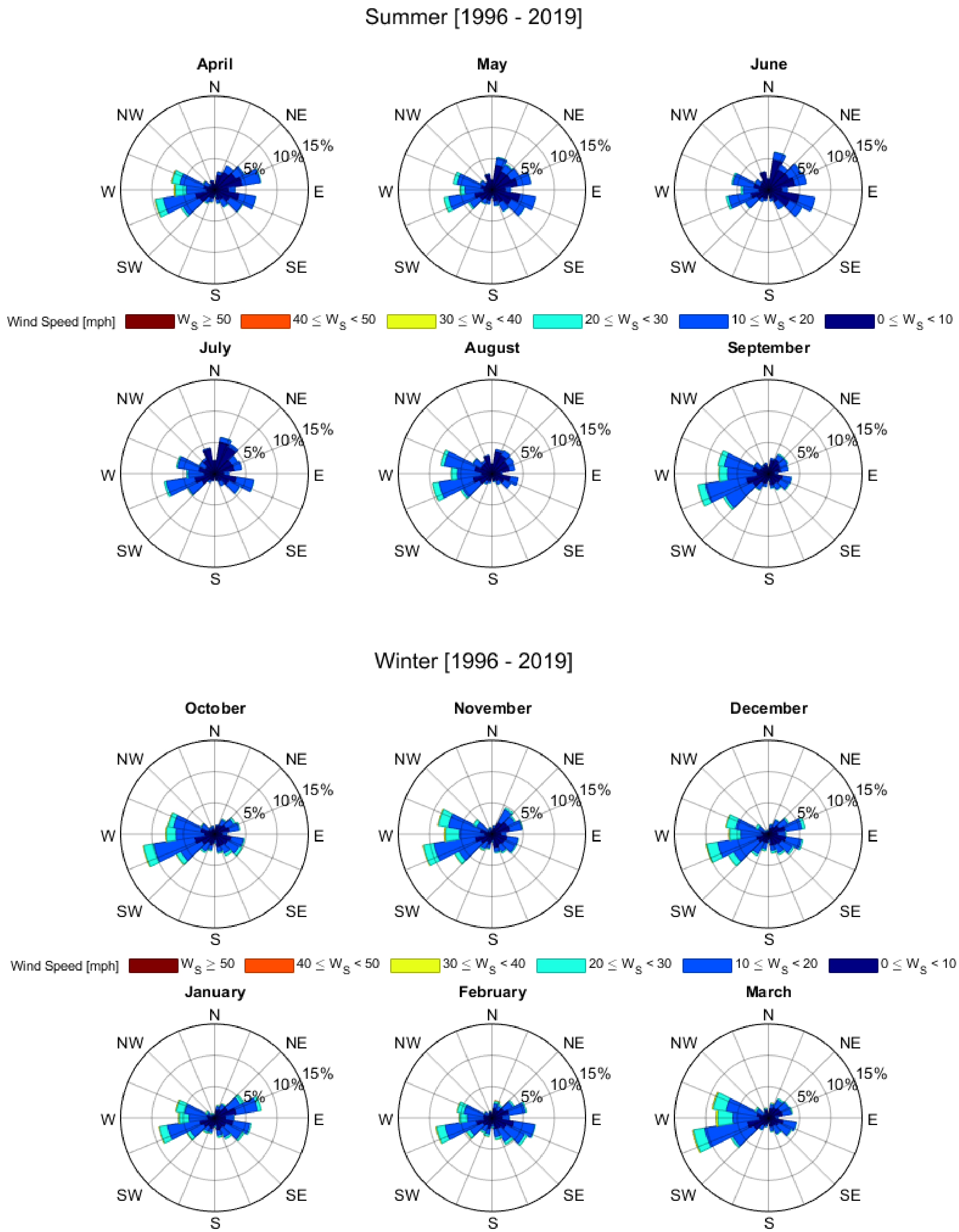

Figure 10. Averaged monthly wind roses for Chignik Bay (1996-2019). Spokes in each plot point in the compass direction from which winds traveled. Colors within each spoke denote wind speed bins and the

length of the spokes denote the frequency of occurrence. For example, in January, 10 mph to 20 mph winds were common and prevailed from the west. (URL: https://mesonet.agron.iastate.edu/ASOS/).

2.5.3 Storm Regime

Cyclones reaching the Gulf of Alaska most often come from the Pacific Ocean. According to the Beaufort Wind Scale, an extratropical cyclone is categorized as a storm when the wind speed attains values greater than 53.7 mph (24.5 m/s; WMO, 1970). Storms can last anywhere from 12 to 200 hours (up to >8 days), depending on the season and local geography, and can vary in size from mesoscale (≤1000 km) to synoptic scale (>1000 km). Storms are often associated with damaging winds (Mesquita et al., 2010) and/or strong precipitation in the form of rain and snow (Sorteberg and Walsh, 2008).

Chignik Bay is in a region of moderate to high storm track density, especially during fall (Stabeno et al., 2004; **Figure 11**). Storms in the region linger due to surrounding mountains that inhibit eastward progression (Wilson and Overland, 1986). Winds in the region are cyclonic typically from the fall season throughout the spring (Stabeno et al., 2004). While wind data has not been well recorded, there have been max wind speeds of almost 67mph with gusts of over 100mph recorded (ASOS, 2023).

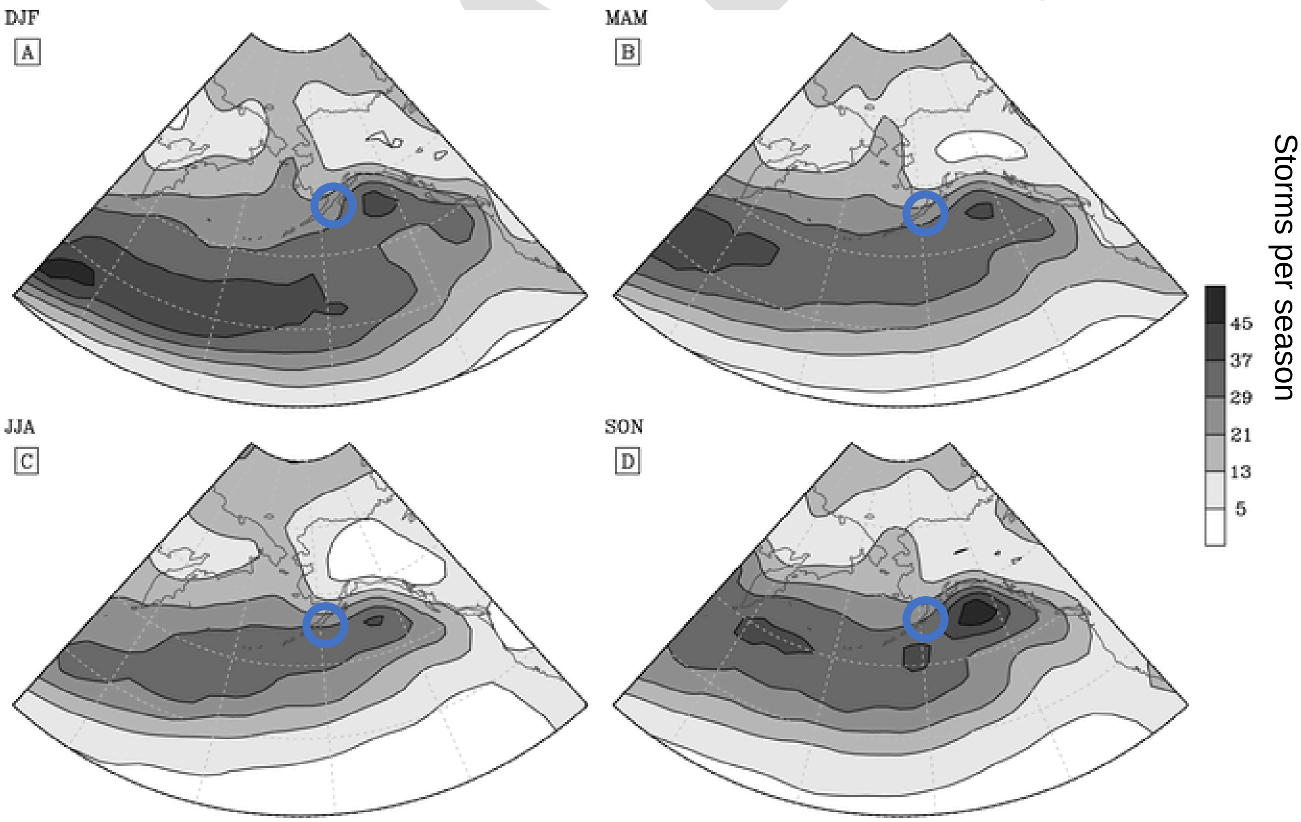

Figure 11. Storm track density climatology in the North Pacific from 1948/49 to 2008. (A) winter (DJF), (B) spring (MAM), (C) summer (JJA), and (D) autumn (SON) seasons. Units: Storms (10^6 km^2 season)$^{-1}$. Location of Chignik Bay is noted by the blue circles. Notice that Chignik Bay observes greater than 21 storms per season on average (after Mesquita et al., 2009). (URL:https://doi.org/10.1175/2009JCLI3019.1).

2.6 OCEANOGRAPHIC SETTING

2.6.1 Tides and Currents

Chignik has semi-diurnal tides with a great diurnal range of 8.93 ft (2.722 m; **Table 1**). The Alaska Coastal Current flows southwest (**Figure 12**).

Table 1. Tidal datum for Chignik, Anchorage Bay (NOAA station ID 9458917).

