Akutan Harbor Navigation Improvements
Appendix A: Hydraulics and Hydrology

Akutan, Alaska

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US Army Corps of Engineers
Alaska District

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1.0 INTRODUCTION

1.1 Appendix Purpose

This hydraulic design appendix describes the technical aspects of the Akutan Harbor Navigational Improvements. It provides the background for determining the Federal interest in construction of a navigation improvement project to decrease transportation inefficiencies between the Native Village of Akutan on Akutan island and the airport on Akun island by constructing a harbor with entrance channel and turning basin protected by a breakwater on Akun island. To determine the feasibility of a project, existing data was gathered and analyzed to determine wave climate for design of the proposed navigation improvements.

1.2 Study Location

The study location is on the islands of Akutan and Akun in the eastern Aleutian Island archipelago, 35 miles east of the city of Dutch Harbor, Unalaska and approximately 763 air miles southwest of Anchorage (Figure 1-Figure 2).

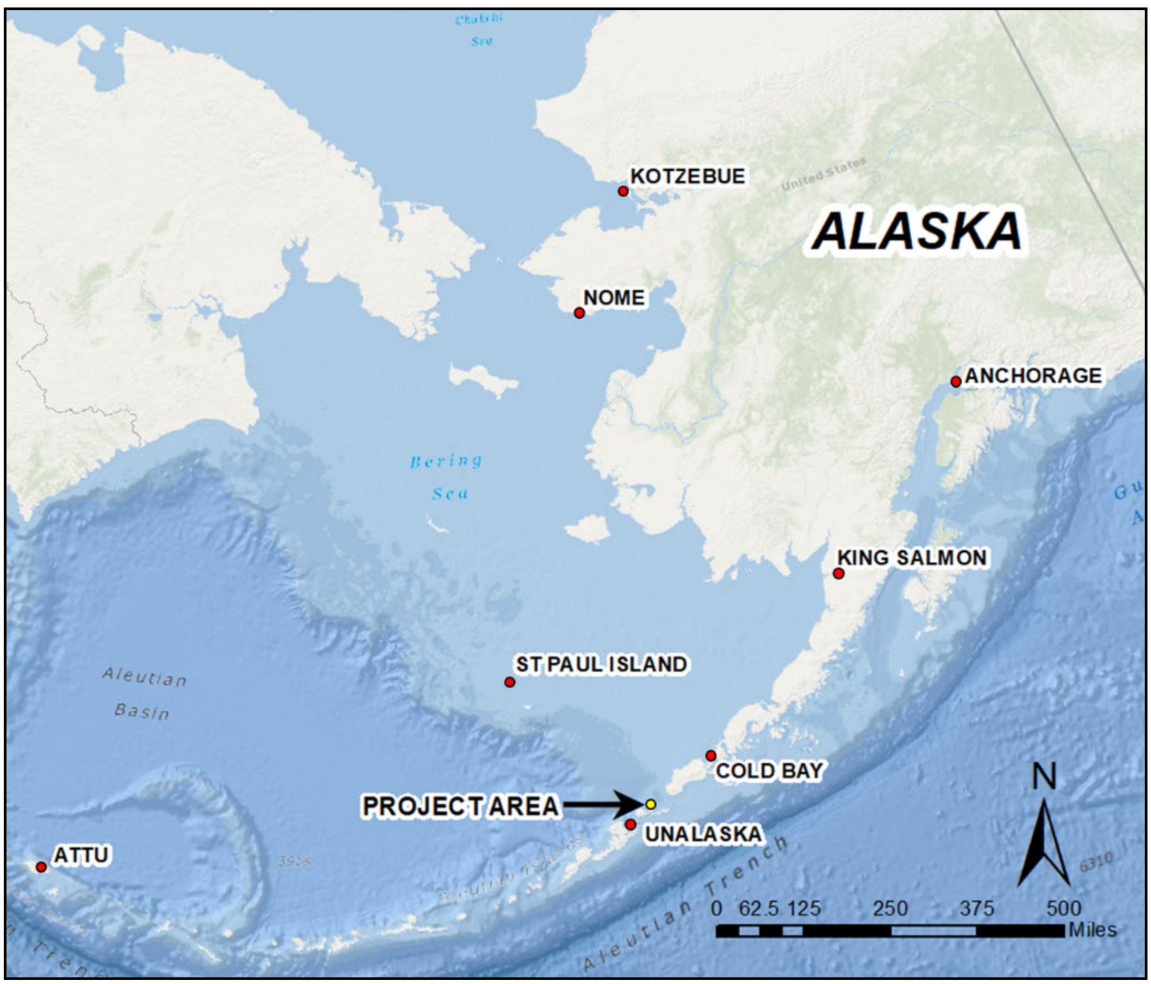


Figure 1: Vicinity Map of Project Area

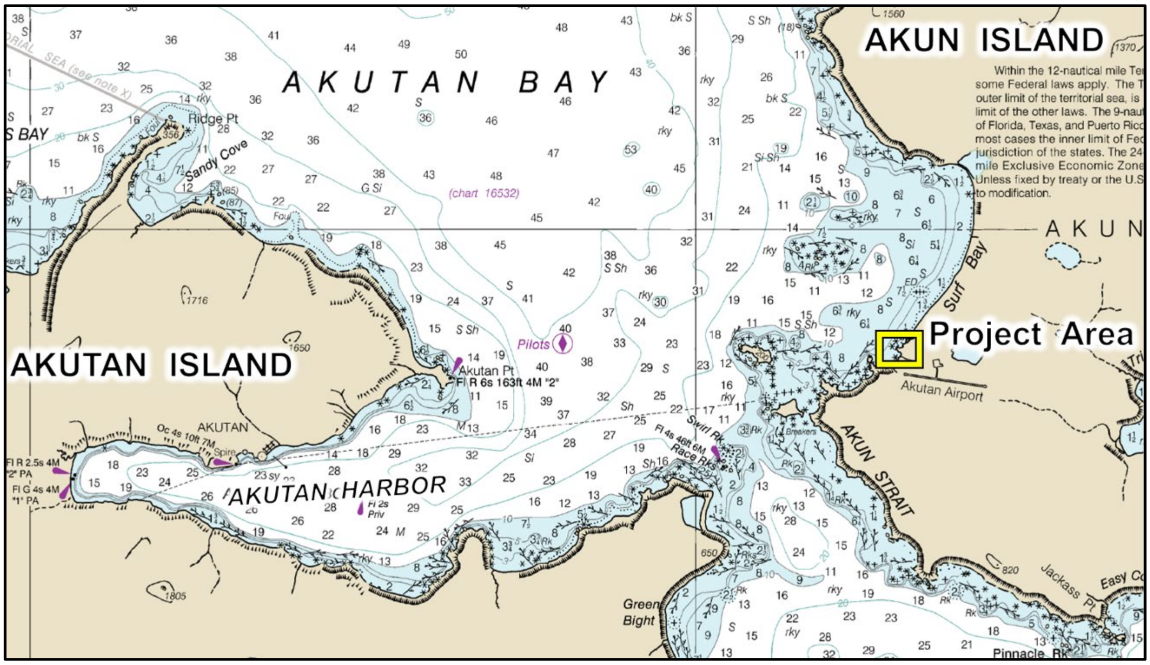


Figure 2: NOAA Coastal Chart 16531, Published 12/01/2015

The Native Village of Akutan is located on the eastern side of Akutan Island, on a flat piece of land on the north shore of Akutan Harbor with the steep slope of a mountain rising behind the village, confining the community to a small area. Akutan Harbor is a large deep body of water, not to be confused with the USACE Federally Constructed small boat harbor at the western end of Akutan Harbor that often shares the same name (Figure 3). Akutan Harbor is a protected body of water sheltered by the island's active volcano that blocks much of the prevailing easterly winds of the Aleutian Islands. Akutan Harbor accommodates large vessels, including floating processors, and large container and cargo ships that service both the Native Village of Akutan as well as the large adjacent shore-based seafood processing facility, Trident Seafoods.

Figure 3: Akutan Harbor Location

Conversely, Akutan Harbor is a USACE Federally Constructed small boat harbor that was completed in 2012. Akutan Harbor consists of a 12 acre basin with depths of -14, -16, and -18 feet MLLW and an entrance channel of -18 feet MLLW (Figure 4). A helicopter maintenance hangar is located at the north end of the boat harbor. The harbor is located 1.5 miles from the Native Village of Akutan.

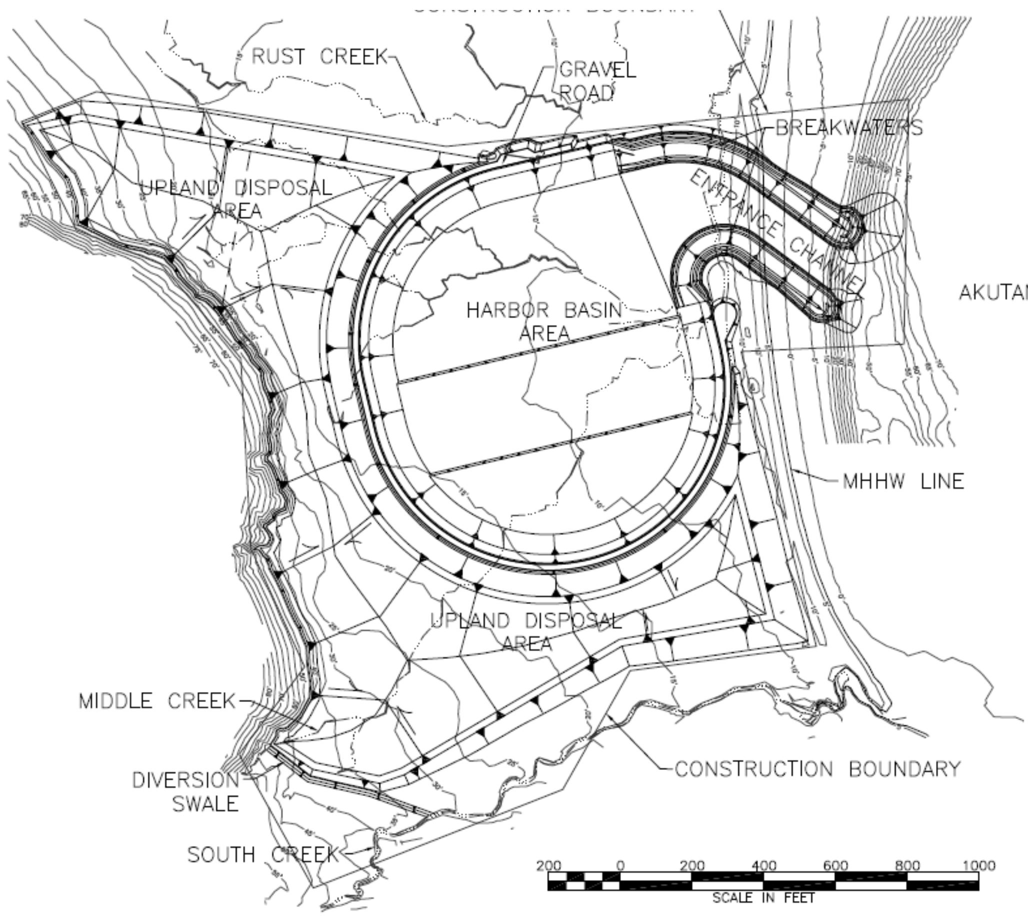


Figure 4: Akutan Small Boat Harbor Drawing – Plan View

Construction of the road to Akutan Harbor is currently underway. Road design has been substantially completed and permitting work is underway. Materials were stockpiled at the site and stored in 2023. Funding has been partially completed with additional funding to fully construct the road under consideration by the Alaska Department of Transportation & Public Facilities under its Community Transportation Program. The road begins on the beach west of the Trident Seafood Plant and maintains a low elevation along the coastline and then crosses the wetlands and Whalebone Creek at the head of the Akutan Harbor body of water. The gravel road is approximately 1.5-miles long with a 12-foot-wide drivable surface and several vehicle turnouts.

Akun Island lies immediately northeast of Akutan Island and has a land area of 64 square miles. The proposed project area on Akun island is located approximately 7 miles east of the Native Village of Akutan immediately west of Akutan Airport. Promontory features inside the project area include No-Name Point and Rocky Outcrop. Facilities at Akun include the Akutan airport and a road connecting the airport to the Surf Bay Inn and the airport to the Former hovercraft pad (Figure 5). The airport was opened in 2012 and includes a 4500 foot runway, parking apron, and maintenance building. Surf Bay Inn has 31 double occupancy rooms and houses passengers that are stranded by weather and unable to transfer from Akun to Akutan.

Figure 5: Study Location on Akun Island

1.3 Airport Operations

1.3.1 Historic Operations

The formerly utilized Grumman Goose was reported to withstand the harsh weather and sea conditions of the Aleutians in which other sea planes would not be able operate (Johnson, 2012). Aircrafts able to match or beat the Grumman Goose's operational parameters would be fixed wing and require an airport.

The formerly utilized hovercraft was an 89-foot vessel. Hovercraft operations were more limited by wind and waves than conventional vessels according to one hovercraft pilot (Joyce, 2013). Winds of 20 knots and choppy waves only a few feet high encountered while passing Akun Strait were reported to be extremely challenging operational conditions. Anecdotal information is that the hovercraft was successful in 30% to 50% of attempted trips, but that it was generally an improvement over the 40% success rate of the Grumman Goose (AEB, 2012). The trip duration between Akutan airport and Akutan island was reported to be 30 minutes by hovercraft.

1.3.1 Current Operations

The existing transportation system in Akutan consists of both a helicopter and a fixed-wing aircraft. Maritime Helicopters operates a 4-passenger Bell 206L4 helicopter that makes trips back and forth between Akutan and the Akutan airport on Akun. Two round trips per day are scheduled, but additional or fewer trips may be necessary. The helicopter is housed in Akutan Harbor. Helicopter flights from 2020 to 2022 to Akutan airport were reported to be canceled on average 30% of the time due to weather. The trip duration is approximately 6 minutes each way by helicopter.

Grant Aviation operates a 10-passenger Piper PA31-350 Navajo Chieftan fixed wing aircraft that makes trips back and forth between Dutch Harbor and the Akutan airport on Akun. Two round trips per day, 6 days a week are scheduled, but the regular schedule may be altered due to demand. The fixed-wing is housed in Dutch Harbor. Fixed-wing aircraft flights from 2020 to 2022 to Akutan airport were reported to be canceled on average 34% of the time due to weather.

2.0 CLIMATOLOGY, METEOROLOGY, HYDROLOGY

Akun island is characterized as a maritime climate moderated by the Japanese Current (Miller, Phillips, & Wilson, 2005). The area is characterized by persistently overcast skies, high winds, and frequent cyclonic storms.

Short term climate data for Akutan is available from January 1986 through February 1990 from a National Weather Service and National Oceanic and Atmospheric Administration (NWS/NOAA) recording station for temperature, precipitation, and snowfall. Long term climate data for the project area is not available, with the next closest site located at Dutch Harbor, Unalaska, 35 miles to the southwest. Due to the limited period of record (4 years) in Akutan as compared to Dutch Harbor (54 years) and closeness in proximity, Dutch Harbor data may be more representative of actual conditions.

2.1 Temperature

Akutan experiences cool temperatures that vary relatively little throughout the year. The highest recorded temperature at Dutch Harbor is 79°F, and the lowest recorded temperature is -8°F, but typically temperatures range from 27°F in the winter to 59°F in the summer. Temperature data for Akutan (1986 to 1990) and Dutch Harbor (1951 to 2006) is provided in Table 1 below (WRCC, 2023).

Table 1: Temperature Data for Dutch Harbor (DUT) and Akutan (AKN)

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Ave Min Temp	DUT	28.0	27.2	28.6	31.3	36.7	41.7	46.0	47.6	43.2	37.0	31.8	30.1	35.8
(°F)	AKN	29.7	29.8	29.9	31.9	36.5	42.8	47.3	47.1	43.6	41.5	34.4	29.9	37.0
Extreme Min Temp	DUT	-8	0	2	-5	15	30	34	30	19	11	8	5	-8
(°F)	AKN	17	15	8	19	25	38	43	35	32	33	16	12	8
Ave Max Temp	DUT	37.0	37.1	39.1	40.9	46.3	51.7	57.0	59.1	54.1	47.4	42.8	39.2	46.0
(°F)	AKN	36.8	37.1	38.5	40.8	45.7	49.9	54.6	56.9	53.0	47.5	41.0	39.1	45.1
Extreme Max Temp	DUT	58	54	61	58	60	73	75	79	74	65	57	59	79
(°F)	AKN	46	46	57	49	56	60	66	72	64	57	52	45	72

2.2 Precipitation

Akutan frequently experiences cloud cover accompanied by light precipitation. Rains occur any time of the year, with an average annual precipitation of 79 inches. The wettest month is October, with a record of 13.4 inches and an average of 11.3 inches of precipitation. A summary of precipitation data for Akutan (1986 to 1990) and Dutch Harbor (1951 to 2006) is provided in Table 2 below.