Datum	Abbreviation	Ft MLLLW	M MLLW
Mean Higher-High Water	MHHW	8.93	2.722
Mean High Water	MHW	8.13	2.477
Mean Tide Level	MTL	4.79	1.459
Mean Sea Level	MSL	4.70	1.432
Mean Diurnal Tide Level	DTL	4.47	1.361
Mean Low Water	MLW	1.45	0.441
Mean Lower-Low Water	MLLW	0.00	0.000
North American Vertical Datum of 1988	NAVD88	1.61	0.490
Great Diurnal Range	GT	8.93	2.722
Mean Range of Tide	MN	6.68	2.036

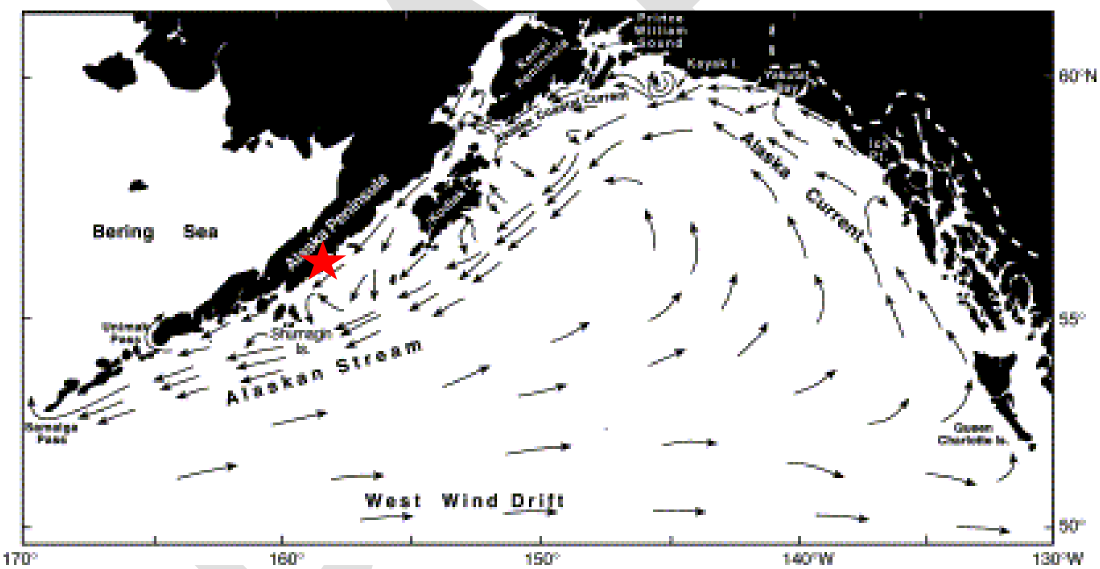

Figure 12. Map of the Gulf of Alaska. The red star represents Chignik Bay. The flow of the Alaska Coastal Current and subarctic gyre are indicated as are several geographic place names. (After Reed and Schumacher, 1986).

2.6.2 Wave Climate

The mean significant wave height (SWH) in Chignik Bay is 1.20 m (SD = 0.32 m), reaching as high as 2.49 m in December 2000 (**Figure 13**). Monthly Mean SWH is lowest in July (0.79 m) and greatest in December (1.59 m). Average annual SWH increased by 0.08 m (7%) from 1959 to 2022. Mean monthly SWH values were modeled by Hersbach et al. (2020).

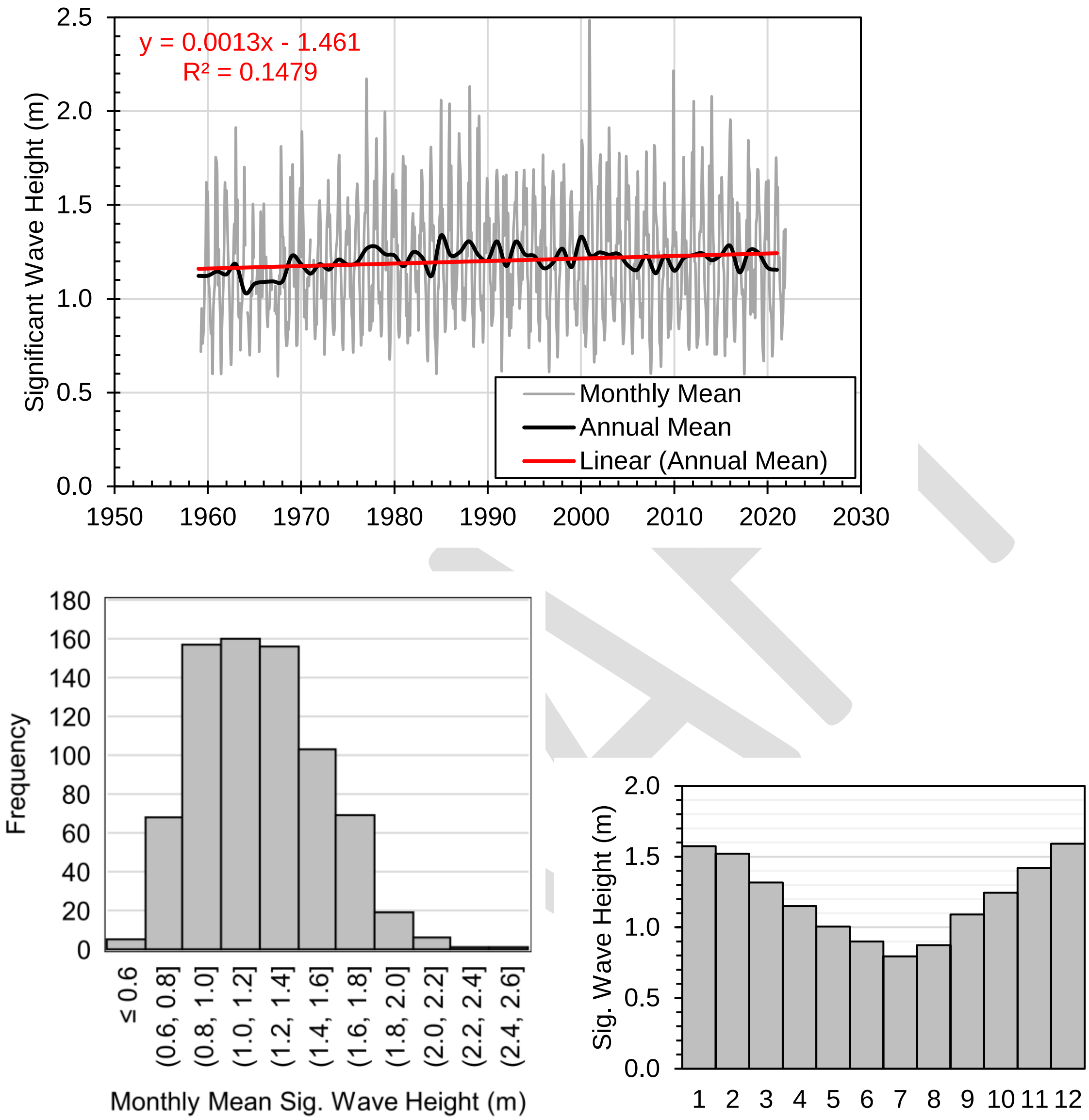

Figure 13. Significant wave height (SWH) statistics for Chignik Bay. (Top) Monthly (gray) and annual (black) mean SWH from 1959 through 2021. The linear regression of annual SWH (red) shows a slight increase but interannual variability is very high. (Bottom Left) Histogram of SWH shows the average is 1.20 m with SD 0.32 m. Values range between 0.5 to 2.6 m. (Bottom Right) Monthly mean SWH shows SWH is greatest in winter and lowest in summer.

2.7 SEA ICE

Coarse-resolution global sea ice models indicate sea ice does not have a significant presence in Chignik Bay. The model used by Hersbach et al. (2020) shows on average 1 month per year of wave-dampening sea ice existed from 1959 to 1971, but this is no longer the case. Sea ice does not play a significant role in Chignik Bay.

3. NATURAL HAZARDS AND MITIGATION EFFORTS

3.1 DESCRIPTION OF HAZARDS

The following subsections (3.1.1 – 3.1.6) describe and quantify the following natural hazards: erosion, flooding, earthquakes, landslides, tsunami, and sea level change. This list specifically pertains to *coastal* related hazards and is partially based on information in the Lake and Peninsula Borough Hazard Mitigation plan and observations by residents. As such, potential non-coastal natural hazards like volcanoes and wildfire are not examined by this report.

3.1.1 Erosion

Shoreline change is the retreat or aggradation of a shoreline as a result of sediment erosion or accretion (Mangor et al., 2017). Shoreline change can occur because of changing sediment supply, oceanographic conditions, episodic storm events, terrestrial degradation through slope failure or permafrost thaw, and other nature- and human-driven processes (**Figure 14**) (Overbeck et al., 2020). Shorelines are naturally very dynamic; however, when changes occur at or near infrastructure and land used for hunting or gathering subsistence resources, erosion can be disastrous.

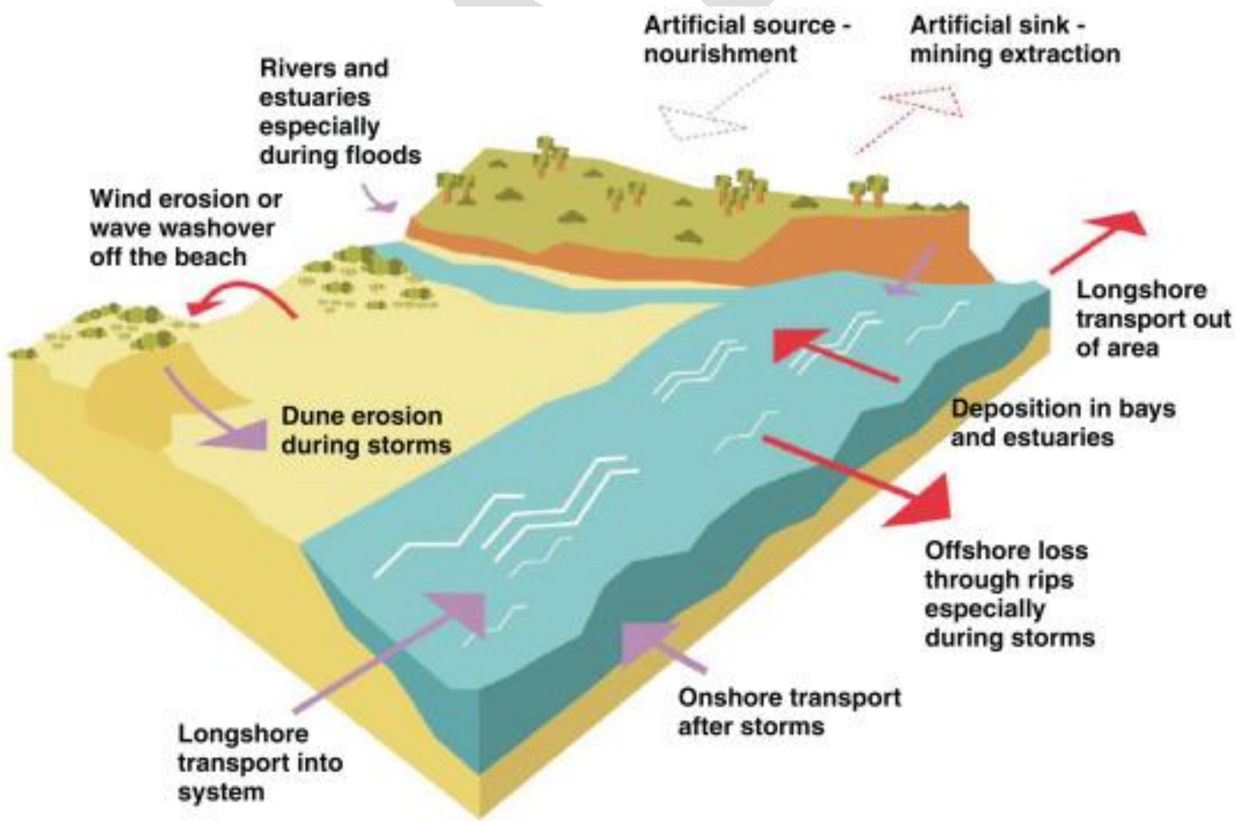

Figure 14. Components of a sediment budget for a sandy coast. From Goodwin et al., 2020 (URL: https://doi.org/10.1016/B978-0-08-102927-5.00025-4).

Riverine flooding can also occur. This may result from heavy rainfall, snowmelt, or a combination of these with a high tide or storm surge.

According to the Chignik Bay Tribal Hazard Mitigation Plan (2019), the erosion of highest concern is the spring runoff in rivers and creeks eroding through the community to the point where homes and the community's infrastructure (utilities, roads etc.) are undermined. Critical assets located near erosion areas include bridges, homes, access roads, the airport, and the clinic. Because the two parts of the community are connected via a road that has been affected by erosion, access to any asset between the two sides can be affected (Chignik Bay Tribal Hazard Mitigation Plan 2019).

3.1.2 Flooding

Coastal flooding is predominately caused by storm surge during high tide (USACE, 2009). Storms drive water to the coastline and raise water levels above normal tide levels (storm surge and wave set-up). As waves break, they can travel up the beach (wave run-up) and temporarily reach higher than the still water level (Sallenger, 2000).

Total water level (TWL) is a summation of the tide, setup, and wave run-up (Erikson et al., 2018) and can be generalized as the combination of 1) a static (or assumed static or slowly varying) mean water level associated with astronomical tides, storm surges, and wave setup; and 2) a fluctuation about that mean (swash) associated with surf beat and the motion of individual waves at the shoreline (**Figure 15**). Wave run-up can add meters to the total water level on the open ocean coast. This also controls the elevation of the primary dune toe and wave impact hours (as computed from a TWL time series; Ruggiero et al., 2001; Ruggiero, 2004).

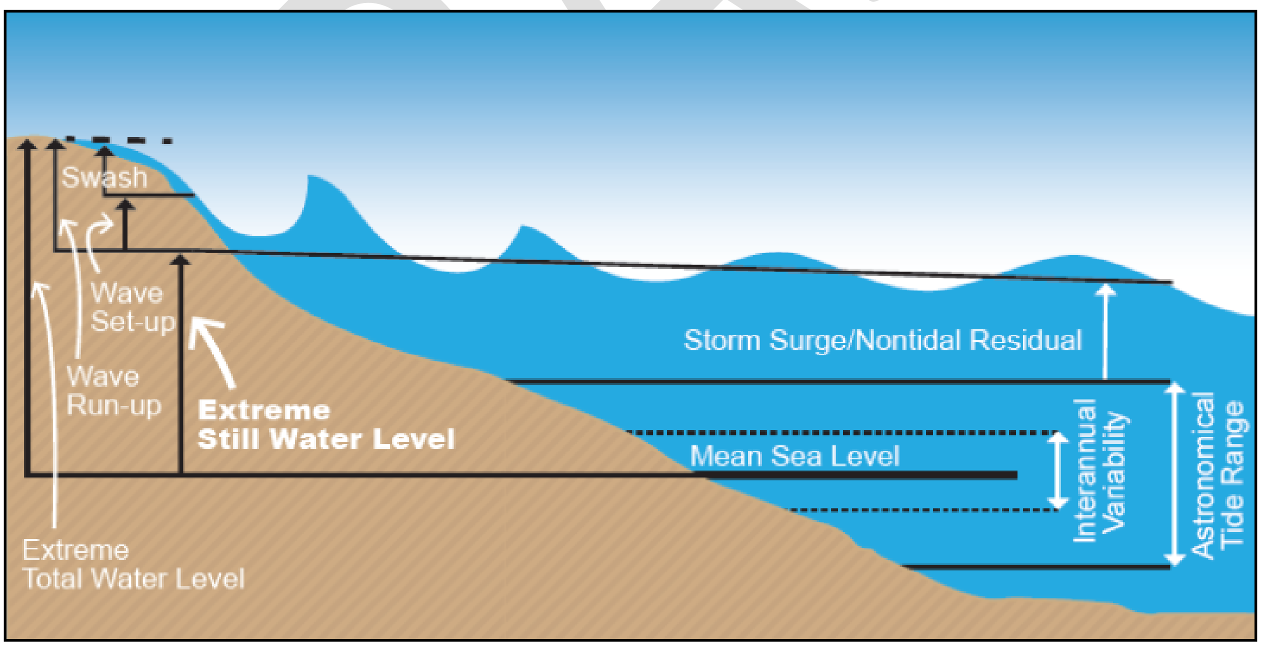

Figure 15. Diagram showing the various components of Total Water Level (TWL); waves, tides, and nontidal residuals. After Moritz et al., 2015.

The Chignik Bay Tribal Hazard Mitigation Plan (2019) explains that annual flooding occurs due to spring melt runoff and rainfall. High tide combined with spring melt can lead to flooding of low-lying areas including the airport runway. Flooding occasionally impacts homes, basements, and other structures. Roads have been built higher to prevent flooding and washouts, but issues from widespread flooding persist.

Chignik Bay does not have a clear or extensive record of the highest known flood, annual flood levels, or flood impacts (**Table 2**). These metrics are invaluable to support endeavors to reduce flood impacts. Chignik Bay does not have a water level sensor to record coastal flooding. FEMA does not have flood maps for this location. A survey of flood records and community infrastructure can be used to inform the elevation for safe construction and even aid in forecasting impacts from storms. A high-resolution DEM can be used to map flood extents and depths.

Table 2. Table of documented flooding events in Chignik Bay from hazard mitigation plans and USACE.

Date	TWL (m)	Cause	Impacts
2018	Unknown	Not specified	12 inches standing water in City Office building[1]
2002-OCT-23	Unknown	Heavy rain, storm surge	Damage to docks, piers, bridge, and homes.[2]
1986-DEC-31	Unknown	Not specified	Photo[2]
1948-OCT	Unknown	Storm surge	See appendix

[1]Chignik Bay Tribal Council (2019)
[2]Lake and Peninsula Borough (2015)

3.1.3 Earthquakes

The USGS produces probabilistic seismic hazard maps based on earthquake history and seismic potential based on the location, depth, and characteristics of geologic faults (**Figure 16**;Wesson et al., 2007). These maps indicate the probability of an earthquake event exceeding a certain measure of ground acceleration, which correlates with the most intense shaking experienced during an earthquake event. The USGS standardizes acceleration into three measures: peak ground acceleration (PGA), 0.2 second spectral acceleration (SA), and 1.0 second SA. Each of these is measured in %g, or percent of the force of gravity. PGA measures particle movement at ground level, whereas SA describes the maximum acceleration in an earthquake on an object – specifically a damped, harmonic oscillator moving in one dimension. 0.2-0.6 second SA is applicable to buildings with less than seven stories. As such, we utilize PGA and 0.2 second SA.

An earthquake with a magnitude of above a 7.0 on the moment magnitude scale is considered a major earthquake (Michigan Technological University, 2021). The Community is located approximately 512 miles southwest of the 1964 earthquake epicenter, the largest recorded earthquake in Alaska. The community is not located on any mapped fault lines. The largest earthquake that has occurred within a 75 miles radius of the community was a magnitude 8.2 on the Richter scale, located 28.5 miles away on the Alaska Peninsula in July 2021 (Chignik Bay Tribal Hazard Mitigation Plan

2019). The closest earthquake to occur near the community above a magnitude 2.5 was a magnitude 2.8 earthquake that occurred 1.7 miles away in June 2006 (USGS 2018).

The most severe earthquake felt in the Community was the Great Alaska Earthquake of 1964 (Alaska Earthquake Center 2018). This earthquake had a recorded magnitude of 9.2 on the Richter scale, making it the second largest recorded earthquake in the world.