Table 2: Precipitation Data for Dutch Harbor (DUT) and Akutan (AKN)

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Ave Min Precip	DUT	1.0	1.6	1.6	0.6	0.1	0.1	0.2	0.1	0.8	1.4	1.1	2.4	21.3
(inches)	AKN	4.3	3.2	3.1	4.1	2.8	4.2	3.8	4.4	6.4	10.1	5.3	4.2	72.4
Ave Max Precip	DUT	17.0	14.0	14.8	6.9	10.3	4.9	7.3	6.2	10.0	18.1	19.6	19.1	86.7
(inches)	AKN	9.4	9.3	8.8	5.8	5.5	6.4	6.2	6.9	8.3	13.4	11.0	13.2	89.3
Ave Precip	DUT	7.5	6.6	5.8	3.6	3.9	2.5	2.2	2.8	5.4	7.4	6.9	8.2	62.7
(inches)	AKN	7.4	6.0	5.1	4.9	4.1	5.3	4.8	5.5	7.4	11.3	7.3	8.9	79.0
1 Day Max	DUT	4.0	3.4	2.3	1.9	3.6	2.0	4.8	2.4	2.0	3.3	3.0	3.0	4.8
(inches)	AKN	1.8	1.2	1.3	0.9	1.0	1.5	1.1	1.7	2.0	2.0	2.3	2.0	2.3

2.3 Snowfall

Akutan typically receives snowfall between November and April. Snowfall data in particular may be underrepresented; interviews with Akutan residents report that the winter of 1999/2000 had an estimated snowfall of over 100 inches (Peterson, 2003).

Table 3: Snowfall Data for Dutch Harbor (DUT) and Akutan (AKN)

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Ave Total Snowfall	DUT	23.0	21.7	14.9	6.0	0.2	0	0	0	0	0.6	5.7	16.4	88.5
(inches)	AKN	13.9	1.3	0.6	2.6	0	0	0	0	0	0	0.8	1.5	19.6
Extreme Total	DUT	93.0	68.0	57.0	18.4	2.5	0	0	0	0	8.0	29.5	60.3	165.7
Snowfall (inches)	AKN	21.4	1.9	1.1	4.5	0	0	0	0	0	0	0.8	2.9	27.7

2.4 Fog

Local pilots report fog is more common in Akun during summer when the seas are calmer, and that it is often clear in Akutan but foggy at the airport on Akun. The percentage of time each month that are cloudy or experience heavy fog from 1961 to 1990 are given for Cold Bay, 140 miles to the east, in Table 4 below (Center, 2023). Heavy fog constitutes visibility of a ¼ mile or less observed sometime during the day.

Table 4: Percent of Time Cloudy or Heavy Fog – Cold Bay

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Cloudy	75%	78%	75%	85%	89%	90%	92%	93%	88%	81%	78%	78%	84%
Heavy Fog	6%	5%	6%	4%	5%	7%	13%	11%	3%	1%	2%	5%	6%

2.5 Ice

The sea ice around Akutan and Akun does not freeze during the winter, but pan ice may sometimes develop at the head of Akutan Bay (Miller, Phillips, & Wilson, 2005). Past interviews of harbor employees at Unalaska, King Cove, and Sand Point conducted for the Akutan Harbor feasibility study revealed that these harbors experience occasional icing during the coldest winter days. The ice consists of a thin slush layer that does not interfere with boat maneuverability.

A recent study analyzed the sea ice extents in the Bering Sea from 1979 to 2012; the project area was at least 80 miles from the maximum ice extent on March 31, 2008 and at least 300 miles from the maximum ice extent on April 10, 2005 (Wendler, 2014).

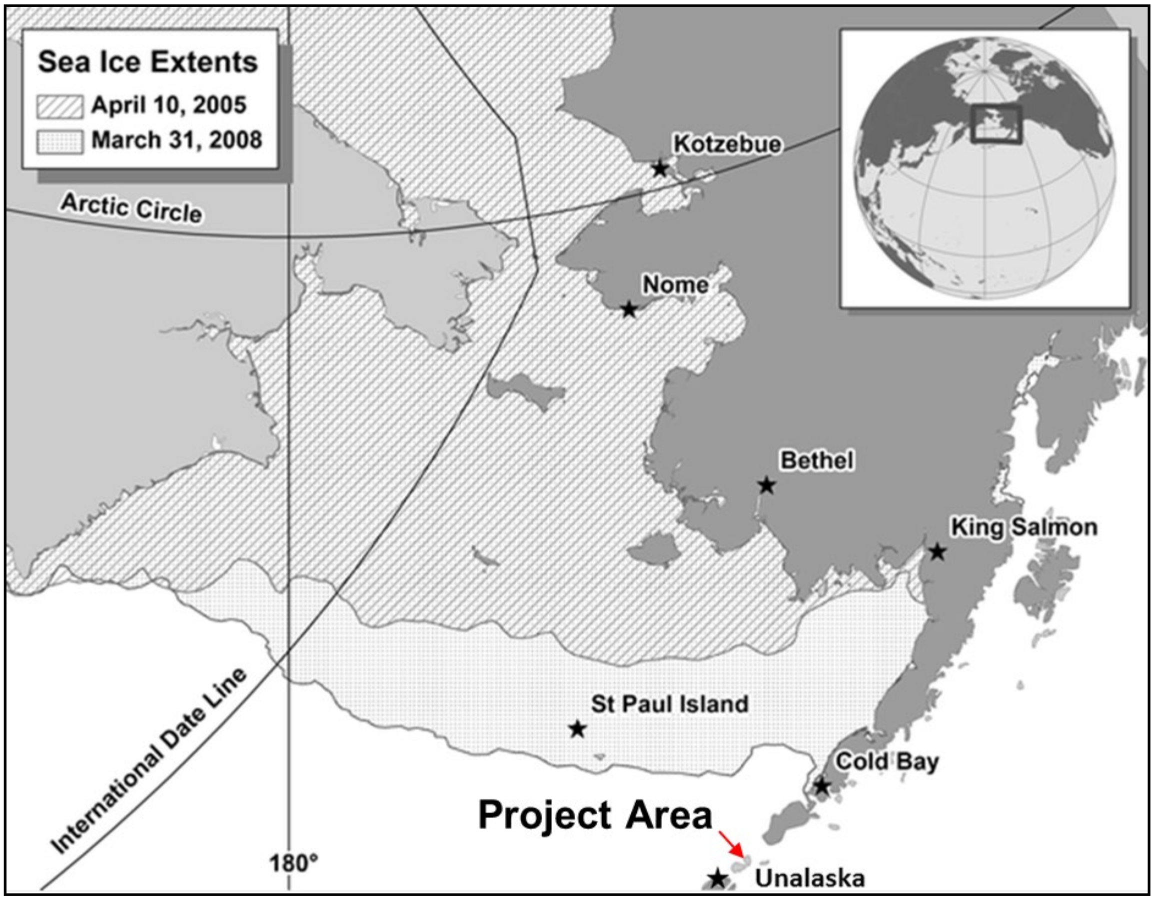


Figure 6: Bering Sea Ice Extents

2.6 Currents

Tidal currents are a significant consideration for small craft when traveling through the Akun Strait (also called Akutan Strait). NOAA Buoys measuring current were deployed near the project area during the summer of 2010, measuring a maximum current velocity of 0.8 knots at the Akutan Bay buoy and 7.5 knots at the Akutan Strait buoy. Approximate flood (increasing) tide directions were 340° and 350° respectively, aligning as expected with the Akun Strait.

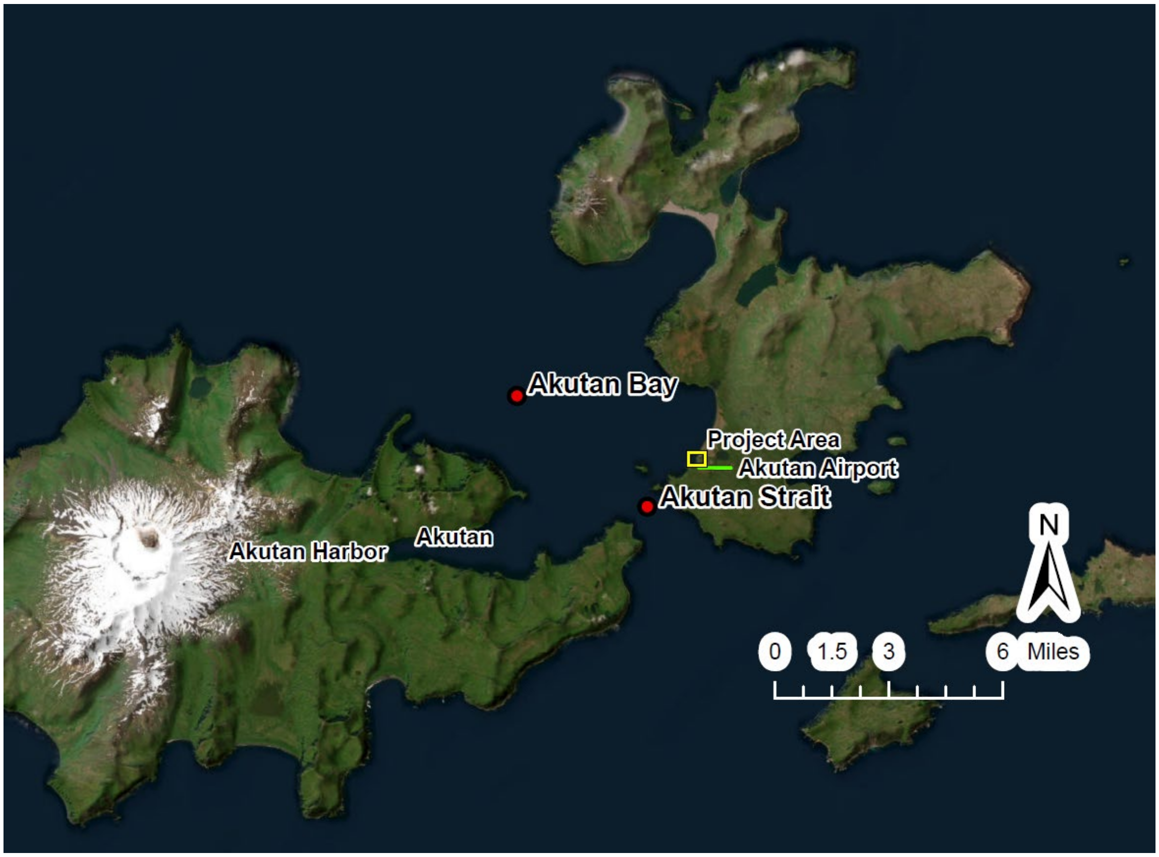


Figure 7: Location of NOAA Buoys Measuring Currents (Red)

Table 5: NOAA Currents Data

	Akun Strait	Akutan Bay
Depth of Data (ft)	10.8	31.8
Deployment Date (UTC)	6/11/2010	6/11/2010
Recovery Date (UTC)	7/23/2010	7/25/2010
Max Current (knots)	7.5	0.8
Approximate Flood Direction	350°	340°

According to the NOAA Coast Pilot, currents in Akun Strait can attain an estimated velocity of 12 knots in the narrowest part, setting north with the flood (NOAA, 2022). The slack period is very short. Tide rips, swirls and overfalls occur and with a northerly wind or swell from the Bering Sea create can be extremely heavy. These tidal rips and currents influence vessel traffic transiting north of Akun Strait, between Akutan and Akun Islands. A local captain with extensive local knowledge of tides and currents in the Akutan/Akun area stated the currents northward through Akun Strait persist to approximately the 40-fathom area in Akutan Bay (Figure 9), at which point the velocity of the currents is reduced by 50%.

Figure 8: Google Earth Imagery of Akun Strait Currents in the Project Study Area

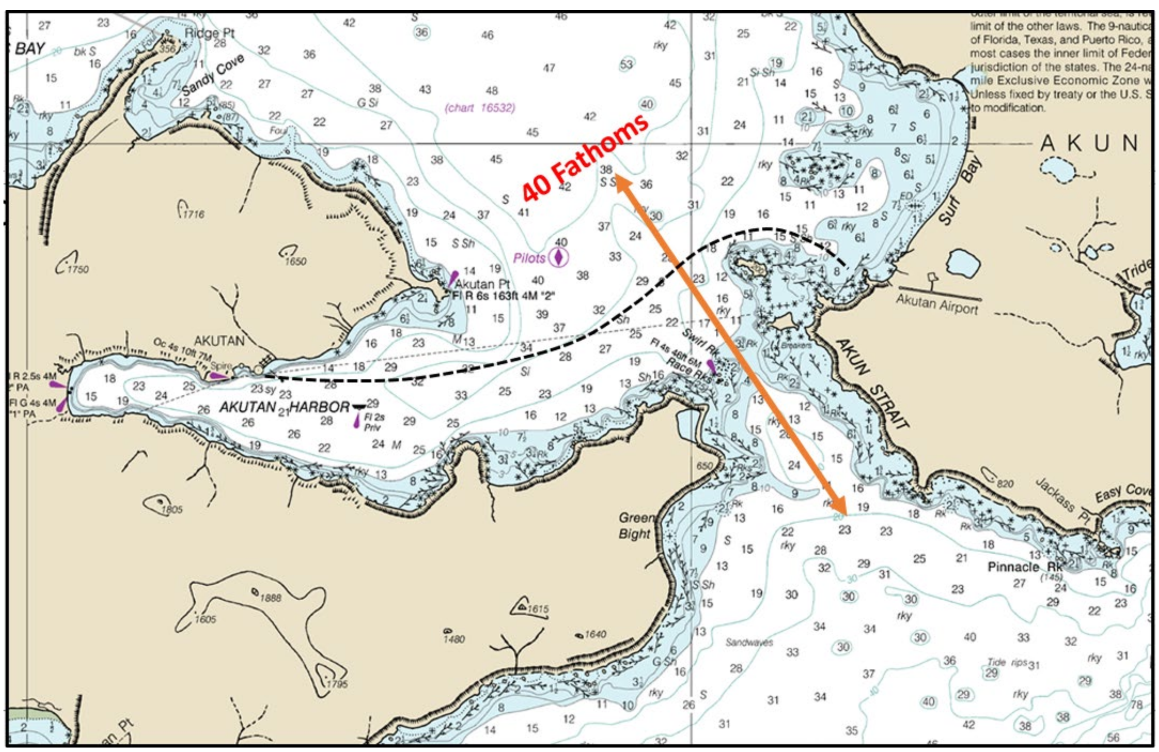


Figure 9: Tidal Current Influence through Akun Strait

A passenger ferry between Akutan and Akun will need to make trips through Akun Strait during unfavorable tidal currents. This could add time to the passage if the ferry must navigate in a wide arc to the north when transiting Akun Strait.

The proposed harbor lies in a large open body of water and is expected to have current values similar to the Akutan Bay Buoy of less than 1 knot. Currents are not expected to pose a navigational concern for the harbor.

2.7 Tides

Akun is in an area of semi-diurnal tides with two high waters and two low waters each lunar day. NOAA tide stations for Akutan (9462694) and Surf Bay (9462711) were deployed for spring of 2009 and three years from 2008 to 2011 respectively. Surf Bay is the closest tidal station to the project area. The closest tidal station with long term data is 35 miles to the southwest at Unalaska (9462620), with over 68 years of data including lowest and highest observed water levels. The location (Figure 10) and data (Table 6) of the tide stations are shown below.

Figure 10: Location of NOAA Tide Stations (Yellow)

Table 6: NOAA Tide Station Data

	Akutan	Surf Bay	Unalaska
Station	9462694	9462711	9462620
Established	3/7/2009	7/15/2008	5/7/1955
Removed	5/1/2009	9/18/2011	N/A
	(Feet MLLW)		
Highest Observed Water Level	-	-	6.70
Mean Higher High Water (MHHW)	3.73	3.76	3.60
Mean High Water (MHW)	3.42	3.47	3.31
Mean Sea Level (MSL)	2.16	2.19	2.08
Mean Low Water (MLW)	0.89	1.00	0.93
Mean Lower Low Water (MLLW)	0.0	0.0	0.0
Lowest Observed Water Level	-	-	-2.78

A tide curve (Figure 11) was developed for Unalaska (9462620) with data recorded between 1982 and 2023. During this period, the tide was above 0 feet MLLW 92.1% of the time. Harbor alternatives at Akutan are designed to allow access at tides above 0.0 feet MLLW. During calm weather conditions, harbor depth allowance for ship motion due to waves can be utilized for access at tides greater than 0.0 MLLW. A sensitivity analysis was performed to evaluate what percent of time marginal weather conditions would occur concurrently with tide greater than 0.0 feet MLLW. Approximately 1% of the time, the events would occur concurrently, and the harbor would not be accessible due to tide.