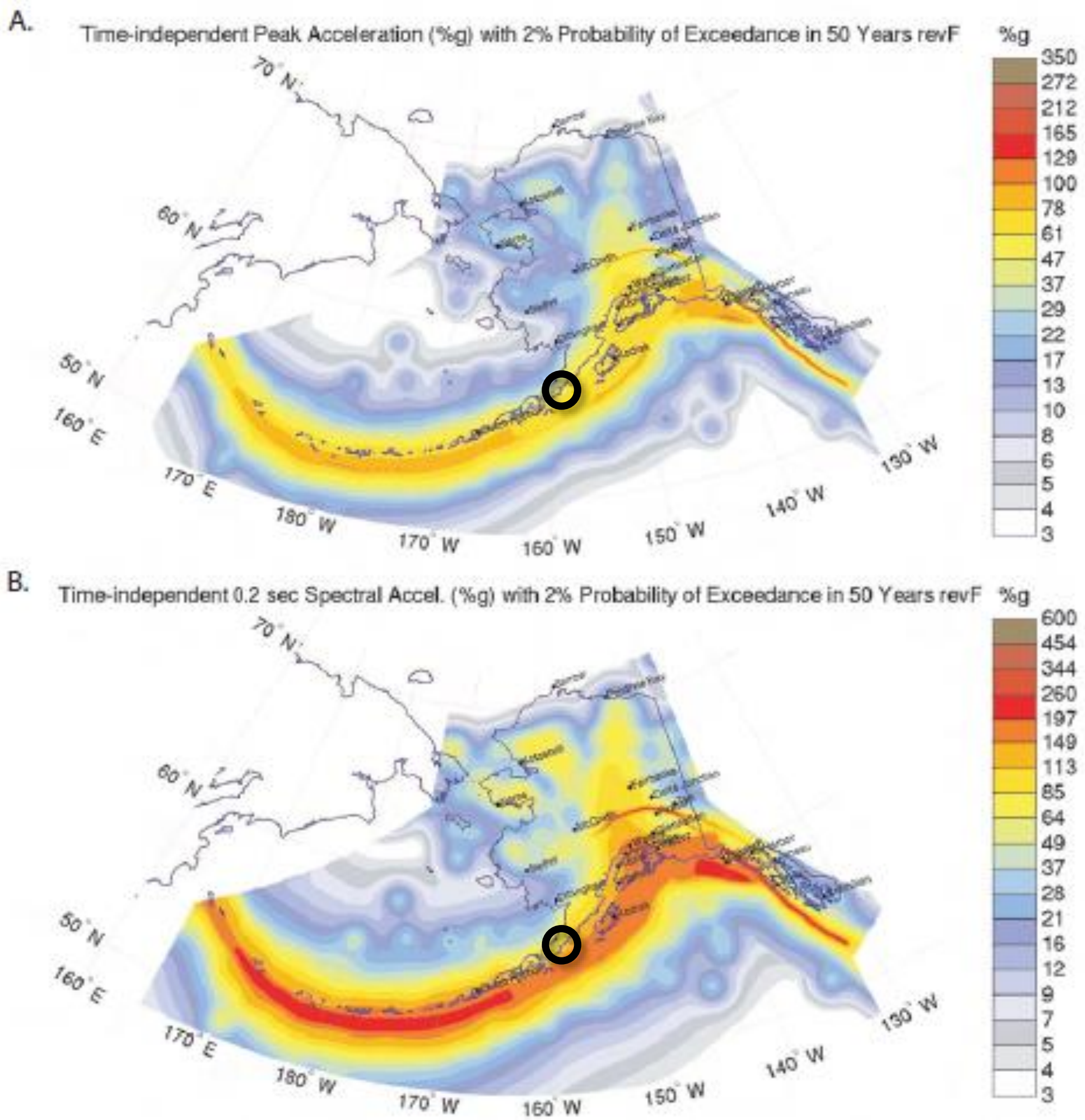

Figure 16. Earthquake probability in Alaska . Probabilistic ground motion with a 2-percent probability of exceedance in 50 years for peak ground acceleration (A), 0.2 second spectral acceleration (B). Nelson Lagoon noted by blue circle. (URL: https://www.usgs.gov/natural-hazards/earthquake-hazards/hazards).

3.1.4 Mass Land Movement

An avalanche is the movement of snow and debris down a slope by force of gravity. Avalanches occur when the stability of the slope changes from stable to unstable. This can be caused by storms, earthquakes, volcanic eruptions, rapid temperature changes, and other human activities. Steep slopes and long slopes have a higher probability to slide.

A landslide is the movement of a mass of debris, rock, or earth by force of gravity down a slope (Cruden and Varnes 1996). This can be caused by storms, earthquakes, volcanic eruptions, fire, erosion, and other human induced activities (Gariano and Guzzetti 2016). Steep slopes and long slopes have a higher probability to slide. Landslides cause infrastructure and property damage, environmental disturbance, and possible injuries and fatalities (Petley 2012).

According to the Chignik Bay Tribal Hazard Mitigation Plan (2019), avalanches occur on the mountains surrounding the community. The areas above the road sections that connect the two sides of the community have long, steep slopes. When avalanches occur, access to critical infrastructure for residents on opposite sides of the avalanche is cut off (Chignik Bay Tribal Hazard Mitigation Plan 2019). For example, the airstrip and medical clinic are located at the north end of town and is accessible only by the main road that runs along the base of steep slopes. If access to this road is obstructed, the airstrip becomes inaccessible to the southern end of the community. In 2002, such was the case when an avalanche obstructed the main road to the airport, separating the north and south ends of town for 2 weeks.

Landslides occur on the mountains surrounding the community (Chignik Bay Tribal Hazard Mitigation Plan 2019). In addition to landslides, large boulders and rocks fall from these steep slopes and pose a threat. Falling boulders or rocks can hit travelers, or land on the road causing a road hazard. When landslides occur, they cut off access to critical infrastructure and can wash out the road. Reportedly, large masses of soil and large rocks slough off or topple down onto the road (Chignik Bay Tribal Hazard Mitigation Plan 2019).

3.1.5 Tsunami

A tsunami is a large, fast-moving wave caused by the displacement of a large volume of water. They can be triggered by earthquakes, volcanic eruptions, submarine landslides, and onshore landslides. Tsunamis caused by earthquakes are generated from the epicenter offshore. With adequate detection, this usually allows warning times of minutes to hours. Tsunamis generated by eruptions and landslides are called “local tsunamis” and have little warning time. Local tsunamis can potentially reach much higher in the area they were generated. For example, the 1964 earthquake caused tsunami waves up to 90 ft (27 m), but a landslide in Valdez Inlet caused a local tsunami reaching 220 ft (67 m). Tsunami waves can bounce off shorelines and cause complex changes to water levels. This process, called seiche, may have occurred in Chignik Lagoon in 1964. The first wave arrived 3 hours after the earthquake, but the highest wave occurred 6 to 7 hours after (Nicolsky et al., 2016).

Chignik experienced tsunamis in 1946 and 1964 that caused water elevation of 5 ft (1.5 m) and 10 ft (3 m), respectively. These were caused by subduction zone ruptures of magnitude 8.6 (1946) and 9.2 (1964). A worst-case tsunami scenario (magnitude 9.25) could result in coastal areas flooded to 80 ft (24 m) with a maximum depth of 102 ft (31 m) on Anderson Street (Nicolsky et al., 2016; **Figure 17**). Evacuations on foot could require up to 43 minutes. While the impacts would be devastating, there is a small likelihood of an earthquake of this magnitude happening any given year. Nicolsky et al. (2016) model earthquakes on the Alaska Peninsula at varying depth between magnitude 8.9 and 9.25. Since at least 1899, only one Alaska earthquake occurred in this range (1964). There were 9 earthquakes between 8.0 and 8.7 magnitude (1 every 13 years on average). The 1964 earthquake is believed to be a 500-year event and may have last ruptured in 1585. Since 1900, earthquakes of magnitude 8.0 to 8.7 have occurred every 14 years on average throughout the entire state. The epicenter location and depth have to be in the correct configuration to affect Chignik, reducing the likelihood an event would cause a tsunami. However, the tsunami generated by local landslides or seiche is also possible.

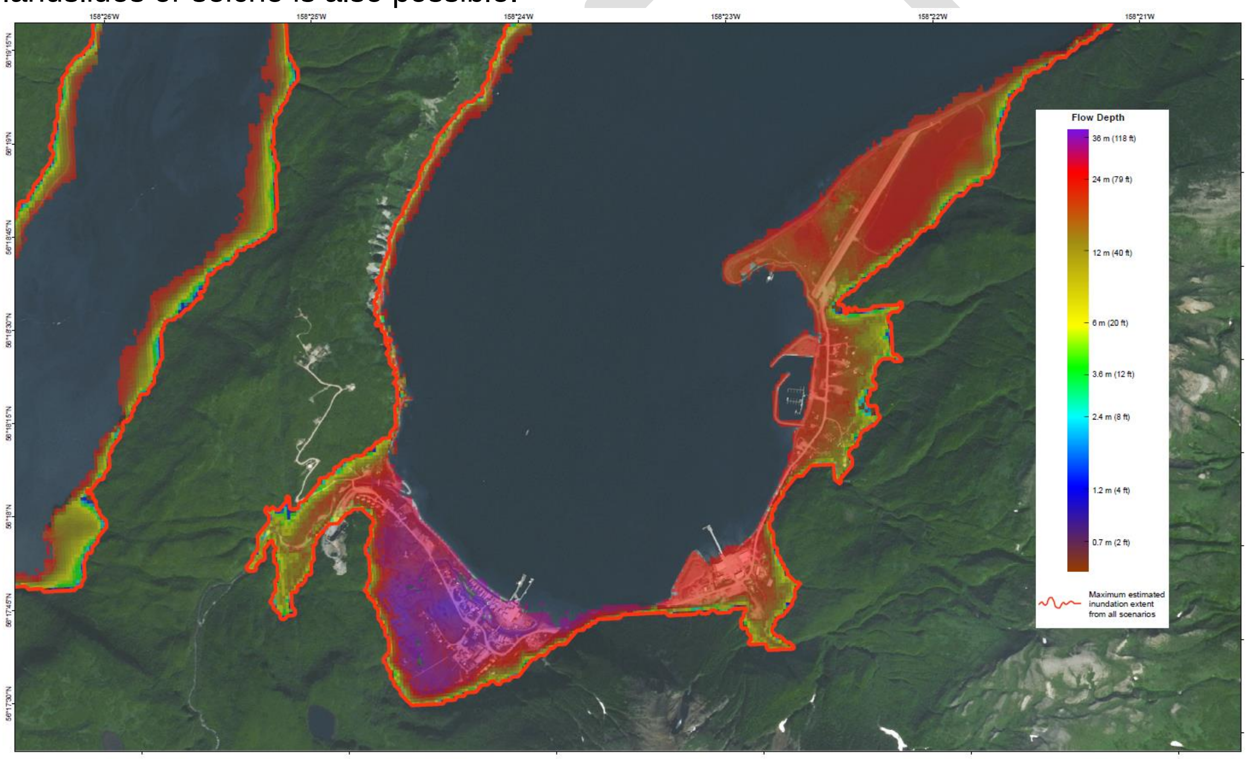

Figure 17. Tsunami hazard map of Chignik Bay (red hatched line represents hazard zone with hatch marks toward potential inundation zone). The map is not appropriate for site-specific use or for land-use regulation (CBTC, 2019).

3.1.6 Sea Level Change

A large number of studies worldwide suggest that over the past 1,000 years global average (eustatic) sea level has risen at a rate of <2mm (<0.08 in) per year (Gornitz, 1995). Eustatic sea level has risen about 21–24 cm (8–9 in) since 1880, with about a third of that occurring in the last 25 years. The rising water level is mostly due to a combination of meltwater from glaciers and ice sheets and thermal expansion of seawater as it warms. In 2019, global mean sea level was 87.6 mm (3.4 in) above the 1993 average—the highest annual average in the satellite record (1993-present). From 2018 to 2019, global sea level rose 6.1 mm (0.24 inches) (Wuebbles et al., 2017; Cazenave et al., 2018; Davidson-Arnott et al., 2019).

Sand Point is the closest geodetically referenced station, 164 km away from Chignik Bay. Relative sea level rise (RSLR) is the combination of eustatic (global) sea level rise and local land subsidence (or in some cases, rise in land elevation). This local change in land elevation has a variety of causes, such as earthquake deformation cycles, groundwater reduction or increase, oil extraction, etc. RSLR in the Chignik area is 1.35 ± 0.83 mm/yr (0.44 ft/century; **Figure 18**).

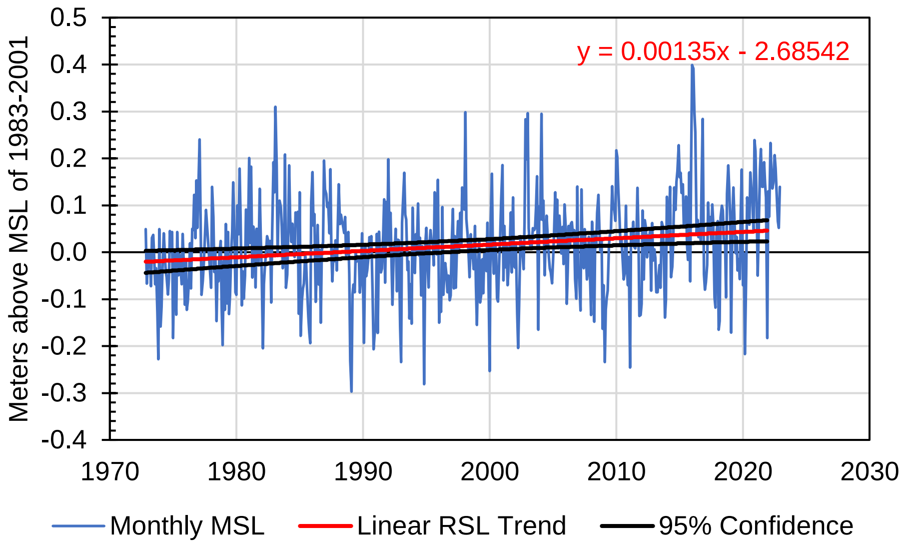

Figure 18. Monthly mean sea level (blue) from 1972 to 2022 at Sand Point (Station ID: 9459450) with average seasonal cycle removed. The long-term linear trend (red) is 1.35 mm/yr with uncertainty of 0.83 mm/yr at a 95% confidence interval (black). Water levels are relative to MSL from the National Tidal Datum Epoch of 1983 to 2001. (URL: https://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?id=9459450).

RSLR is anticipated to accelerate due to warming, but the rate of acceleration is complex to predict due to several factors including anthropogenic actions and uncertainty about ice-sheet response. Sweet et al. (2022) anticipate a high likelihood of global mean sea level (GMSL) exceeding 0.5 m by 2100, with a <5 to 23% probability of exceeding 1.0 m if warming reaches 3 to 5ºC. Exceeding 1.5 m by 2100 is less likely given the current understanding of ice-sheet response.

RSLR projections for Chignik Bay are shown for three scenarios of GSLR by 2100 of 0.5, 1.0, and 1.5 m (**Table 3**, **Figure 19**). Levels are relative to mean sea level in 2005. There is a reasonable likelihood of 13-17 cm (0.4-0.6 ft) by 2050 and 36-80 cm (1.2-2.6 ft) by 2100.

Table 3. RSLR projections for Chignik Bay computed from global models by Sweet et al. (2022). Rows represent different RSLR scenarios depending on GMSL. Each scenario has a probability of happening

given the anticipated warming of 2ºC by 2100 and less likely but possible warming up to 5ºC. Projections are split into three dates (2050, 2100, and 2150), then subdivided into mean values and the low and high boundaries of a 95% confidence interval. Projections are in cm above Chignik Bay modeled MSL in 2005.

GMSL by 2100	Likelihood for 2 to 5ºC	2050 (cm)			2100 (cm)			2150 (cm)		
		Low	Mean	High	Low	Mean	High	Low	Mean	High
0.5 m	50 to >99%	9	13	18	24	36	47	39	61	85
1.0 m	<5 to 23%	12	17	25	59	80	93	105	160	349
1.5 m	<1 to 2%	16	24	38	92	130	148	155	224	330

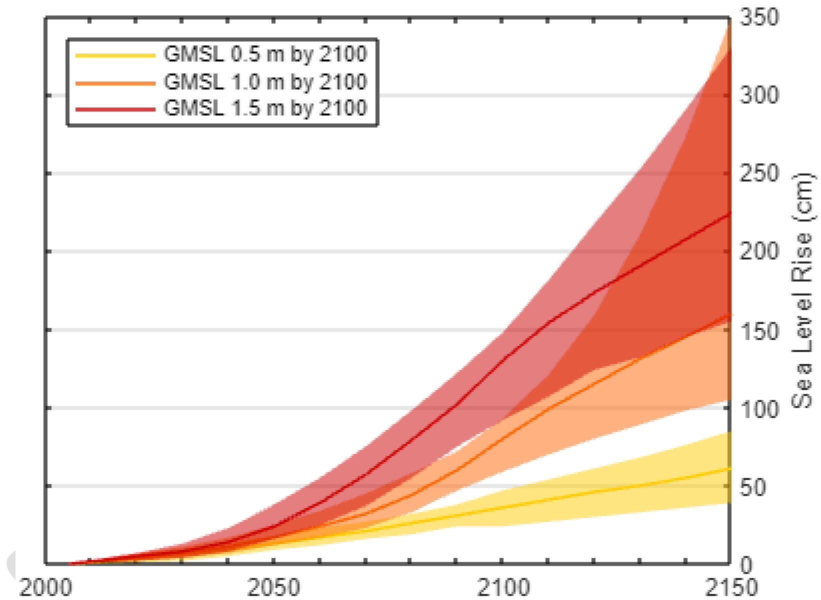

Figure 19. Graph of RSLR projections for Chignik Bay. Mean projected values are solid lines with the colored area representing a 95% confidence interval. The GMSL 1.0 and 1.5 scenarios have faster RSLR rates beginning around 2070.

3.2 PAST/ONGOING MITIGATION EFFORTS

The community of Chignik Bay has drafted a pre and post mitigation plan in the 2020 Tribal Hazard Mitigation Plan. The Community is working to protect their bridges by placing armor rock along the edges of the supports to stabilize the area (THMP 2019). As of 2022, the Chignik Bay Tribal Council has contracted Bristol Engineering to conduct their own infrastructure assessment in the community and have plans to construct tsunami shelters on both sides of the community.

4. DATA PRODUCTS AND ASSESSMENT TOOLS

This research was conducted in part to assess spatial patterns of vulnerability to erosion and flooding over long- and short-timescales, as well as to identify at-risk infrastructure in Nelson Lagoon. This was accomplished through ground-, water-, and air-based surveys coupled with computer-based processing and analysis using a geographic information system (GIS).

4.1 PREVIOUS ASSESSMENTS

Chignik Bay has two hazard mitigation plans and one assessment each for flooding, erosion, and tsunamis (**Table 4**).

Table 4. Summary of existing hazard assessments for Chignik Bay.

Date	Report	Leading Org.	Subjects
1992	High water mark survey	USACE	• Flooding
2007	Erosion information paper	USACE	• Erosion
2009	Community plan	City of Chignik Bay	• Community priorities
2014	Hazard mitigation plan	Lake and Peninsula Borough	• All hazards • Community priorities
2019	Tsunami inundation maps	DGGS	• Tsunami
2019	Hazard mitigation plan	Chignik Bay Tribal Council	• All hazards • Community priorities

The University of Alaska Fairbanks ACGL has been actively conducting coastal hazard related research a Chignik Bay since the spring of 2019 (**Table 5**). This includes a series of topographical surveys and the establishment and maintenance of erosion monitoring sites. The results of this continuing work are delivered in this report.

Table 5. Summary of ACGL community visits and field work.

Date	Individuals	Research Activities	Monitoring Activities	Outreach
May 2019	Chris Maio, Reyce Bogardus, Ed Krauss	• GNSS survey • UAV survey(s)	• Established 2 sites • Training on measurements	• Meeting with environmental program staff • Community meeting
May 2021	Chris Maio, Reyce Bogardus, Jessie Christian, Ed Krauss	• GNSS survey • Temporary pressure gauge	• Site maintenance • Establish 1 site	• Meeting with environmental program staff
May 2022	Chris Maio, Reyce Bogardus, Jessie Christian, Matthew Balazs	• Install water level gauge • GNSS survey • Install tidal staff	• Site maintenance	• Meeting with environmental program staff • Community meeting
May 2023 (planned)	Chris Maio, Michael Willis, Matthew Balazs, Sue	• Water level gauge maintenance • GNSS survey • Bathy survey(s)	• Site maintenance	• Climate Symposium

	Flensberg, Casey Ferguson	• UAV survey(s) • Survey in tide staff		• Meeting with environmental program staff

4.2 REFERENCE DATASETS

The following subsections (4.2.1 – 4.2.5) describe baseline geospatial datasets and hydrological datums as collected or compiled by the ACGL. These data contain aerial imagery, continuous elevation surfaces, as well as discrete point data. Source information and links to data portals are included in sections related to compiled data. This information is intended to assist any future environmental assessments of Chignik Bay. Data collected by the ACGL is available upon request.

4.2.1 Ground Control Points and Checkpoints

Ground control points (GCPs) and checkpoints are locations on the ground that have a precise coordinate associated with them. In photogrammetry, they are used to tie the map down to the Earth—matching the drone or satellite location data to the location data measured terrestrially. It's important to note that GCPs are not the same as checkpoints, which are used in post-processing to validate accuracy by checking the map against the known points on Earth as captured during the survey.

At Chignik Bay, the ACGL has collected 187 GCPs or checkpoints (**Table 6**). Precise horizontal and vertical measurements were collected with a GLONASS-enabled GNSS system consisting of dual frequency Trimble R2 and R8s receivers with a TSC3 field controller running Trimble Access software. These measurements broadly fall into the following categories during three field surveys: ground control points and checkpoints, shoreline indicators, profiles, cross-spit profiles, benchmarks, and other (including waterlines, timelapse camera locations, erosion monitoring stake locations, and water level gauges).

Table 6. Summary of GPS survey points per product type and year. Unless otherwise specified, the number displayed below is the number of points of this product type taken per survey. For profiles, the number of linear profiles is listed first, with the total number of points taken at all profiles listen in parentheses.