Table 7: Water Level Duration - Unalaska (9462620)

Water Level (ft MLLW)	-1.5	-1	-0.5	0	+ 0.5	+ 1	+ 1.5
Percent of Time Equal or Above Water Level	99.7%	98.8%	96.5%	92.1%	86.0%	78.7%	69.9%

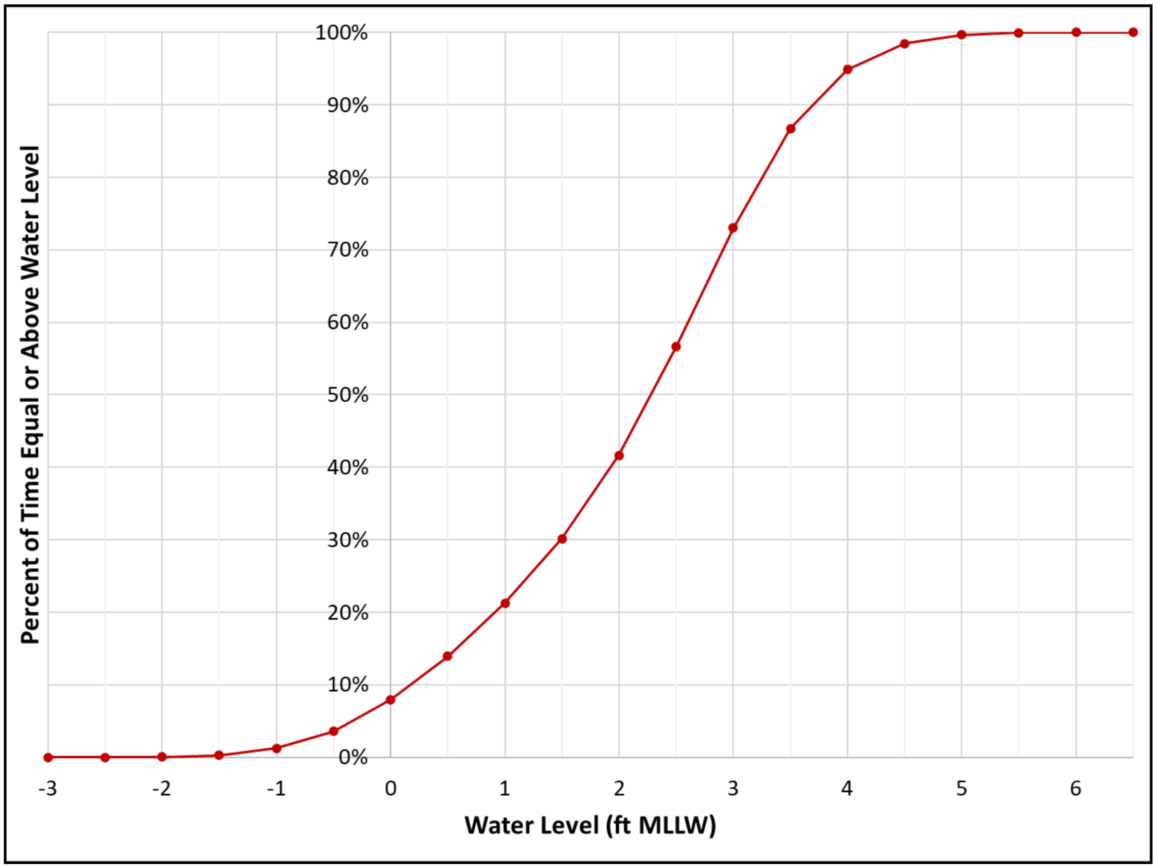


Figure 11: Water Level Duration Curve - Unalaska (9462620)

2.8 Wind

2.8.1 Wave Information Studies

Wind analysis was performed for this study by the Coastal and Hydraulics Laboratory, Flood and Storm Protection Division, Coastal Processes Branch (CEERD-HFC). The basis of the analysis is Wave Information Studies (WIS), a US Army Corps of Engineers (USACE) sponsored project that generates consistent, hourly, and long-term wave climatologies (Hesser, 2018). WIS point 82327 was chosen to be representative of offshore wind and wave conditions that would affect the project area at Akun. Station 82328 to the east is sheltered by Akun while station 82326 to the west is located farther from the Akun Strait. Station 82355 to the south is also sheltered by the island chain south of Akutan and Akun islands and local commercial vessel operations indicated the most severe storm events originate from the north. WIS Station 82327 is located approximately 30 miles from the project area.

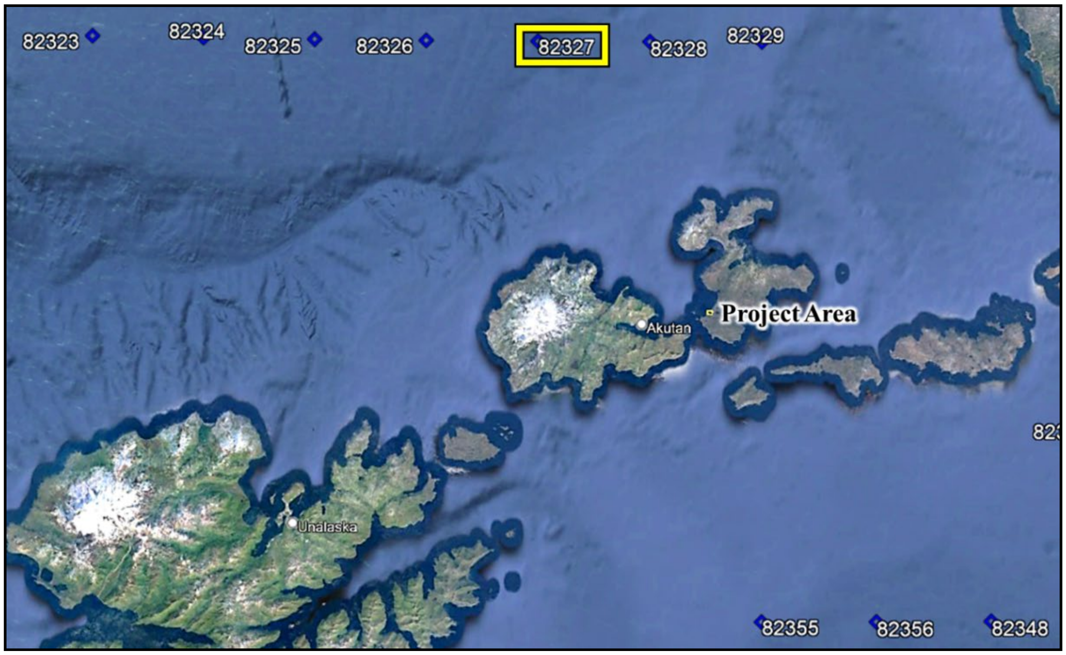


Figure 12: Location of WIS Point 82327

The islands of Akutan and Akun as well as the island chain to the south provide a limited window for Bering Sea energy to pass into the area traveled by the ferry. Therefore, ERDC approximated that the area of influence of WIS Station 82327 would be from about 290° to 330°.

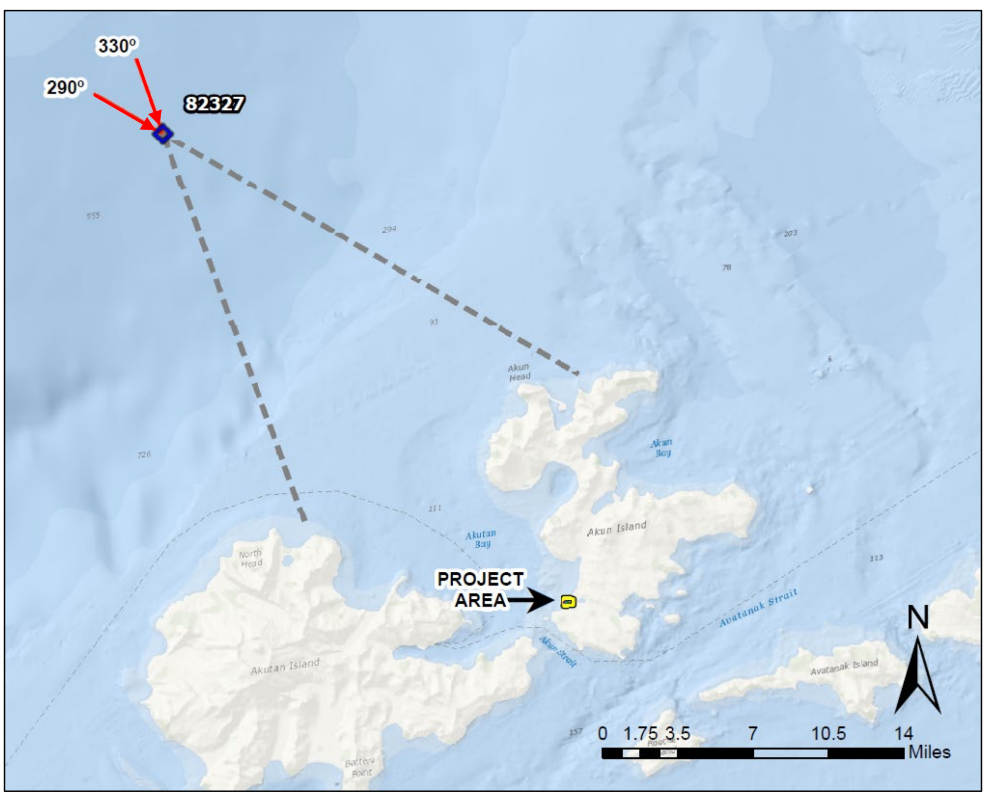


Figure 13: Approximated Area of Influence of Point 82327

Meteorological and oceanographic measurements are available at 3 sites near the project area. Figure 14 displays the location of these sites as compared to WIS points in the area. Site 46126 (magenta) offshore Unalaska Island contains wave-wind estimates from 2013 to 2014. Site 9462620 (blue) on Unalaska Island contains meteorological information from 2010 to 2019, and buoy 46032 (blue) offshore Akun Island also contains meteorological information from 1984 to 1985.

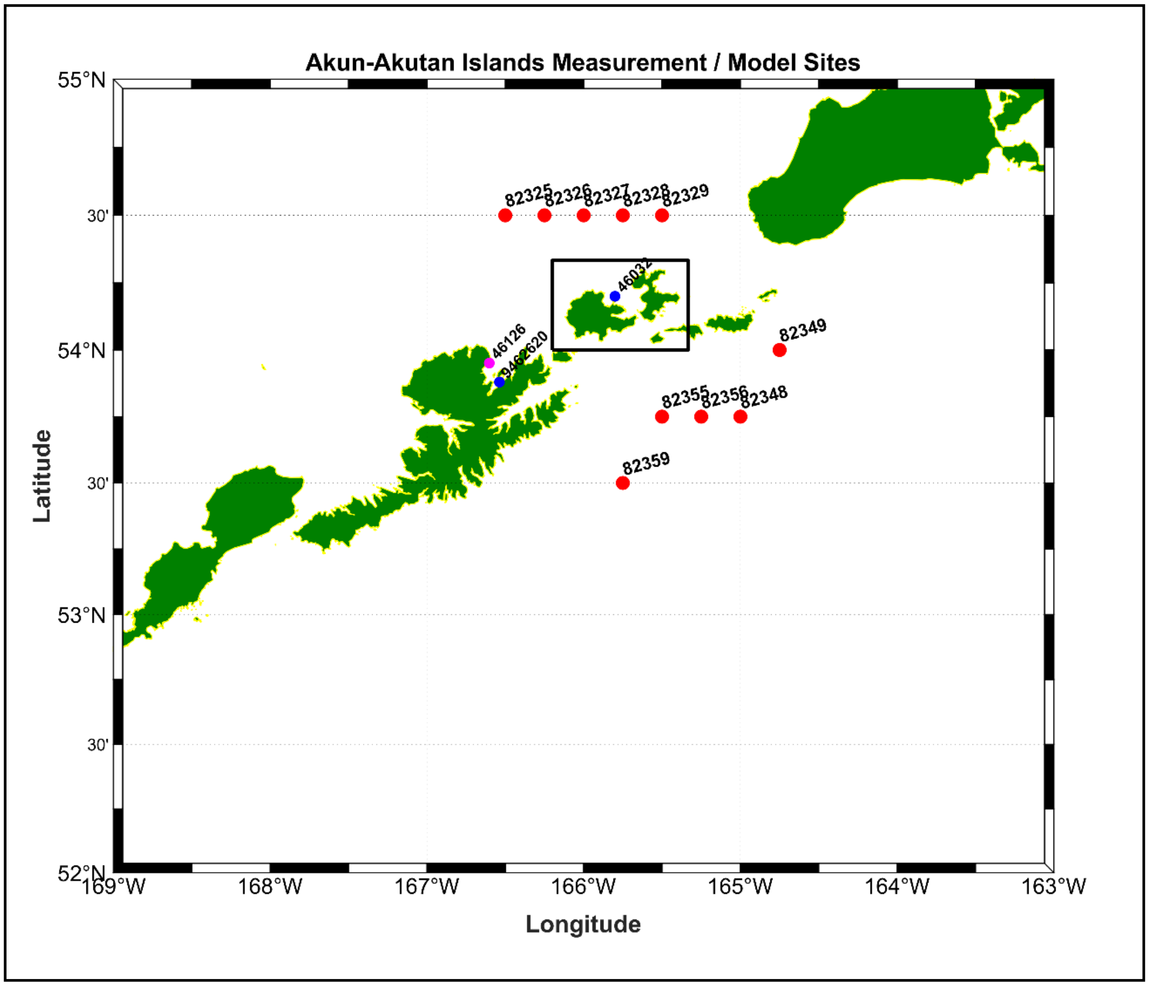


Figure 14: Location of WIS Stations (Red), Wave (Magetna), and Meterological Station/Buoy (blue)

Site 46032 is of limited duration but is the only wind measurement site located in the study area. Therefore site 46032 was the sole basis of the evaluation of WIS station 82327 relative to local conditions. Wind analysis performed by CEERD-HFC compared the one year of data overlap between modeled WIS wind and measured wind at site 46032 using a Quantile-Quantile (QQ) comparison. The result was the following QQ correlation equation, which when inverted, can be used to adjust the modeled wind speeds.

$$WS_{modeled\ WIS} = 0.13 + 1.03WS_{measured\ 46032}$$

The slope of the QQ equation being so close to one indicates that the differences between modeled WIS and measured site 46032 wind were nominal. Therefore, WIS station 82327 winds would be considered representative of the wind conditions in the project area and are used for design.

Figure 15: Location of Buoy Site 46032 relative to Akutan and Akun

Looking at the wind rose for 82327, the largest population of wind speeds is 5 to 10 m/s (10 to 19 knots).