Year	GCPs	Shoreline	Profiles	Benchmarks	Other	Total
2019	167	0	539	2	5	713
2021	20	0	689	1	8	718
2022	39	0	722	1	22	784

4.2.2 Benchmarks

Benchmarks are intended to be permanent points of reference for surveyors to verify their survey is consistent with prior work and have precise real-time coordinates during surveys. NOAA's National Geodetic Survey (NGS) manages approximately 240,000 stations gathered over the last two centuries. This survey benchmark data is made available through the National Geodetic Survey Data Explorer (https://geodesy.noaa.gov/NGSDataExplorer/). Two main types of benchmarks exist – "vertical control points" and "horizontal control points". Vertical control points contain a precisely measured orthometric height. The elevation is usually measured as height above sea level. Horizontal control points simply contain latitude and longitude values. Within these two broad types of survey benchmarks, there are different types of categories for horizontal control markers as described in NOAA's Horizontal Control documentation. There are two NGS benchmarks in and around Chignik Bay (**Table 7**). One is GPS and vertical control while the other is GPS and approximate height.

Table 7. NGS benchmarks within 10 km of Chignik Bay.

Site Name	Latitude	Longitude	Ortho. Height (m)	Control Type
AI1023	56° 17' 44.87610"	-158° 24' 19.91039"	14.572	GPS and Vertical Control
AI1024	56° 18' 18.80460"	-158° 24' 59.18464"	14.583	GPS and Approx. Height

When surveyors occupy benchmarks over several hours, they measure an extremely precise position. Surveyors can upload their measurement to the Online Positioning User Service (OPUS; https://www.ngs.noaa.gov/opusmap/) to share the solution with others. This user-maintained database provides a catalog of the most reliable benchmarks. There are 3 OPUS benchmarks around Chignik Bay (**Table 8**).

Table 8. OPUS benchmarks at Chignik Bay.

OPUS Position ID	Stamping	Latitude	Longitude	Ortho. Height (m)	Last Occ.
BBFS48	DEROCCHI 2017	56° 18' 26.78396"	-158° 22' 37.74266"	5.321	2017
BBDW16	CHIG-2 USACE 2004	56° 18' 8.23604"	-158° 22' 43.91080"	4.711	2017
BBDW14	945 8917 COR 4	56° 17' 46.33526"	-158° 24' 22.70783"	5.231	2019

4.2.3 Digital Surface Model and Orthomosaic

A digital surface model (DSM) was derived from 2,400 aerial photographs taken from 100 m (330 ft) altitude with a FC300S camera aboard a DJI Phantom 3 Advanced uncrewed aerial vehicle (UAV). The survey, consisting of 9 individual flights, took place over a period of 4 days and was flown during low tide stages when it was feasible to capture as much of the beach face and mud flats as possible.

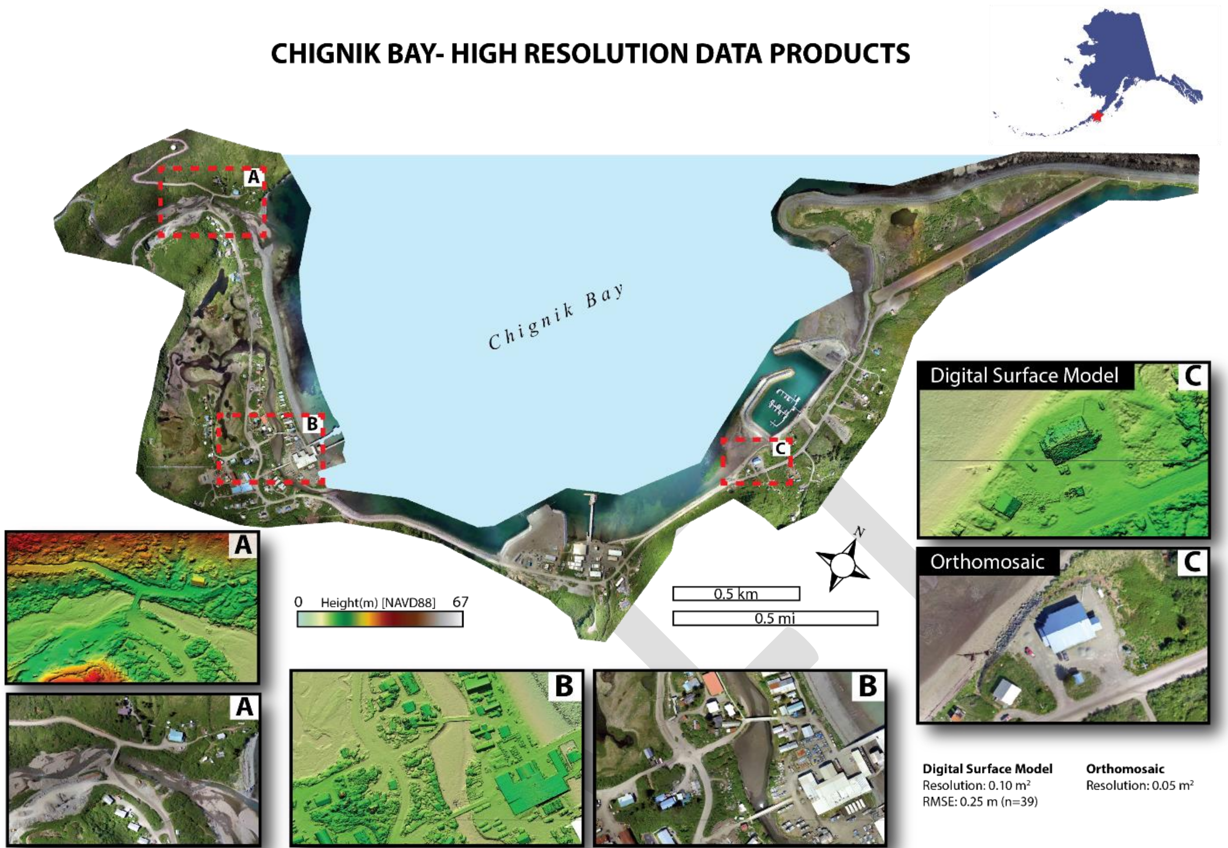

Figure 20. Orthomosaic (A&B) and DSM (C&D) of Chignik Bay generated using UAV imagery in 2019.

The survey was accompanied by an extensive ground control campaign using RTK-GNSS to vertically reference the DSM, relate elevations to the tidal datum computed for this project, and validate the vertical accuracy of the refined topographic surface. This validation was computed by comparing vertical values of the unused GCPs from the alignment phase to the resulting topographic surface. The covariance test showed a high degree of accuracy, with an average Root Mean Square Error (RMSE) of ~0.17 m (~0.56 ft) (n = 30).

4.2.4 Tidal Datums

A tidal datum is a standard elevation defined by a certain phase of the tide and is used as a reference to measure local water levels. Tidal datums are calculated from geodetically tied local water level data, which provides a necessary conversion for storm forecasting and floodplain mapping (Overbeck, 2018). Chignik Bay's tidal datum is found in **Table 1**. The tidal datum was connected to NAVD88 through the OPUS-shared benchmark with ID BBDW14 (**Table 8**).

Two water level gauges were installed in Chignik Bay. One was installed on a dock overlooking Anchorage Bay and the other was installed on a bridge over Indian Creek (**Figure 20**).

Figure 21. Map Chignik Bay water level gauges, represented by gold stars.

4.2.5 Bathymetry

The National Centers for Environmental Information (NCEI) maintains the digital data archive for all hydrographic data of the coastal waters and exclusive economic zone of the United States and its territories collected by Coast Survey. The database provides hydrographic survey products which contain additional details of the ocean floor not shown on the nautical charts. NCEI also maintains an interactive data viewer for other sources of bathymetric and ocean depth data collected by other agencies.

This interactive viewer (https://www.ncei.noaa.gov/maps/bathymetry/) allows for the identification of NOAA bathymetric data for both visualization and download. The viewer contains single beam track lines, multibeam surveys and mosaics for data visualization, the NOS hydrographic surveys, BAG footprints and shaded imagery, digital elevation models (DEMs), and coastal LiDAR datasets available.

Table 9. Overview of compiled and collected bathymetry surveys of Chignik Bay. The survey, survey type, year of acquisition, source, and datum is provided.

Survey	Type	Year	Source	Datum
H04389	Sounding Rope	1924	NOAA	MLLW
H10759	Side Scan Sonar	1997	NOAA	MLLW
W00245	Multibeam Sonar	2011	NOAA	MLLW
D00170	Multibeam Sonar	2012	NOAA	MLLW

4.3 REPEAT DATASETS

To better understand the processes that continuously shape the landscape and quantify change, repeat measurements of the surface are needed. After the first measurements of the surface are taken (known as the baseline dataset) subsequent data collected over the same location can be compared. Each survey must be accurately co-registered to the previous data to minimize error when calculating change. This report summarizes the findings from several repeat surveys including, shoreline indicators, stake measurements, cross-shore profiles, and timelapse photography.

4.3.1 Shoreline Change

A shoreline is a linear demarcation between land and water that can be represented by a visual feature or an elevation contour on the beach. Either type of shoreline (i.e., visual- or elevation-identified) can be delineated within a Geographic Information System (GIS) program (e.g., ArcGIS) based on source orthoimagery or elevation data (Overbeck et al., 2020). Shoreline data are created in the form of a vector (line) that represents the shoreline position at a particular time along a section of coast. For example, if multiple shoreline datasets are available, they can be compared visually to show how the shoreline has changed through time. The distance between shoreline vectors can also be measured to compute shoreline change distances and rates.

A long-term shoreline change study has not been conducted for Chignik Bay. Non-orthorectified aerial imagery was collected for photogrammetric mapping of Chignik Bay in 1957, 1963, 1965, 1974, 1977, and 1983. These images are publicly available from USGS and can be orthorectified (https://earthexplorer.usgs.gov/; method described by Buzard, 2021). Shoreline change is known to be relatively slow, but documenting this observation can help identify any sudden changes in erosion patterns. In addition, the pre- and -post 1964 earthquake imagery may show shoreline change from tectonics. These images can also be used to identified landslide scars.

4.3.2 Community-Based Erosion Monitoring Data

As of 2023, 13 rural coastal communities in the Bristol Bay region utilize stake ranging to monitor erosion. The Stakes for Stakeholders program trains environmental coordinators from each community in data collection (Buzard et al., 2019a). Stake ranging uses a permanent landmark or a stake (wooden or metal) to measure the distance to the eroding feature. Several transects are set up perpendicular to the eroding feature with two to three stakes along each transect. The local data collector can visit stake sites a few times a year and before and after big storms.

Two stake ranging sites were set up in Chignik Bay in May 2019 and one site in May 2021 (**Figure 22**). Measurements are collected by local environmental coordinators every 1-3 months and before and after large storms. The data collectors measure from the site reference point (typically a wooden stake, or other permanent feature) out to the eroding feature. These datasets provide a high-resolution look at the most recent shoreline change. These datasets can help better understand shoreline change in terms of recent climate settings. They can also highlight storm events in great detail. Between the start of monitoring and spring 2021, the ACGL has received six sets of measurements that are reported here (**Figure 23**). Time-lapse cameras were also set up at each site to capture images every hour (described below).