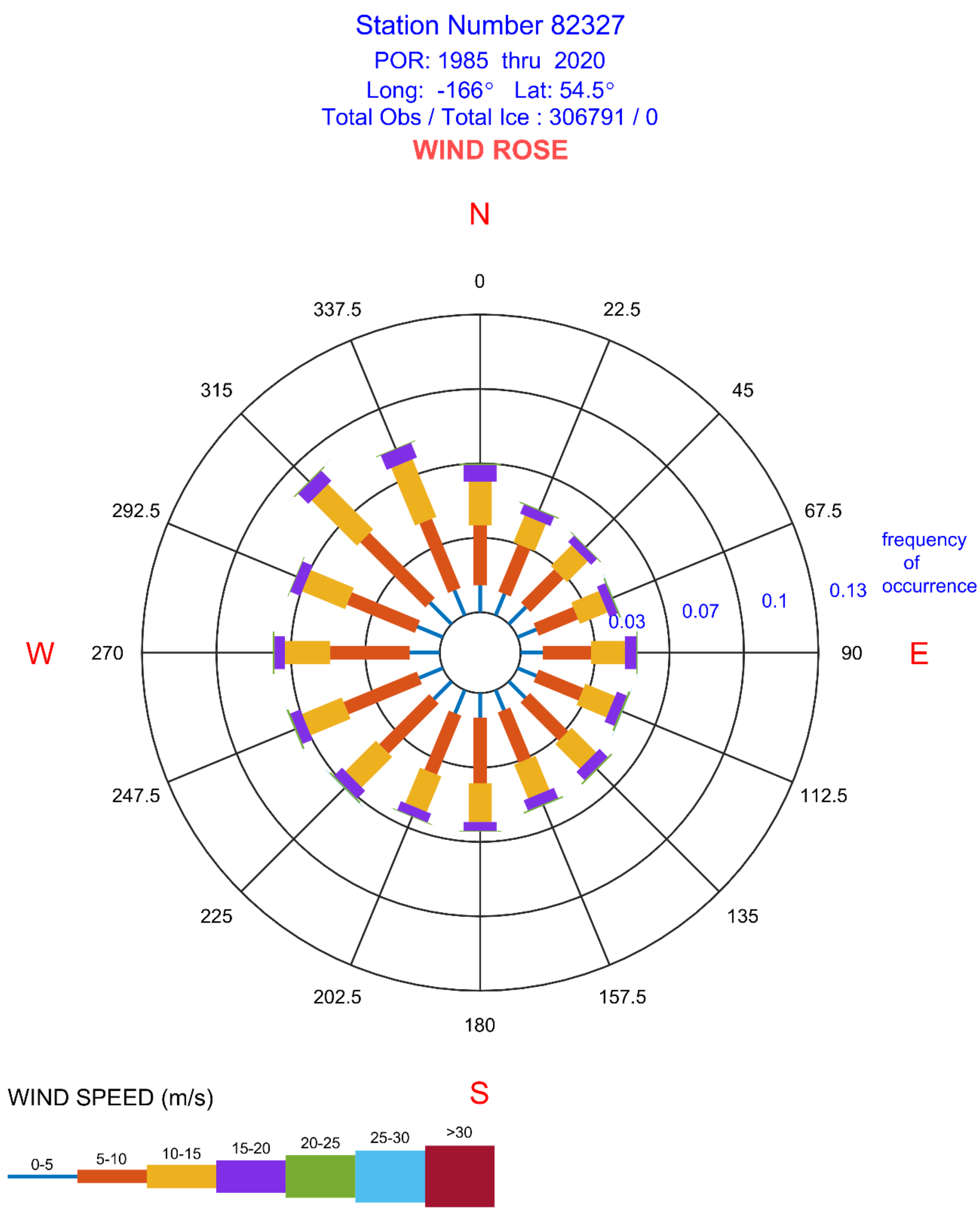
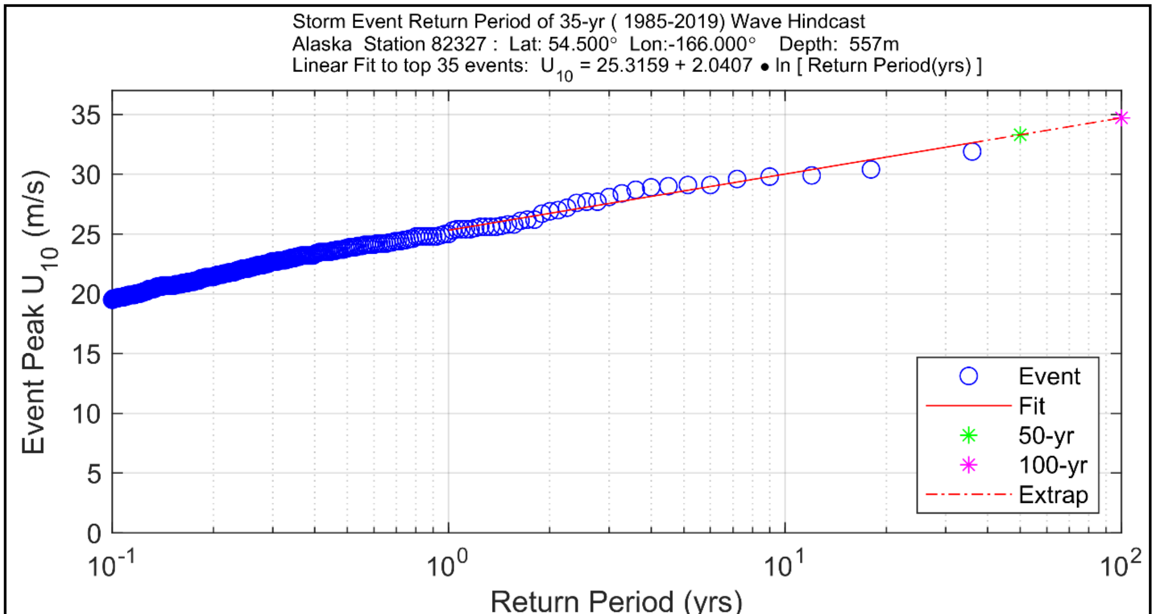


Figure 16: Wind Rose WIS Station 82327

2.8.2 Wind Extreme Analyses

The extremal analysis for the offshore wind and wave climate was performed by CEERD-HFC using a Peaks-Over-Threshold method (Jensen, 2022).

Table 8 below lists the top 35 storms for the 35-year period of record from 1985 to 2019. They are ranked by wind speed with corresponding significant wave height (**H_{m0}**) and period (**T_p**) provided as well. The author noted that the top ten storm values are surprisingly high. Wind speeds and direction reflect open water conditions and cannot capture local orographic steering of wind from the land masses of Akutan and Akun. Gap-wind studies for the Aleutian Islands confirm this (Pan, 1999).



Top 10 events based on Peak U_{10}

Event	Date/Time(UTC)	U_{10}	θ_{wind}	Event	Date/Time(UTC)	U_{10}	θ_{wind}
1	1992/11/23 23:00	31.90	319.00	6	2000/11/03 23:00	29.10	115.00
2	1988/12/27 11:00	30.40	231.00	7	1994/10/01 05:00	29.10	59.00
3	2001/12/23 23:00	29.90	119.00	8	1988/03/09 17:00	29.00	16.00
4	1985/11/26 23:00	29.80	266.00	9	1988/12/10 23:00	28.90	355.00
5	2006/02/13 23:00	29.60	160.00	10	2015/12/14 00:00	28.70	218.00

An event is defined as any period when U_{10}> 17.38m/s θ_{wind} is direction that waves are arriving from

Figure 17: Wind Speed Extremes for WIS Station 82327

To try and account for the orographic effects of Akutan and Akun, winds originating from 290° to 330° are highlighted in green. This still includes the worst storm recorded in the area, 62 knots from 319°. Knowledge of local commercial vessels confirms that the most severe storm events are coming in from the Bering Sea to the north. This also represents the worst case for a ferry vessel transiting between Akutan and Akun.

Table 8: WIS Station 82327 Wind Speed Extremes (Imperial)

Wind Speed Extremes (All Hourly Estimates)						
Rank	Peak Date	WndSpd (knots)	WndDir (°)	H_{m0} (ft)	T_p (s)	WavDir (°)
1	19921123230000	62.0	319	50.5	14.86	325
2	19881227110000	59.1	231	32.2	13.51	235
3	20011223230000	58.1	119	17.7	7.63	116
4	19851126230000	57.9	266	48.9	17.99	264
5	20060213230000	57.5	160	24.0	10.15	164
6	20001103230000	56.6	115	22.6	9.23	115
7	19941001050000	56.6	59	25.6	10.15	57
8	19880309170000	56.4	16	27.9	11.17	29
9	19881210230000	56.2	355	41.7	11.17	354
10	20151214000000	55.8	218	40.7	19.78	240
11	19970107170000	55.2	59	26.9	10.15	52
12	19880221170000	54.6	66	25.3	10.15	65
13	20111215000000	53.8	83	23.6	9.23	89
14	20111215000000	53.8	139	22.0	9.23	126
15	19911226110000	53.6	226	20.0	9.23	225
16	20170122210000	52.9	101	21.7	9.23	98
17	20110403120000	52.5	302	31.5	9.23	305
18	19910314110000	52.3	249	35.8	14.86	263
19	20070125050000	51.9	57	26.6	10.15	57
20	20041204110000	50.9	113	15.1	6.93	110
21	20020129110000	50.9	317	34.8	13.51	326
22	20001113170000	50.7	238	45.3	19.80	257
23	20140208060000	50.2	3	36.7	13.51	7
24	19971204230000	50.2	232	28.5	14.86	241
25	20111213090000	50.0	109	21.0	9.23	106
26	20151111180000	49.8	304	26.2	11.17	293
27	19990123050000	49.8	223	26.6	13.51	228
28	19940306050000	49.8	34	24.9	10.15	37
29	19920329170000	49.8	102	21.3	9.23	95
30	19950323230000	49.6	69	27.2	11.17	61
31	20161224000000	49.4	111	21.7	9.23	108
32	20090225140000	49.4	241	23.6	13.51	250
33	20041121110000	49.4	156	16.1	7.63	155
34	19931111110000	49.4	225	17.7	7.63	200
35	20161030120000	49.2	147	19.0	7.63	187

2.8.3 Wind and Airport Operations

Akutan Airport rather than WIS station data was used in airport operation analysis. The analysis compared the weather conditions in which each existing and proposed craft could access the Akutan Airport. The data used for the analysis was from 5/15/2014 when the station became operational to 5/18/2023 at an interval averaging 3 readings per hour.

In general, winds that prevent fixed-wing aircraft landing at the Akutan airport are crosswinds. The Akutan runway is aligned east to west. Based on the Pilot's Operating Handbook for a Piper Navajo 310, the type of fixed-wing aircraft landing at Akutan Airport, flights would be able to operate in up to 20 knot crosswinds ("LICENCIAS", 2013). Winds of 40 knots or greater will cause cancelations of fixed-wing aircraft into both Unalaska Airport and Akutan Airport.

The crosswind component is calculated by taking the Sine(ϴ) of the wind angle multiplied by the total windspeed. Table 9 below shows a general rule of thumb used for calculating at what angle the total windspeed would exceed the 20 knot maximum crosswind. These values assume a dry or damp runway, whereas a runway covered with snow, slush, or standing water can reduce the maximum crosswind allowance by up to half.

Table 9: Crosswind Calculations

Wind Angle	**Crosswind Calculation**	**Max Total Wind Speed** (kts)
30°	1/2 x Total Wind	40
45°	3/4 x Total Wind	26.7
60°	1 x Total Wind	20

Grant Aviation fixed-wing aircraft flights from 2020 to 2022 to Akutan airport were reported to be canceled on average 34% of the time due to weather. Maritime helicopters had an average of 30% of their flights canceled due to weather over the same time period. Helicopters are better able to travel through cross winds but may cancel due to fog. Fixed-wing aircraft would control airport access for the harbor alternative. Note that these statistics reflect weather cancellations of scheduled trips, and the fixed-wing and helicopter operators frequently run "catch up" trips during good weather.

The maximum allowable tailwind or crosswind for hover operations of the existing Bell 206L4 helicopter are 30 knots and a larger Bell 412 helicopter are 35 knots. The maximum available crosswind for the existing Piper PA31-350 Navajo Cheiftan is 20 knots. The results of the amount of time successful trips could theoretically be conducted at Akutan Airport for these craft are found in section 4.1.1 Operational Conditions.

2.8.4 Local Wind-Wave Generation

Local wind generated fetch limited waves was considered for two different scenarios. One is a skiff transporting crew between the Native Village of Akutan and Akutan Harbor, and the other is the ferry traveling between the Native Village of Akutan and the proposed Akun harbor. Locally generated waves would have short periods of approximately 2 to 4 seconds. Formulas used to calculate fetch limited used were obtained from the Shore Protection Manual (1984), using the fetch length (F) in nautical miles, the wind speed U_A in knots, and the significant wave height (H_{m0}) in feet.

Fetch Limited:

$$H_{m0} = 3.714 * 10^{-2} U_A F^{1/2}$$
$$T_m = 6.14 * 10^{-1} [U_A \cdot F]^{1/3}$$

2.8.4.1 Skiff

Skiff travel between the Native Village of Akutan and Akutan small boat harbor is within the protected body of water of Akutan Harbor. A small window of wind generated waves can enter Akutan Harbor from the east that would affect skiffs as they move past the Trident plant.

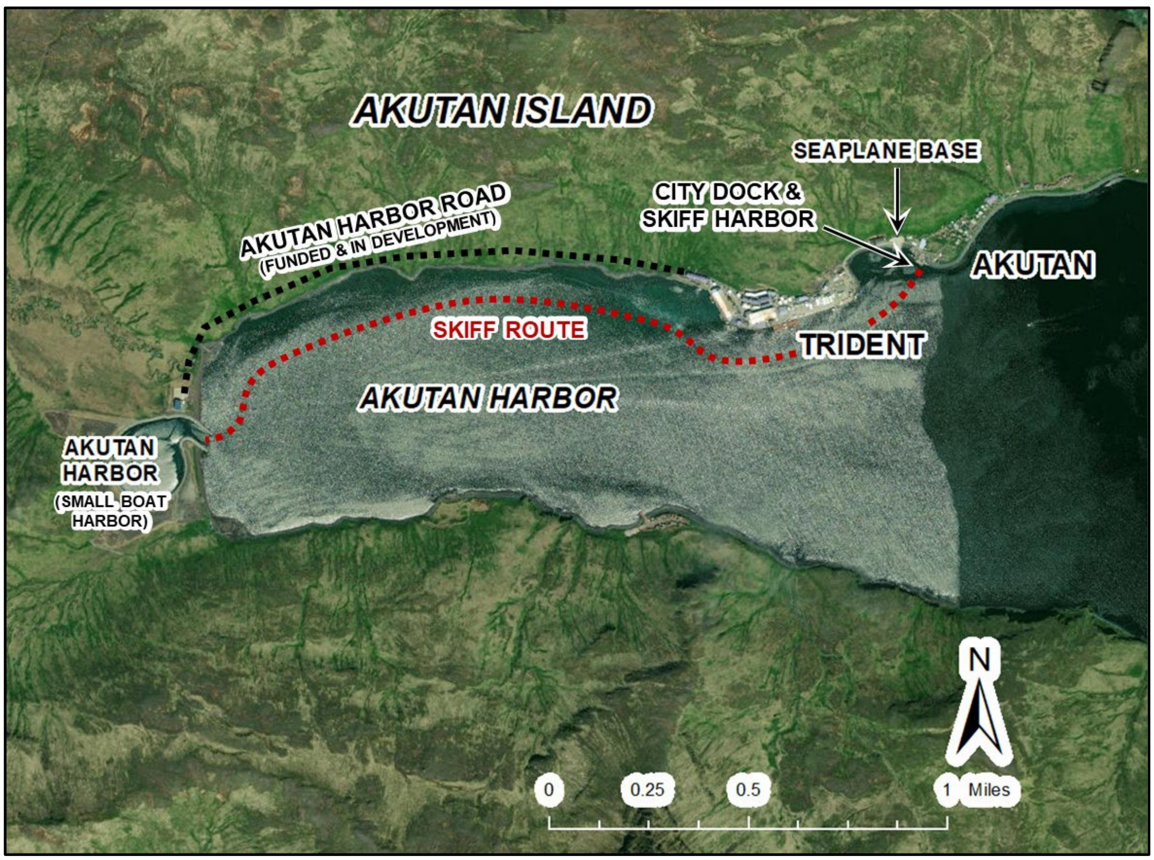


Figure 18: Route Between Native Village of Akutan and Skiff Harbor

The longest open water fetch length for wind generated waves in Akutan Harbor is approximately 4.8 nautical miles. A wind speed of 40 knots was used for wind generated wave calculations as a 40 knot wind along the runway will cause a cease operation for fixed-wing aircraft. A wind speed of 40 knots over a 4.8 nautical miles fetch would generate a significant wave height of 3.3 feet with a period of 4 seconds. Skiff travel to and from Akutan Harbor would not be a limiting factor of ferry operations with the completion of the Akutan Harbor Road. The road is partially funded and stockpiling of materials began in 2023 with a tentative completion date of 2024.

Figure 19: Skiff Operations Maximum Fetch Length

2.8.4.2 Ferry

The longest fetch length for wind generated waves (outside of the 290°-330° direction directly open to the Bering Sea) that would affect a ferry traveling between the Native Village of Akutan and Akun is approximately 7.7 nautical miles. A wind speed of 26 knots was used for wind generated wave calculations as a 26 knot wind at a 45° to the runway will cause a cease operation for fixed-wing aircraft. A wind speed of 26 knots over a 7.7 nautical miles fetch would generate a significant wave height of 2.7 feet with a period of 4 seconds. This is less than the normal ferry operations significant wave height of 3 feet (see Section 4.1.1 Operational Conditions). Therefore, wind generated waves would not be a limiting factor for ferry operations.

Figure 20: Ferry Operations Maximum Fetch Length

2.9 Wave Climate

Akutan Bay is open to the Bering Sea to the north. Akun Strait gives access to the North Pacific (Gulf of Alaska) to the south, but Akun Strait is subject to strong currents. Refraction around Rootok Island (southwest of Akun Strait) and shoaling and wave breaking in Akun Strait prevent most of the wave energy generated in the Gulf of Alaska from penetrating into Akutan Bay but can cause a confused and severe breaking wave environment within Akun Strait. While these features protect Akutan Bay from Pacific swell from the south, it is subject to Bering Sea swell arriving from the north. Akutan Bay opens into Akutan Harbor extending along an east-west axis towards the west. See section 3.0 WAVE ANALYSIS for more information.

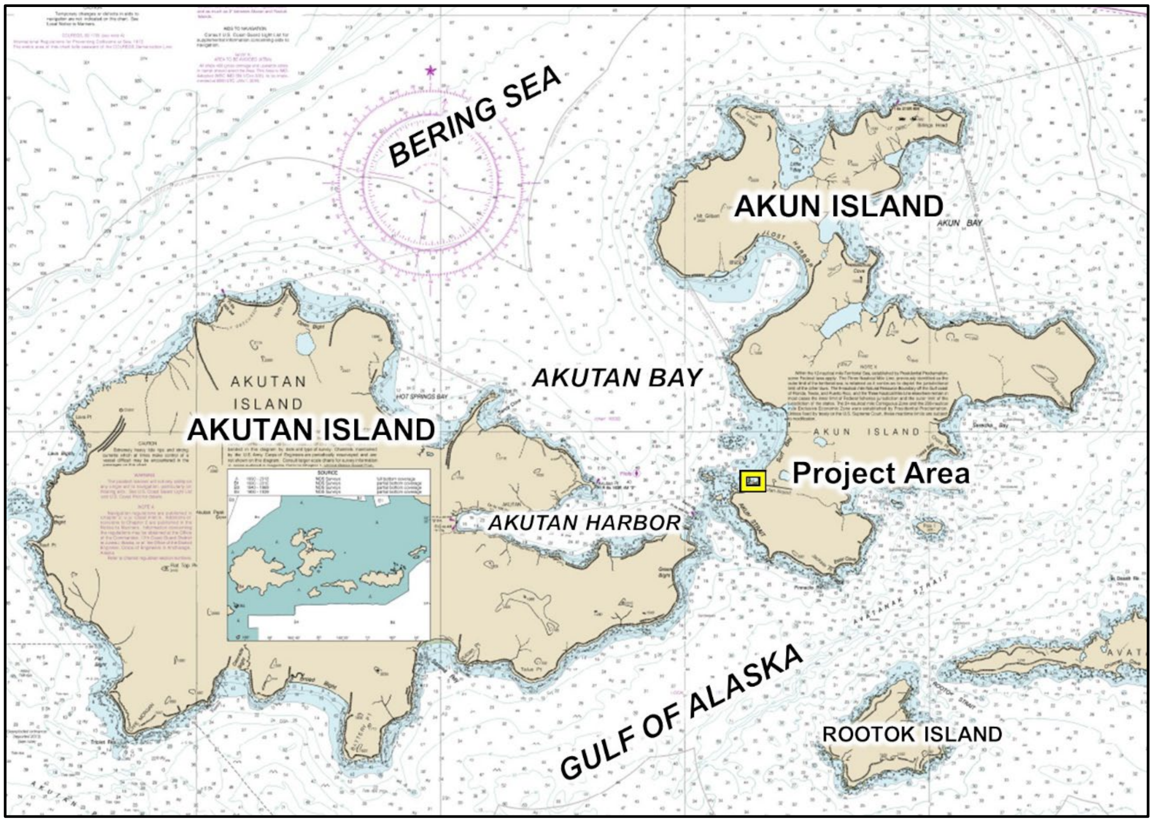


Figure 21: Wave Climate Features

2.9 Hydrology Analysis

Engineering Construction Bulletin (ECB) 2018-14 provides guidance for incorporating climate change information in hydrologic analysis in accordance with the USACE overarching climate change adaptation policy. A literature review, per ECB 2018-14 guidance, was conducted using the following sources.

1) Recent US Climate Change and Hydrology Literature Applicable to US Army Corps of Engineers Missions – Alaska Region (USACE, 2015)

2) Climate Change Indicators in the United States (EPA, 2023)

3) Climate Science Special Report: Fourth National Climate Assessment, Volume I (Wuebbles, et al., 2017)

4) Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II (Gray, et al., 2018)

According to the Fourth National Climate Assessment, a warming trend relative to average air temperatures was recorded from 1925 through 1960. A trend of increasing temperatures starting in the 1970s has been identified and is projected to continue throughout the state of Alaska. The largest temperature increases have been found in winter months with average minimum temperature increases of around 2° F statewide. Carbon emission models project variable increases in statewide temperatures across the state. Forecasted temperature increases for the project location are in the 4 – 6°F range for the intermediate model (RCP4.5) and in the 6 – 8°F range for the high model (RCP8.5) (Figure 22).

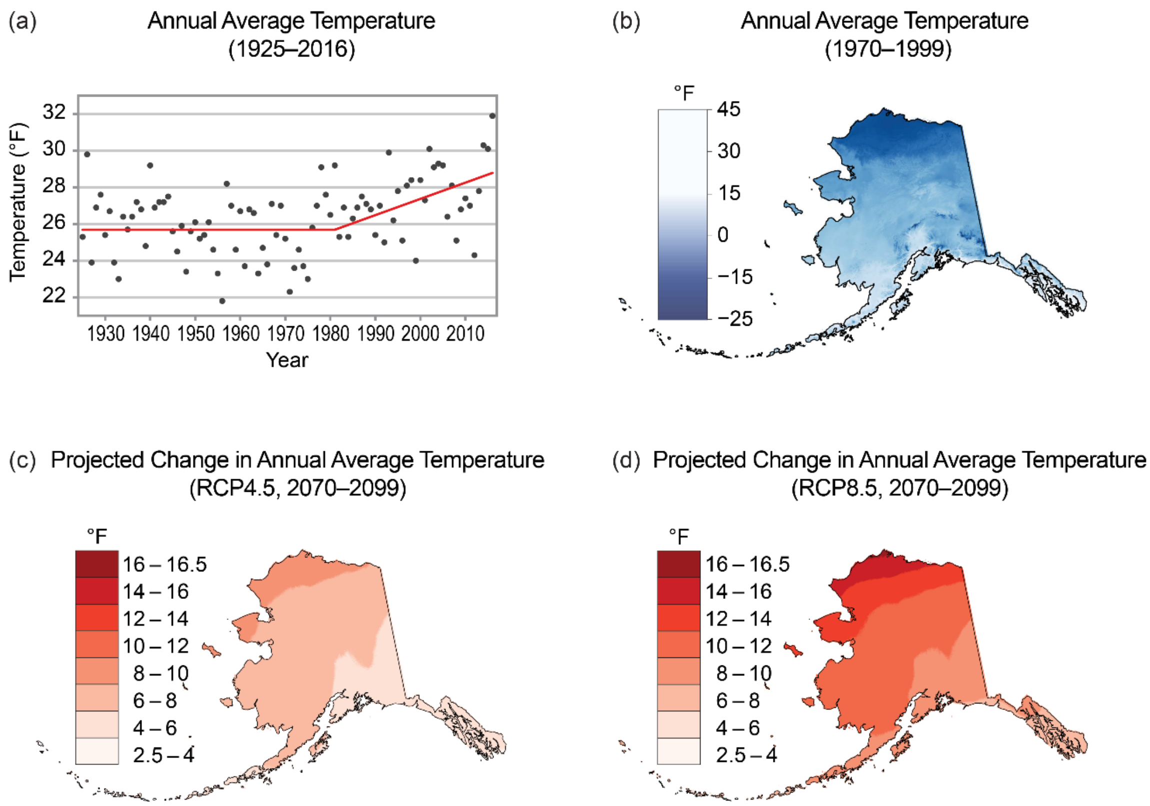


Figure 22: Observed and Forecasted Changes in Annual Average Temperature from 1925 to 2016 (Gray, et al., 2018)

Observed precipitation has shown an upwards trend across Alaska. Average observed precipitation changes have varied since the 1900s. A trend of increasing precipitation has been observed across the state since the 9180s (Figure 23).

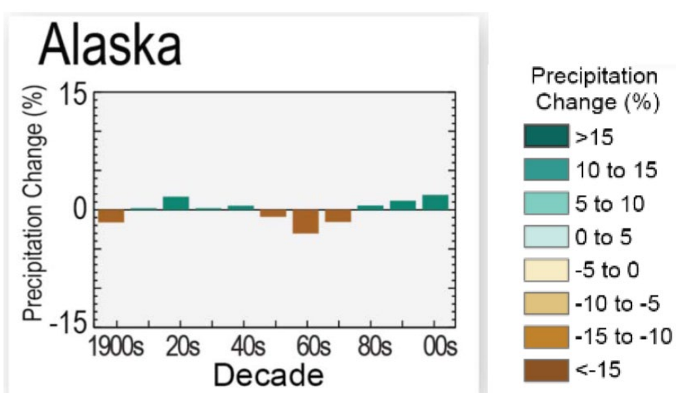


Figure 23: Average Precipitation Changes Compared to 1901 to 1960 Average (USACE, 2015)

Forecasted precipitation models also predict an upwards trend across Alaska, though it is less pronounced in the Aleutian Islands. The simulated changes in the average amount of precipitation falling on the wettest day of the year for 2070 to 2099 as compared to 1971 to 2000 for the project location is 0% to 10% for the low model (RCP2.6) and 20% to 30% for the high model (RCP8.5). In Figure 24 below, stippling indicates areas where changes are consistent among at least 80% of the models used in the analysis (USACE, 2015).

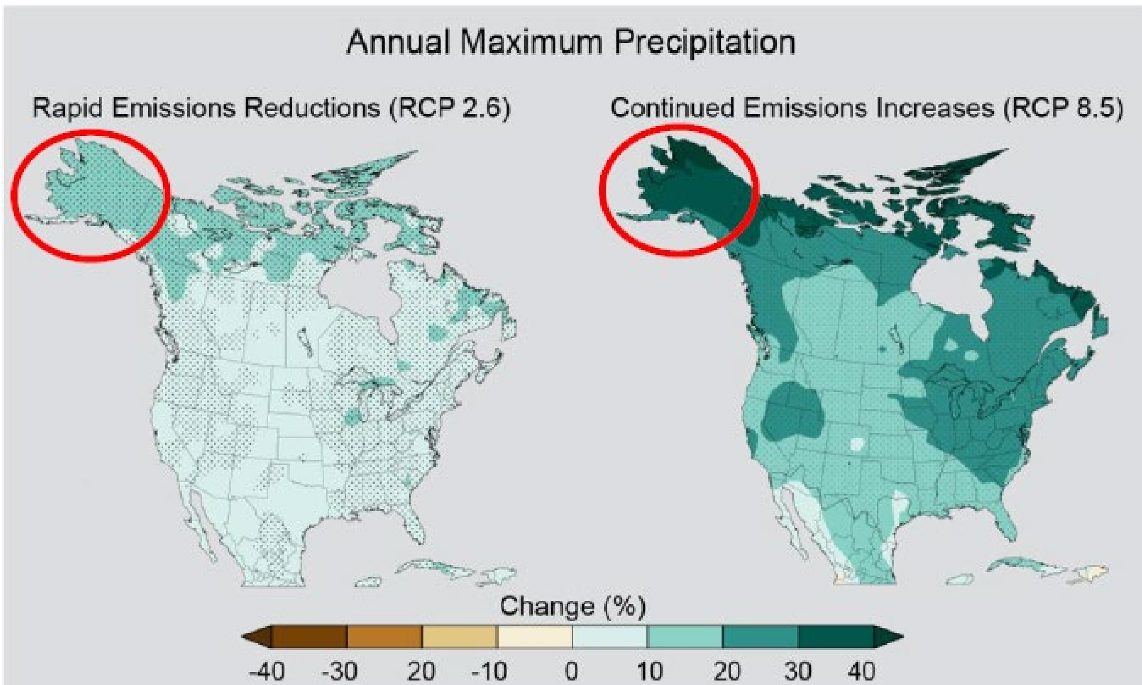


Figure 24: Simulated Changes in the Precipitation for 2070 to 2099 Compared to 1971 to 2000 (USACE, 2015)

The USACE Screening-Level Climate Change Vulnerability Assessment (VA) Tool was consulted to identify watersheds that present risk in the navigation business line, but the VA tool is only available for the contiguous 48 states. Therefore, the VA tool was not used for this project.

A formal hydrology analysis of was not completed for this project. No USGS gages exist in the project area, with the closest stream gage with a significant period of record being Russell Cove (15297610) 140 miles to the northeast. One small, ungagged salmon stream occurs one bay to the north of the project location, but it is not expected to have an impact on the proposed project. There are no streams in the project location.

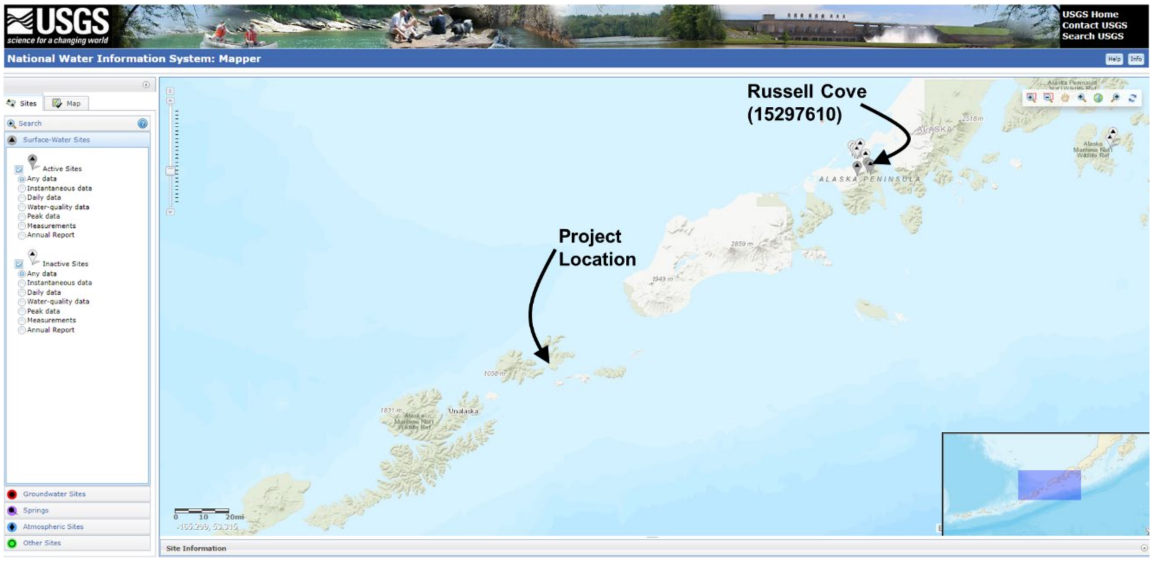


Figure 25: Closest USGS Gage to Project Location

Alaska is anticipated to trend towards an increase in temperature and precipitation in the future. These climate changes are most pronounced in the Arctic, and less pronounced in the Aleutian Islands and the project area. These changes are not anticipated to affect the project design outside of relative sea level change (RSLC), which is examined in section 2.11 Relative Sea Level Change.

2.10 Seasonal Oscillations

Seasonal oscillations such as the El Niño-Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO) were evaluated at the project location. The oscillations primarily affect ocean temperature, precipitation, water level, and storm intensity. The primary factor that would affect the project is water level.

On average, the PDO cycles every 20 to 30 years and ENSO every 2 to 10 years (Woods Hole Oceanographic Institution, 2023). They can occur simultaneously and either reinforce or dampen each other's effects. It is estimated that from 1990 to 2000 the magnitude of the ENSO and PDO swing globally was about 6 inches of ocean water level change (NASA, Dueling climate cycles may increase sea level swings, 2023).

The two strongest ENSO seasons on record are by many accounts 1997/1998 and 2015/2016 (Paek, Yu, & Qian, 2017). Looking at Figure 26 below, the effects of these two ENSO events is primarily in the equatorial region, with the sea surface height anomalies being near zero in the project location.

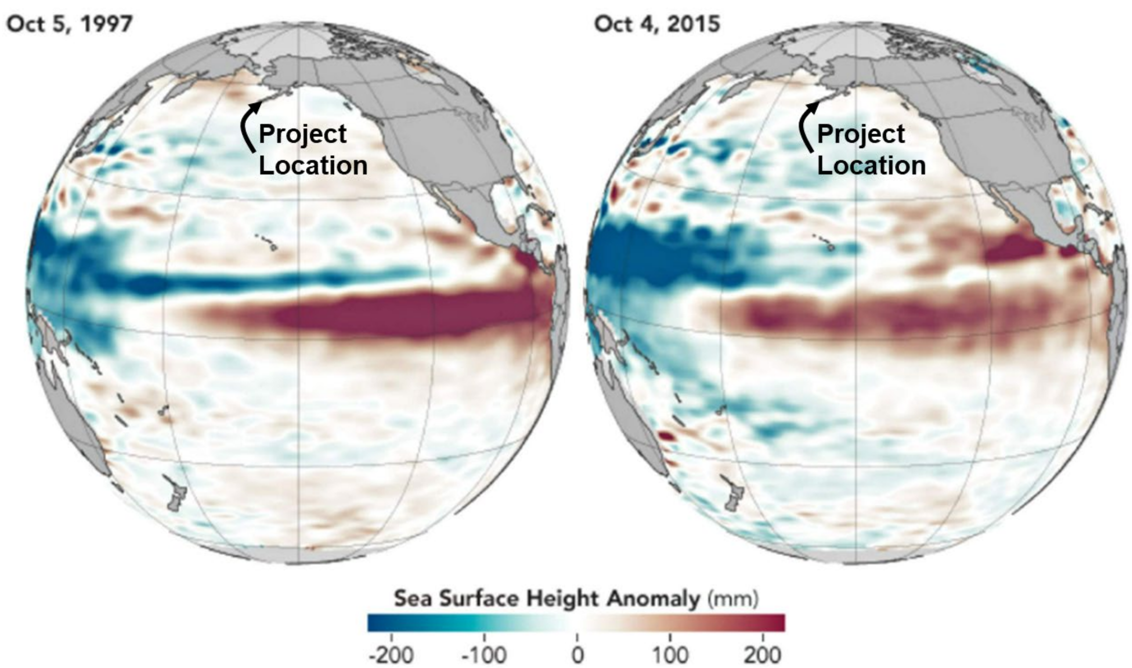


Figure 26: NASA Earth Observatory Map of ENSO Sea Surface Height Anomalies (Carlowicz, 2015)

The contribution of the PDO to sea level trends from 1993 to 2010 was estimated by an empirical orthogonal function analysis of Archiving, Validation, and Interpretation of Satellite Oceanographic (AVISO) data shown in Figure 27. Similar to ENSO, the PDO resulted in sea level height changes of approximately 0.8 inches (2 mm) at the project location.