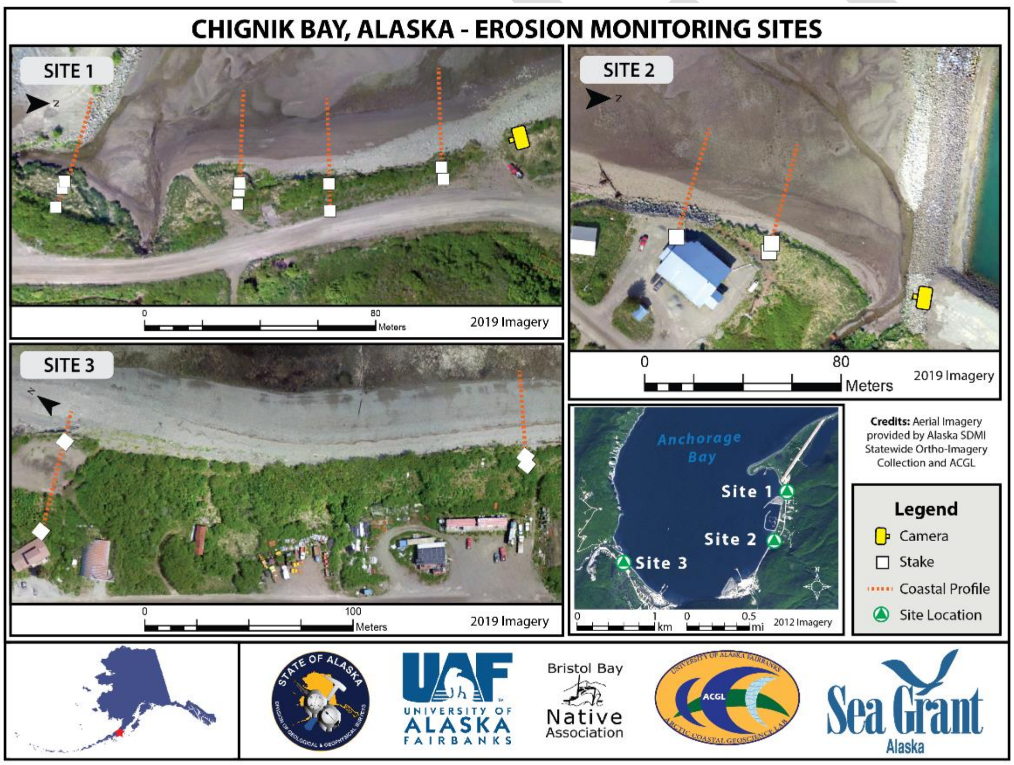

Figure 22. Map of erosion monitoring sites and stake measurement transects. Each site consists of a time-lapse camera with 2-4 staked transects where local environmental coordinators take repeat measurements.

On-site measurements for sites 1 and 2 at Chignik Bay show slower shoreline change rates with the most erosion occurring at site 1, transect 1 of 0.67 m (2.3 ft) over the past 3 years of participation, or 0.22 m (0.8 ft) of erosion per year (**Figure 23**). Most erosion occurs at Site 1, which is in front of the main road to the airport. A draft protocol of stake ranging measuring and site set up was created, describing how to set up sites, take measurements, and highlight important reminders when collecting data.

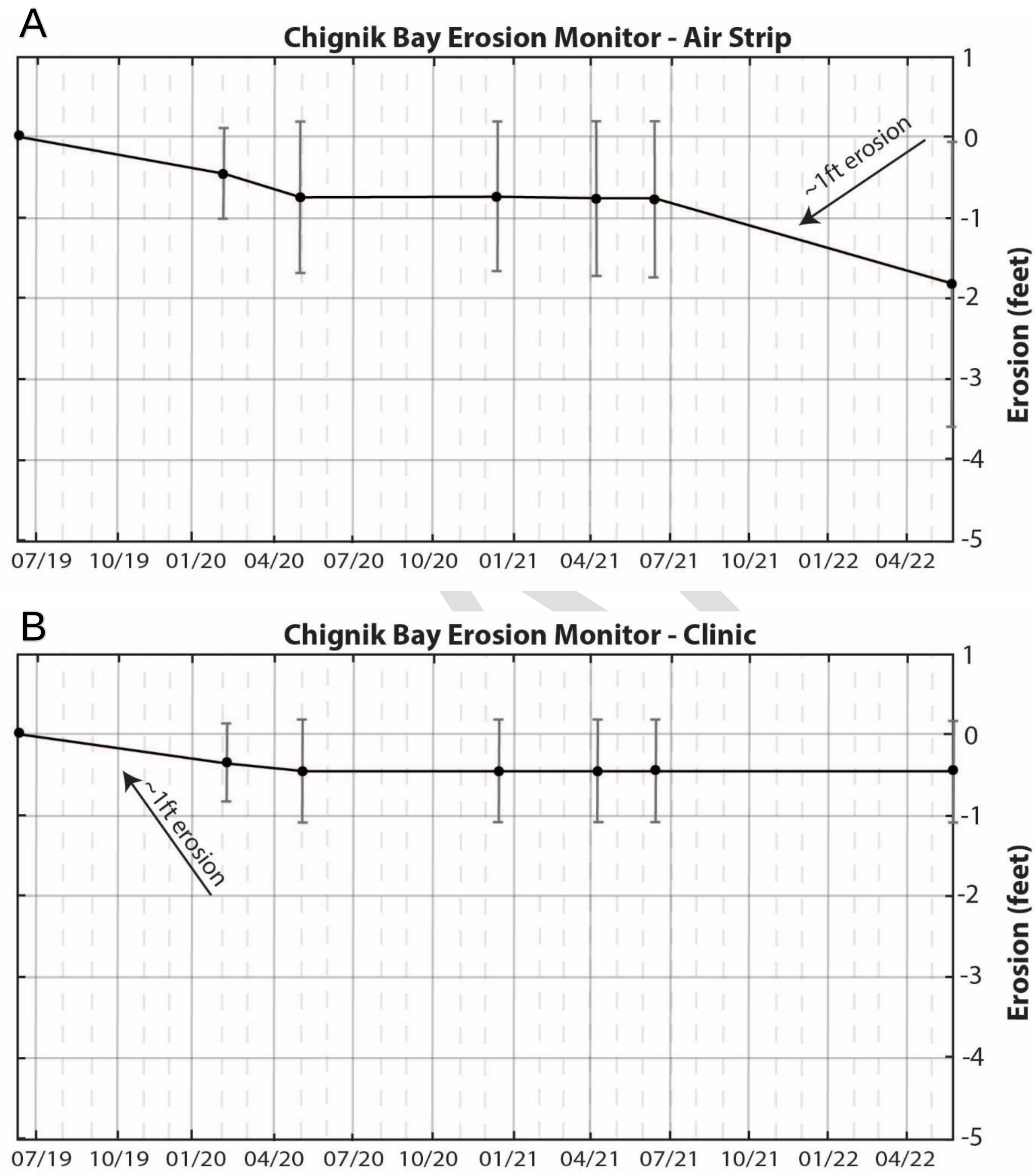

Figure 23. Graphs showing average erosion monitoring stake measurements taken by local environmental coordinators. (A) The black line represents the average of the 4 transects at the air strip site. Each dot represents community measurement. Grey error bars calculated with Excel STDEV function. (B) The black line represents the average of the 2 transects at the clinic site. Each dot represents community measurement. Grey error bars calculated with Excel STDEV function.

4.3.3 Cross Shore Elevation Profiles

Coastal elevation profiles represent the elevation of the beach from ocean (right) to land (left). When plotted through time, coastal elevation profiles can be used to understand coastal dynamics including the impacts of storms and changing ocean conditions.

Elevation profiles at Chignik Bay were collected by the ACGL along cross-shore transects at 33 locations in 2019, 2021, and 2022 (**Figure 24 & Figure 25**). Representative coastal elevation profile

Figure 24. Map showing the location of each cross-shore elevation profile. Red brackets represent CBM sites. Yellow bracket represents cross-river elevation profiles.

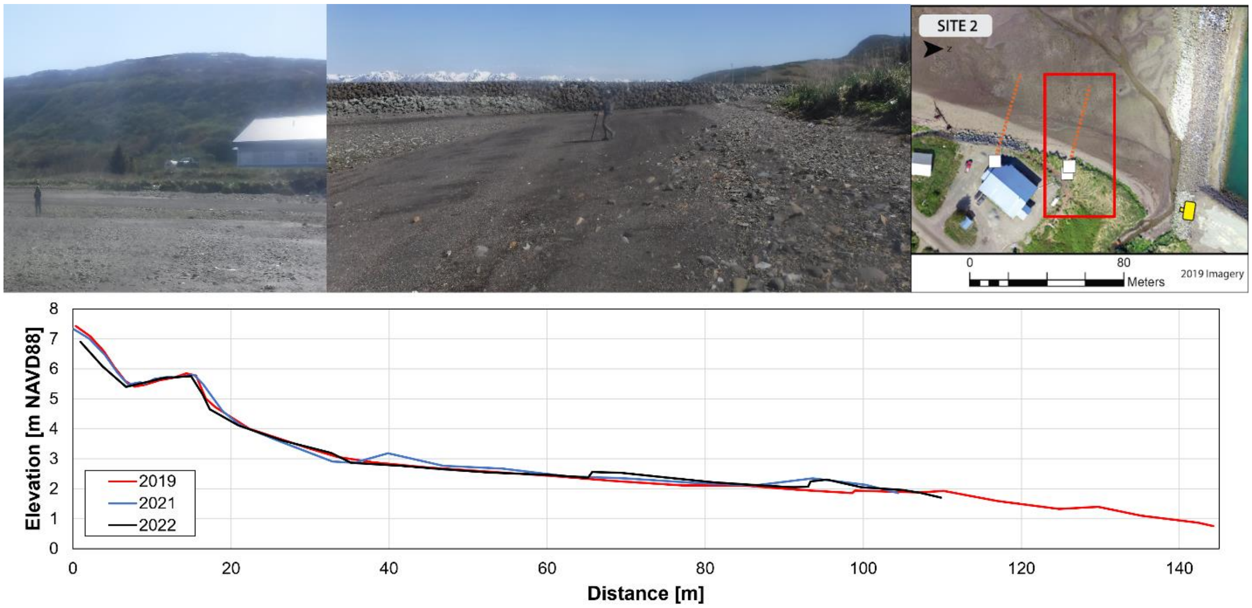

Figure 25. Example cross shore profile from the City Clinic with data plotted from 2019, 2021, and 2022. This is profile An (reference figure 22). Notice how much erosion has occurred.