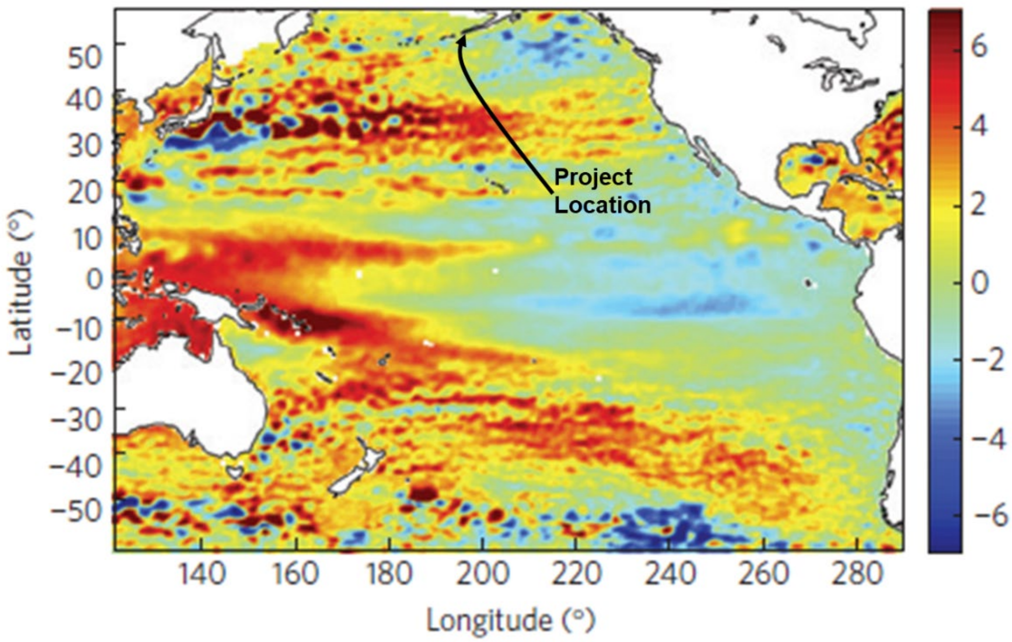


Figure 27: PDO Contribution to Sea Level Trends in mm/year from 1993 to 2010 (Hamlington, et al., 2014)

The period of record for temperature, precipitation, and tide data for Dutch Harbor is 54, 54, and 68 years respectively. WIS point 82327 has hindcast data for 35 years of wind and wave data that describe storms. Therefore, it is reasonable to conclude that the data being utilized captures the seasonal variations of ENSO and PDO. Additionally, sea level anomalies caused by ENSO and PDO are primarily focused in lower latitudes than the project location. Therefore, sea level change inclusions for ENSO or PDO was not incorporated into the project design.

2.11 Relative Sea Level Change

The Corps of Engineers requires that planning studies and engineering designs consider alternatives that are formulated and evaluated for the entire range of possible future rates of RSLC. An analysis was performed on the two closed tide stations to determine which was representative of the site location. The low, intermediate, and high RSLC scenarios for the representative station were then evaluated for impact on dredging and breakwater design.

2.11.1 Tide Station Selection

The two closest tide stations, Unalaska (9462620) and Sand Point (9459450), were evaluated to determine which was most representative of the project for RLSC analysis. The closest tide station is Unalaska, located approximately 35 miles southwest of the project site. Sand Point is located 220 miles to the northeast. The period of record is 1965 to 2015 (50 years) for Unalaska (9462620) and 1982 to 2015 (33 years) for Sand Point (9459450). Note that Sand Point does not have the recommended 40-year period of record. Table 10 below compares

NOAA tide station data between the project location at Surf Bay (9462711) and Unalaska (9462620) and Sand Point (9459450). Surf Bay tides most closely resemble Unalaska.

Table 10: NOAA Tide Station Comparison

	Surf Bay	**Unalaska**	**Sand Point**
Station	9462711	9462620	9459450
Established	7/15/2008	5/7/1955	9/10/1972
Removed	9/18/2011	N/A	N/A
	(Feet MLLW)		
Highest Observed Water Level	-	6.70	11.59
Mean Higher High Water (MHHW)	3.76	3.60	7.24
Mean High Water (MHW)	3.47	3.31	6.53
Mean Sea Level (MSL)	2.19	2.08	3.88
Mean Low Water (MLW)	1.00	0.93	1.34
Mean Lower Low Water (MLLW)	0.0	0.0	0.0
Lowest Observed Water Level	-	-2.78	-3.81

Unalaska and Sand Point stations were also compared using local rates of vertical land movement (VLM) published by NASA Jet Propulsion Laboratory (NASA, 2023). The local rate of VLM for Unalaska is +0.00901 feet/year ±0.00104 feet/year and the local rate for Sant Point is -0.00065 feet/year ±0.00083 feet/year. The positive value of VLM indicates that Unalaska is experiencing isostatic rebound, or the rising of land in response to the removal of the weight of glacial ice. The closest measurement of VLM to the project location is five miles to the southwest on Akutan (AV15), where the local rate is +0.00663 feet/year ±0.00088 feet/year. Therefore, Unalaska is a better representation of VLM at the project location.

The two gages are also classified in different physiographic divisions of Alaska as shown in Figure 28 below. Sand Point is located in the Aleutian Range, which is an extensively glaciated region consisting of ridges under 4,000 feet high and volcanos under 8,500 feet high with an abrupt and rugged south coast. Unalaska and Akutan are located in the Aleutian Islands, which are a chain of islands along the crest of a submarine ridge 12,000 feet above the sea floor.

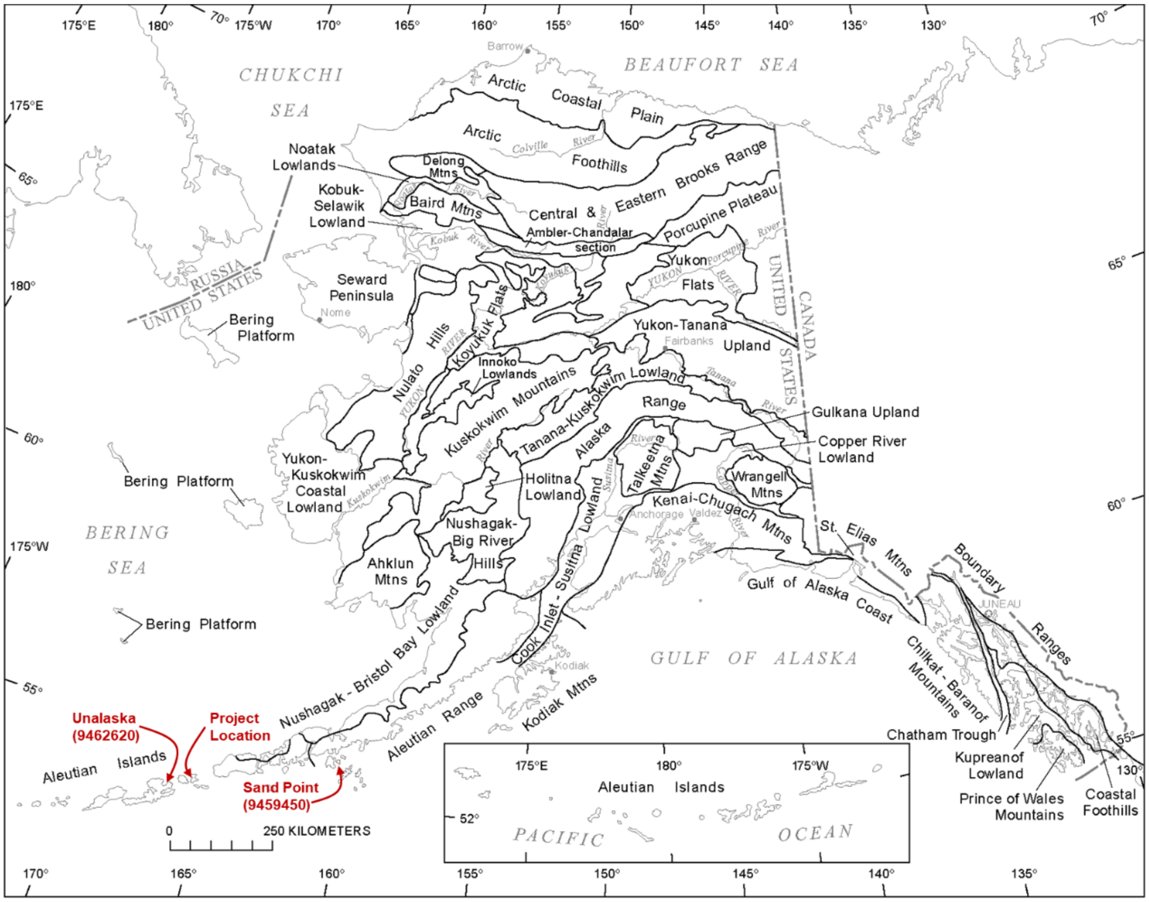


Figure 28: Physiographic Regions of Alaska (J.R. Riehle, 1996)

Comparing tide, VLM, and physiography, Unalaska tide station location is preferrable to Sand Point, and it can be considered a good RSLC representation for the project.

2.11.2 RSLC Scenarios

The USACE 2013 low, intermediate, and high RSLC scenarios for Unalaska tide station are shown in Figure 29 and Table 11 below. All three RSLC scenarios are equally as likely to occur over the 50-year design life of the project. Low and intermediate scenarios predict that the isostatic rebound rate will be greater than the sea level rise rate, resulting in an overall sea level drop between anticipated construction completion in 2032 and the 50-year project life in 2082. The high scenario predicts that the isostatic rebound rate will be less than the sea level rise rate.

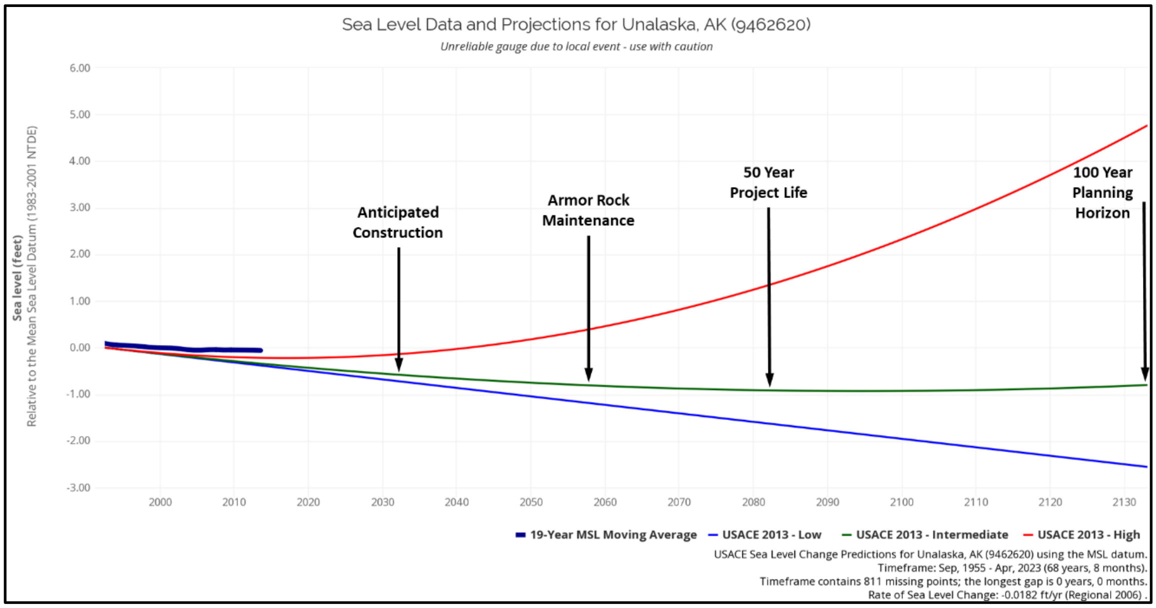


Figure 29: RSLC Projection Graphs for Unalaska

Table 11: RSCL Projection Values for Unalaska

Year	Description	**USACE Low**	**USACE Intermediate** (Feet MLLW)	**USACE High**
1992	USACE RSLC Projection Begins	0.00	0.00	0.00
2032	Anticipated Construction	-0.73	-0.60	-0.14
2042	Maintenance Dredging	-0.91	-0.69	+ 0.02
2052	Maintenance Dredging	-1.09	-0.77	+ 0.24
2057	Armor Rock Maintenance	-1.18	-0.81	+ 0.38
2062	Maintenance Dredging	-1.27	-0.84	+ 0.54
2072	Maintenance Dredging	-1.46	-0.89	+ 0.92
2082	50 Year Project Life	-1.64	-0.92	+ 1.37
2132	100 Year Planning Horizon	-2.55	-0.81	+ 4.72

2.11.3 RSLC for Dredging Depth Design

The suite of RSLC scenarios were considered for dredging depth design calculations. The high scenario predicts a RSLC of +1.37 feet for the project, which would result in an increase in vessel underkeel clearance. This scenario was not considered for dredging depth design. The intermediate and low scenarios predict a RSLC of -0.92 feet and -1.64 feet respectively, which would result in a decrease in vessel underkeel clearance. If the intermediate or low scenarios are realized, dredging would need to occur during the 50-year life of the project if the project depth is to be maintained. Since blasting of bedrock is anticipated, the cost including an additional depth for RSLC during the construction of the project is significantly less than remobilizing to dredge for a later contract.

In order to maintain the project depth at year 50, 1 foot of dredging will be incorporated in the entrance channel, turning, and mooring design depths at construction. This would ensure project depth is maintained at year 2082 for the intermediate RSLC scenario and year 2050 for the high RSLC scenario. If the high scenario is realized, the project would lose 0.64 feet of underkeel clearance at year 2082. The harbor would still function, but ferry operation may be reduced due to the decrease in underkeel clearance. It was determined that dredging more than 1 foot for RSLC was not economical due to the uncertainty associated with RSLC. The additional 1 foot of dredging is a reasonable assurance for RSLC resiliency.

2.11.3 RSLC for Breakwater Design

The suite of RSLC scenarios were also considered for breakwater design calculations. The intermediate and low scenarios predict a RSLC of -0.92 feet and -1.64 feet respectively, which would result in a decrease in wave height impacting the breakwater. Therefore, the intermediate and low scenarios were not considered for breakwater design. The high scenario predicts a RSLC of +1.37 feet for the project, which would result in an increase wave height impacting the breakwater. If the high scenario is realized, an increase in wave height could result in the armor stone being undersized and the breakwater height being insufficient. The stability of the breakwater structure could be at risk. Due to the high consequences associated with RSLC for breakwater design, the high scenario of +1.37 feet was chosen for design.

In order to maintain breakwater stability at year 50, an allowance of +1.37 feet for RSLC was included in total water level calculations used in breakwater stone size and breakwater dimension calculations. Designing the breakwater for the high RSLC scenario is prudent for this remote location given the minimal wave information available and helps increase resiliency for the project.

2.11.4 RSLC for Local Service Facilities

The elevation of the local service facilities (LSF) causeway, dock, and uplands pad was designed at 8 feet MLLW. This includes a MHHW tide of 3.76 feet, high RSLC scenario of 1.37 feet, wave height in the harbor of 1 foot, and 1.87 feet of freeboard. The high RSLC scenario was chosen for the LSF design to ensure future operation of the dock facilities remains operational for the life of the project. Further analysis in PED may result in an increase or decrease of the LSF design elevation (see section 4.7.2 Causeway, Dock, and Uplands Pad).

One foot of dredging will be incorporated in the mooring basin dredge depth at construction (see 2.11.3 RSLC for Dredging Depth Design). The access road is not anticipated to be affected by RSLC during the life of the project.

3.0 WAVE ANALYSIS

3.1 Wave Hindcast

Wave analysis, as well as wind analysis (see 2.8.1 Wave Information Studies) performed for this study by CEERD-HFC. The basis of the analysis is WIS, a USACE sponsored project that generates consistent, hourly, and long-term wave climatologies (Hesser, 2018). WIS point 82327 was chosen to be representative of offshore wind and wave conditions that would affect the project area at Akun. The WIS point is located approximately 30 miles from the project area (as shown in Figure 12 above).

Waves traveling through the Akun Strait (originating from 290°- 330°) dictates ferry operations. Akutan and Akun islands shelter waves from other directions (see section 2.9 Wave Climate), except for local fetch-limited waves (see section 2.8.4 Local Wind-Wave Generation) as discussed previously.

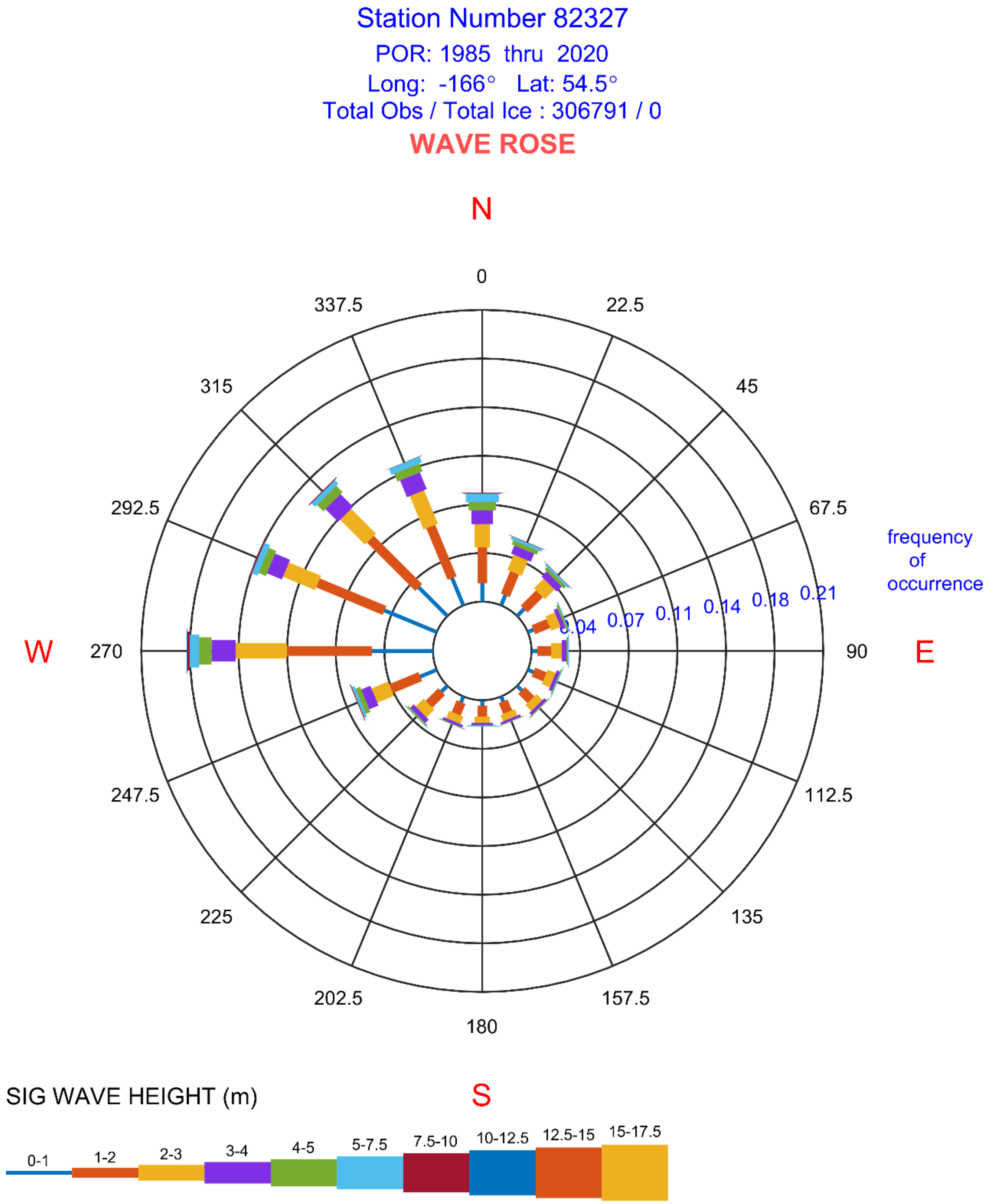


Figure 30: Wave Rose WIS Station 82327

Table 12: Directional Window (290° to 330°) for Significant Wave Height Extremes (Imperial)

Directional Window (290° to 330°) for Significant Wave Height Extremes							
Rank New	Rank Orig	Peak Date	H_{m0} (ft)	T_p (s)	WavDir (°)	WndSpd (knots)	WndDir (°)
1	1	1992112401	51.8	15.8	325	62.0	319
2	8	2017112321	39.7	16.0	305	45.3	313
3	16	2013030806	36.4	14.3	299	48.2	294
4	24	2002012912	35.1	13.5	326	50.9	317
5	33	2011040316	33.1	12.4	305	51.5	303
6	40	2009011701	31.8	12.8	303	46.5	296
7	44	1989011113	31.5	13.9	308	40.2	303
8	45	1985041620	31.5	12.8	327	44.7	316
9	49	2017112007	31.2	14.7	323	39.3	322
10	59	1995020602	30.2	13.4	300	39.8	288
11	61	2010030512	29.9	12.4	323	47.0	315
12	64	2001092408	29.5	13.9	292	41.0	306
13	66	1999111403	29.5	13.7	327	39.3	332
14	67	1992120515	29.5	13.6	315	40.0	311
15	86	2005110922	28.2	13.4	322	39.1	313
16	89	2010120419	27.6	13.8	299	36.9	303
17	94	1998091918	27.6	12.5	307	43.0	309
18	109	2004110314	26.2	13.4	323	34.8	310
19	117	2011102513	25.9	12.8	296	38.5	295
20	123	2004120902	25.6	12.9	316	36.0	318
21	148	2009032916	24.3	11.1	303	45.7	284
22	150	2013101312	24.0	13.0	302	35.8	301
23	151	2007041810	24.0	12.3	298	36.7	295
24	152	2003122913	24.0	11.1	294	43.5	305
25	156	1986112907	23.6	12.2	313	37.5	302
26	161	2006022802	23.3	12.2	307	35.4	324
27	170	1992032008	23.0	12.4	300	34.8	299
28	171	2015041907	23.0	12.0	328	37.3	321
29	186	1992100201	22.3	12.4	301	35.8	309
30	189	2012112719	22.3	12.4	293	34.4	322
31	193	2006040418	22.0	11.8	324	36.2	323
32	195	2011090622	22.0	12.2	315	33.6	318
33	201	2014102904	22.0	12.0	308	36.7	313
34	204	2012091615	21.7	11.3	307	38.3	292
35	207	1990011407	21.7	12.0	291	35.0	285

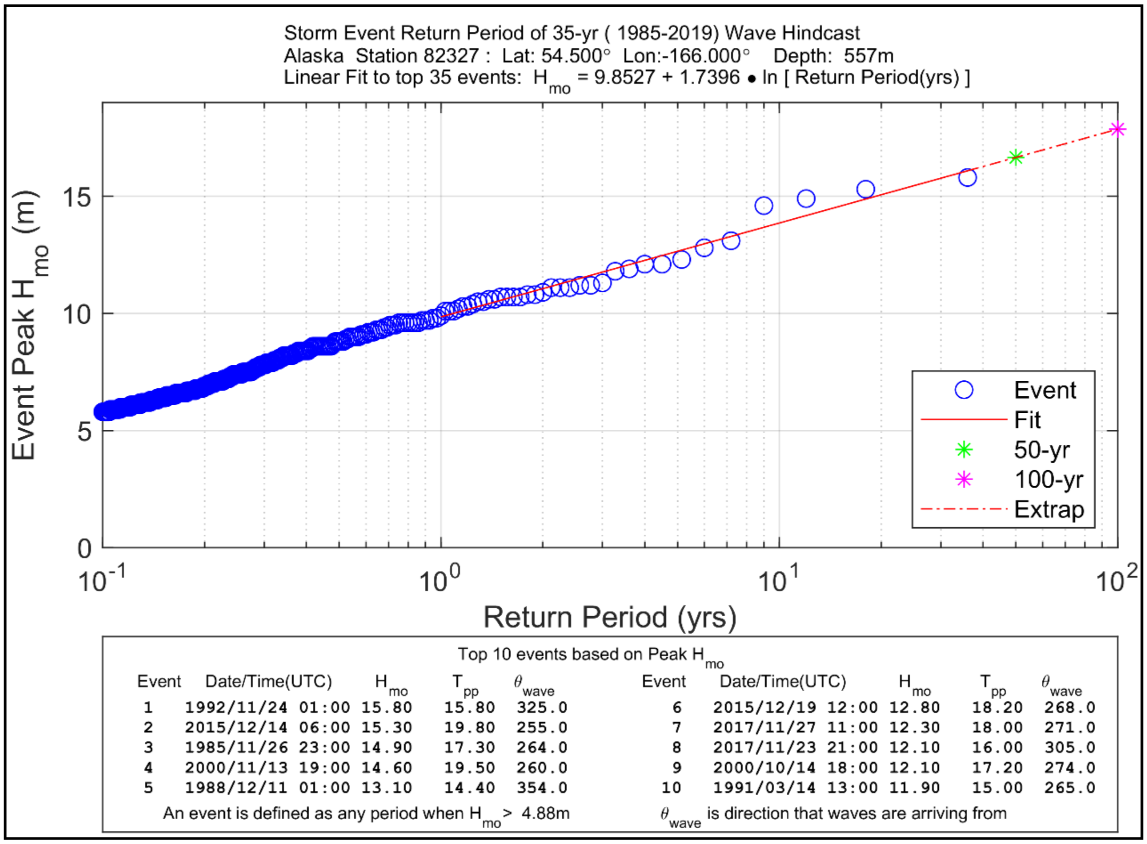


Figure 31: Significant Wave Height Extremes for WIS Station 82327 (All Directions)

The equation for the linear fit of the top 35 events from WIS station 82327 for all directions is shown in the top of Figure 31. This equation generates the wave height for a given return period, or recurrence interval, for the WIS location 30 miles from the project area. This equation incorporates wave data from all directions. The wave data was limited to 290° to 330° as would be applicable to the project site. Results of the significant wave height for each annual exceedance probability (AEP) are given in Table 13 below. It does not consider depth dependent mechanisms such as wave-bottom effects, attenuation from small-scale obstructions, or depth induced wave breaking.

$$H_{m0} = 4.028 + 1.3094 \cdot \ln\{Return\ Period\ (yrs)\}$$

$$Annual\ Exceedance\ Probability\ (AEP) = \frac{1}{Return\ Period}$$

Table 13: Significant Wave Heights at the Project Site

Annual Exceedance Probability	Wave Height (feet)
1	13.2
0.2	20.1
0.1	23.1
0.04	27.0
0.02	30.0
0.01	33.0

Wave heights generated by the 290° to 330° windowed equation are representative of the deep water waves encountered at Akun Strait. To approximate wave heights in the project area for breakwater sizing calculations, wave heights at the Akun Strait need to be transformed using wave modeling. The 2% AEP or 50-year wave used for design is 30 feet.

3.2 Wave Modeling

Steady-State Spectral Wave (STWAVE) modeling was used to transform wave energy from WIS station 82327 to the breakwater and harbor alternatives. STWAVE is a spectral wave energy propagation model that includes refraction, diffraction, and shoaling, but does not include reflection. It should be noted that STWAVE is the Hydraulic, Hydrologic and Coastal (HH&C) Community of Practice (CoP) preferred model for modeling coastal processes.

3.2.1 Model Bathymetry

In order to optimize the bathymetric grid sizes for model runs, wave data was ran from a coarse grid to a fine grid as shown in Figure 32 below. Model bathymetry was obtained from NOAA charts for the coarse grid, 2015 Stantec survey for the fine grid at the project area, and 2022 Golder survey for the project area land-water interface. The coarse grid consists of 50 meters by 50 meters (164 feet by 164 feet) cells and transmits the WIS wave data from deep water oriented at 302°, as this would be the worst-case scenario of waves hitting directly perpendicular to the structure from the Bering Sea. The fine grid’s northern boundary is where the wave transmitted by the coarse grid begins to interact with the ocean bottom and experience a decrease in wave height. It consists of 2 meters by 2 meters (6.6 feet by 6.6 feet) cells oriented at 310°.

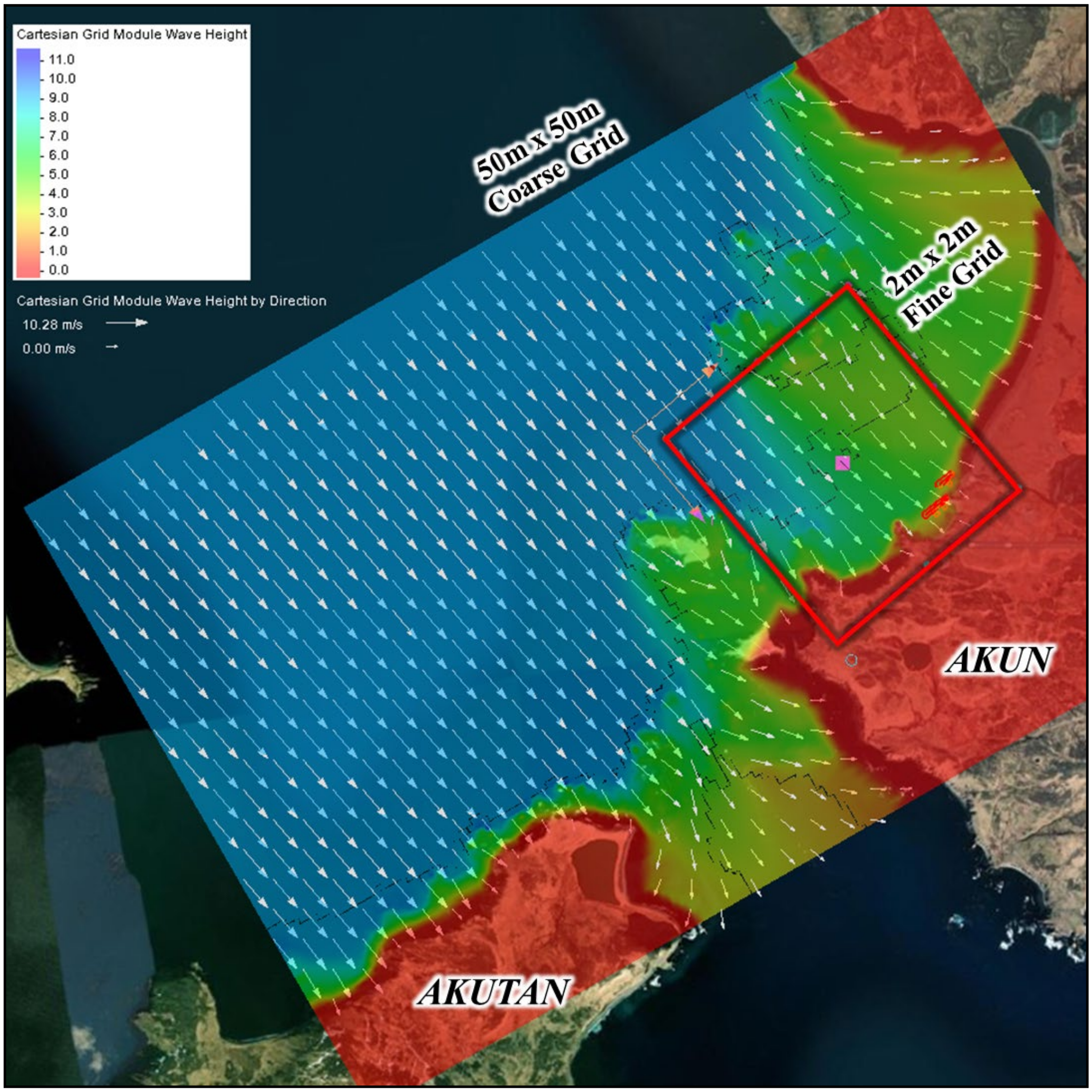


Figure 32: STWAVE Coarse and Fine Grids - Wave Height and Direction, Without Project Condition

Model runs are in half-plane mode with propagation of the boundary conditions only, no wind propagation. Results of the wave height and direction for the without project condition are shown in Figure 32 and then zoomed in on the project area in Figure 33.