4.3.4 Timelapse Photography

Time-lapse cameras were set up at two sites in May 2019 and data is currently being collected. The cameras were oriented perpendicular to a single profile at each site. Images were taken every hour and compiled into time-lapse videos (**Figure 26** & **Figure 27**). These datasets visually show change at each shoreline and can capture storm events. Erosion measurements were unable to be processed as the cameras were not secured tightly enough and the camera was frequently shifted out of place. Future site visits will require proper securing of these cameras.

Figure 26. Time-lapse picture and compiled video of erosion monitoring site 1. Images taken at Chignik L Bay from June 2019 to May 2020. (URL: https://youtu.be/5lisv9sMA1M).

Figure 27. Time-lapse picture and compiled video of erosion monitoring site 2. Images taken at Chignik Bay from June 2019 to May 2020. (URL: https://youtu.be/3SjWLrm6vOw).

4.4 HAZARD AND EXPOSURE ASSESSMENTS

Hazard maps indicate the potential for coastal hazards in a given location, such as flooding or erosion, while exposure maps indicate the proximity of infrastructure or human life to these hazards. For instance, shoreline change analysis describes coastal hazards by quantifying the spatial extent and rates of erosion along the beach, while shoreline change maps indicating areas where critical infrastructure is in close proximity to quickly eroding land constitute an exposure map.

4.4.1 Flood Maps

There is currently no flood hazard or exposure map for Chignik Bay. A flood map is created using a DEM, tidal datum connected to NAVD88, historical flood record, and impacts to infrastructure (Buzard et al., 2021). Chignik Bay has a DSM (**Figure 20**) and will receive a lidar-derived DTM. The tidal datum was connected to NAVD88 in this report's 2023 update (**Table 1**). The remaining components can be determined through GNSS surveying, community observations, and delineating infrastructure in imagery using GIS (Buzard et al., 2021a). With these components, flood maps can be created to show flood extent, severity, and likelihood. The maps would allow tide, storm, and tsunami forecasts to be related to infrastructure elevation. May 2022, a flood staff was installed on a utility pole in the flood plain of the community (**Figure 22**). This flood staff will allow residents to send in photos of flooding events. These measurements can be used to create flood extent maps.

Figure 28. Location of tide staff installed May 2022. It was installed on a utility pole near the tribal office.

4.4.2 Erosion Maps

There is currently no erosion hazard or exposure map for Chignik Bay. A coastal erosion hazard map (or shoreline change analysis) is created by measuring long-term and recent erosion rates. This is achievable as described in Section 4.3.1. An erosion exposure map is created by projecting erosion rates near infrastructure and computing the time to impact (Buzard et al., 2021b). However, if the long-term shoreline change rates are very slow it may be unfeasible to simply project erosion with reasonable confidence. The community has also performed shoreline modifications that prohibit projections of natural erosion rates. It may be impractical to attempt a community-wide erosion map, but site-specific studies can be conducted to document specific issues.

5. IDENTIFIED COASTAL HAZARD AREAS

This section identifies infrastructure at risk of erosion over spatiotemporal scales relevant to community planning; long term morphodynamic evolution is beyond the scope of this report. Identified coastal hazard areas are identified as such based on erosion rates coupled with proximity to infrastructure or otherwise cultural significant features.

Identified coastal hazard areas in Chignik Bay are as follows:

1. Indian Creek Bridge
   Local anecdotal input has pointed to erosion of the bank under the Indian creek bridge connecting the community to their tsunami evacuation route and waste disposal site. High water events from storms cause the majority of erosion according to local residents (**Figure 29**). A water level gauge was installed in 2022 and baseline data has been collected for future monitoring efforts.

Figure 29. (Left) Photo taken by Jeanette Carlson standing on Indian Creek bridge during a flood in June. (Right) Photo taken by Jessie Christian on a calm day on a berm in Indian Creek with bridge in background.

2. Road by Airstrip
   Unarmored sections of the bluff fronting the main road by the air strip are eroding. When the road is obstructed, access to the airport get cut off and transportation to and from the village slows. Coastal profiles and CBM measurements show the bluff has eroded approximately 1ft over 4 years. Residents shared information and photos of a large storm in December 2022 that

caused a large amount of erosion (**Figure 30**). Baseline data has been collected in the area for future monitoring efforts.

Figure 30. Photos taken by Andrew Anderson (Left) Main Road after December 2022 storm. (Right) Community Monitoring site located by airport after December 2022 storm.

3. Medical Clinic
   The bluff fronting the clinic is not at immediate risk, however, it is an area of concern. The clinic sits about 6 m (20 feet) away from the eroding bluff. The bluff is eroding at a rate of 0.08 m/yr (0.25 ft/yr).

6. SUMMARY OF COMMUNITY THREATS AND RESILIENCY

6.1. SUMMARY OF THREATS

- Erosion at of the main road directly threatens access throughout the community to critical infrastructure such as the airport and the medical clinic.
- Erosion around Indian creek directly threatens the integrity of the bridge connecting the community's tsunami evacuation route and their waste disposal site.
- Erosion fronting the medical clinic has been an ongoing issue but does not pose an immediate risk at this time.

6.2. COASTAL RESILIENCY

Chignik Bay faces many challenges related to coastal geohazards. The oceanographic setting means that any mitigation structures must consider waves and currents, large tides, and flooding. The climatic setting means that there is a short (seasonal) construction window for any largescale projects. However, the strongest defense against coastal geohazards at Chignik Bay has been and is its extremely proactive and hard-working people. The community has ongoing erosion monitoring efforts and numerous partnerships with state and private entities.

7. DATA GAPS AND FUTURE WORK

7.1. PRIORITY DATA GAPS

While the data products in this report describe coastal processes through their impacts on shorelines and beach profiles, a more thorough understanding of the local oceanographic setting would improve predictions regarding erosion at Chignik Bay. Additionally, improving understanding of potential storm and flooding impacts is a major goal for mitigation efforts in Chignik Bay. In order to more accurately assess these risks, additional data products are necessary, including past storm total water levels and building first floor heights (**Table 9**)

Table 10. Summary of data gaps at Chignik Bay. Applications and expected acquisitions for each item is provided.

Item	Applications	Actions	Exp. Acquisition
Water level gauge	Developing a historical index of past storm events; informing city planning and decision making. Develop tidal datum.	Install water level gauge Create local tidal datum for Chignik Bay	Summer 2022
Bathymetry	Fills data gaps on coastal erosion, aid in nearshore planning and development	Collect nearshore single or multibeam bathymetry	Spring 2023
Lidar DTM	Flood, erosion, and tsunami hazard maps	Collect ground control and check points.	2023
Wave buoy	Developing a historical index of past storm events with wave and water level data	Deploy Wave buoy Collect Wave buoy	TBD
Stream gage	Record stream elevation to inform and validate flood models	Install stream gage Survey gage	TBD
Some infrastructure heights	Relate infrastructure to flood and tsunami elevations.	Survey elevation of critical infrastructure and low-lying structures.	Spring 2023

Flood History	Identify the frequency and severity of flooding to create hazard/exposure maps and recommend building elevation.	Compile list of known floods Estimate flood elevations	Spring 2023
Orthorectify Historical Aerial Imagery	Used for long-term shoreline change mapping and identification of landslide scars and tsunami impacts.	Download imagery from Earth Explorer Process using SFM Reference to recent imagery.	Not planned.

7.2. ACGL FUTURE WORK

Continued work is being carried out to improve the hazard assessment of Chignik Bay and another field work campaign is planned for spring 2023. This will include repeat surveys, along with continued correspondence with members of the community. These datasets will feed into the comprehensive coastal hazard assessment produced by ACGL and will be updated annually.

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APPENDIX

USACE (1992) high water elevation survey.

ALASKA DISTRICT CORPS OF ENGINEERS
FLOOD PLAIN MANAGEMENT SERVICES

HIGH WATER ELEVATION IDENTIFICATION

Community: **CHIGNIK**

Date of Visit: 20 November 1992

General Observations/Comments:

Chignik, also commonly called Chignik Bay, is on the south shore of the Alaska Peninsula at the head of Anchorage Bay.

Historical Record of High Water:

The highest flood of record was the flood of October 1948, which was said to have flooded the first floor of the building that is now the Chignik Bible Chapel with 13 inches of water. The 1964 earthquake has since raised the land 18 inches. More recent floods have reached, or nearly reached, the low cord of the cannery bridges crossing the former channel of Indian Creek.

People Interviewed:

Roy Skonberg

Actions Taken:

No High Water Elevation signs were placed.

Miscellaneous:

The 1948 flood elevation was estimated at 14.08 feet. Two existing temporary bench marks were employed: a spike in power pole no. 12 on the south side of Harold Skonberg's house, at elevation 15.50 feet; and a spike in a power pole nearest the south bridge abutment on West Third Avenue, at elevation 12.25 feet.

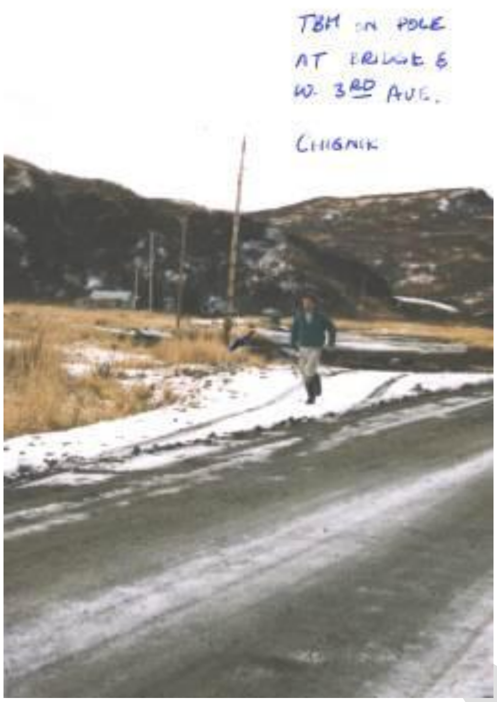
Chignik/21 March 94

Community: **CHIGNIK**

Chignik Bible Chapel.

Temporary bench mark on the power pole at Harold Skonberg's house.

Chignik/21 March 94


TBM ON POLE
AT BRIDGE &
W. 3RD AVE.
CHIGNIK