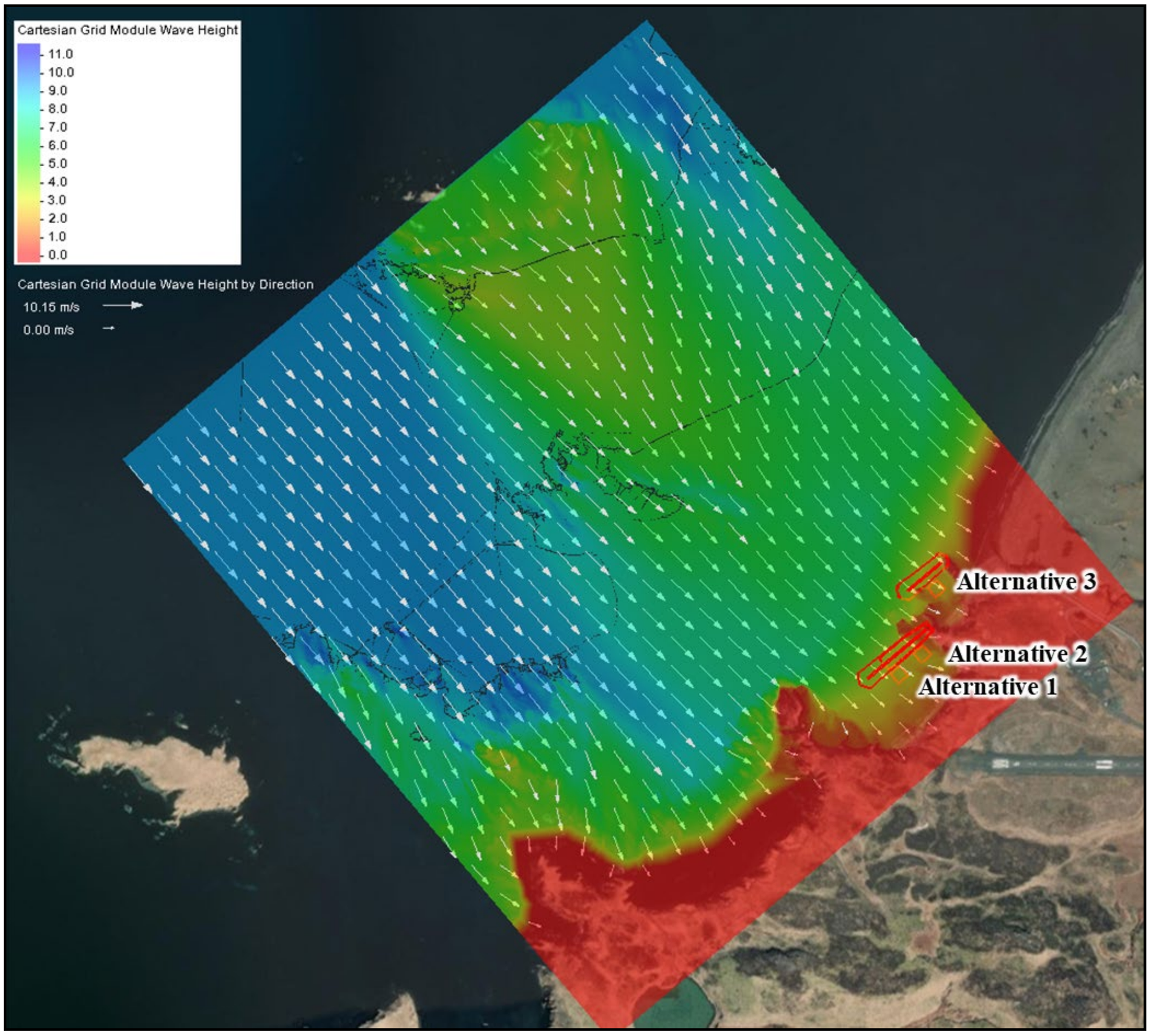


Figure 33: STWAVE Fine Grid - Wave Height and Direction, Without Project Condition

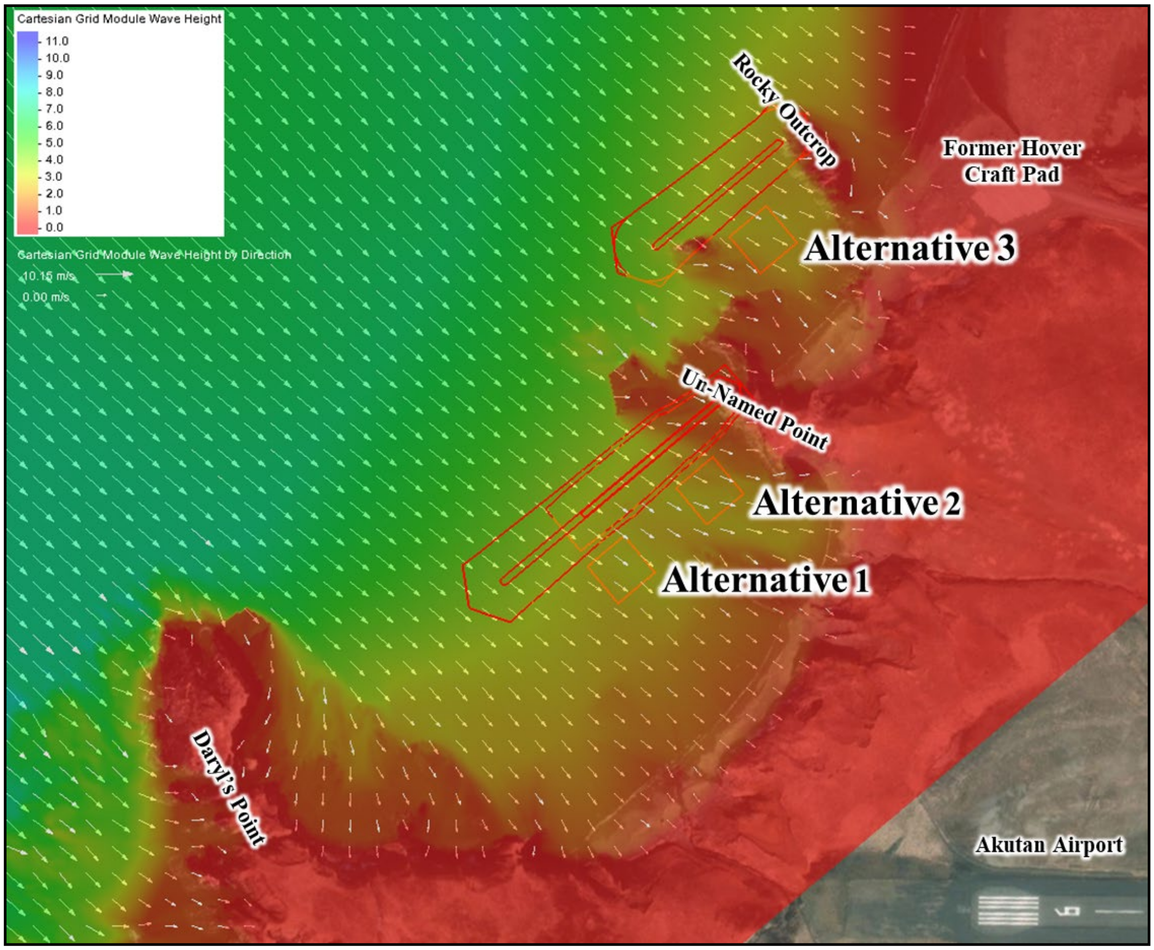


Figure 34: STWAVE Fine Grid Closeup on Alternavies - Wave Height and Direction, Without Project Condition

3.2.2 Water Level

The design wave and total water level are used to inform breakwater design. The total water level to be modeled was determined using the following equation:

$$Total\ Water\ Level = Tide + Wave\ Setup + Storm\ Surge + RSLC$$

3.2.2.1 Tide

The tide used for wave modeling was MHHW of 3.76 feet.

3.2.2.2 Wave Setup

Wave setup is an increase in water level due to breaking waves in the surf zone. The proposed breakwater is located in water depths beyond the surf zone and influence of wave setup. Wave setup was not considered for water level determination.

3.2.2.3 Storm Surge

Storm surge is an increase in water level due to low atmospheric pressure and wind driven transport of seawater over relatively large and shallow unobstructed waters. Storm surge can produce short term increases in water level considerably over normal tidal levels. There is no known storm surge model or study near the project area. The best approximation is NOAA AEP curves at Unalaska (9462620) tidal station. The AEP curves model extreme water levels during storms known as storm tides, which are a combination of astronomical tide, storm surge, and wave setup. As MHHW tide is included in the water level and wave setup is not expected, the AEP curves are a good approximation for storm surge. The 2% AEP is 2.66 feet (0.81 meter) and 1% AEP is 2.76 feet (0.84 meter) as read from Figure 34. The 2% AEP prediction of 2.66 feet was used for the breakwater design water level calculation.

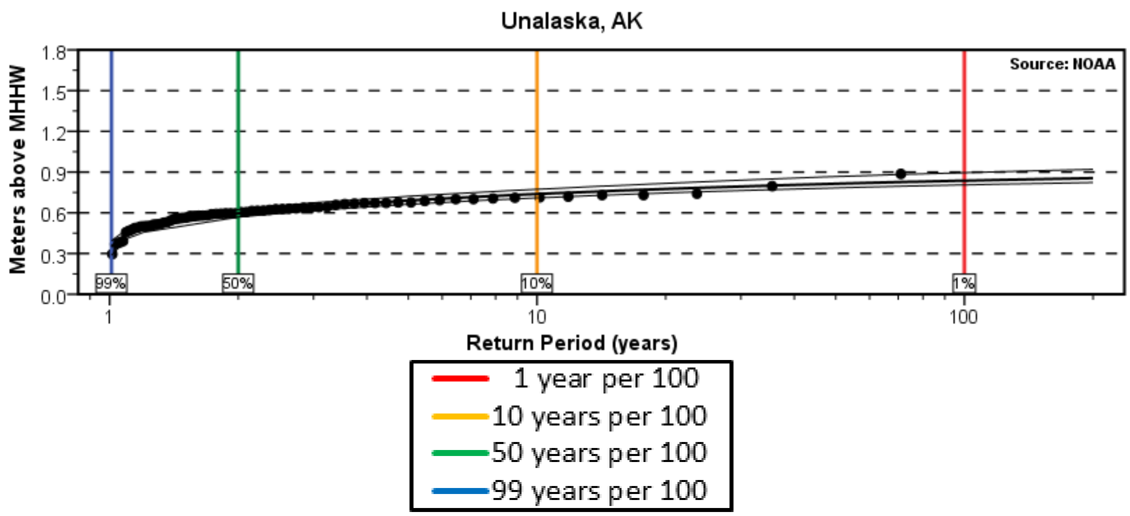


Figure 35: NOAA AEP Curves for Unalaska, AK (NOAA, Tides & Currents, 2023)

3.2.2.4 Sea Level Change

To capture resiliency in the project design, the most conservative or high RSLC prediction of +1.37 feet was incorporated for the total water level calculation. See Section 2.11.3 RSLC for Breakwater Design for more information.

3.2.2.5 Total Water Level

The total water level including a MHHW tide of 3.76 feet, storm surge of 2.66 feet, and RSLC of 1.37 feet is 7.79 feet MLLW. This value was checked against the highest observed Unalaska station value of 6.70 feet, which is a reasonable approximation to the total water level without RSLC of 6.42 feet. The total water level of 7.79 feet MLLW was inputted in STWAVE to model the design wave. These calculations were used in designing the breakwater length, crest height, crest width, and stone size.

Table 14: Total Water Level for Breakwater Design

Description	Water Level (feet MLLW)
Tide (MHHW)	3.76
Wave Setup	0.00
Storm Surge	2.66
RSCL	1.37
Total Water Level	7.79

3.2.3 Wave Modeling Results

STWAVE was used to transmit the 2% AEP WIS wave of 30.0 feet from deep water to the project area. The total water level modeled was 7.79 feet. The design wave for each alternative was determined by measuring for the highest wave value just offshore of the toe of the breakwater. The wave will begin to break at this point due the sudden decrease in water depth due to the breakwater structure at the toe. Breaking waves at the toe of the breakwater would be the worst case from a design perspective and would drive the armor stone size for the breakwater. The design waves heights produced in STWAVE for the three alternatives are found in Table 15.

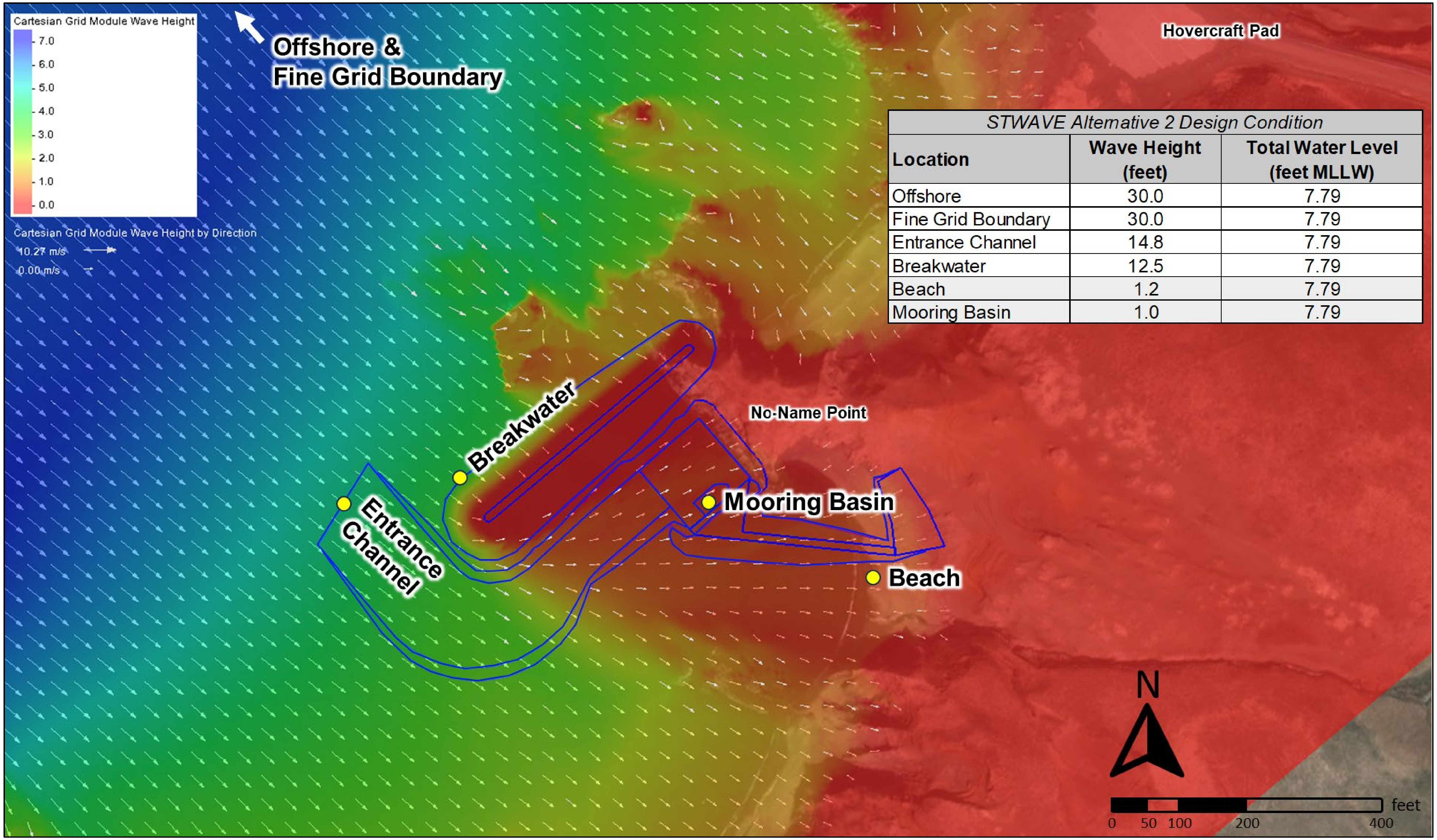
Table 15: STWAVE Results - Design Wave

Alternative	2% AEP Wave (feet)	Total Water Level (feet MLLW)	Design Wave (feet)
Alternative 1	30.0	7.79	14.5
Alternative 2	30.0	7.79	12.5
Alternative 3	30.0	7.79	15.0

Maximum wave heights in the mooring basin are predicted to be 1.0 feet by STWAVE (Figure 36). Due to the limitations of STWAVE modeling small wave heights, the actual maximum wave height at the mooring basin may be 3 feet or greater. Additional modeling in PED will be required in order to determine a more accurate design wave and currents inside the harbor, see 7.2 Future Work to be Completed in PED.

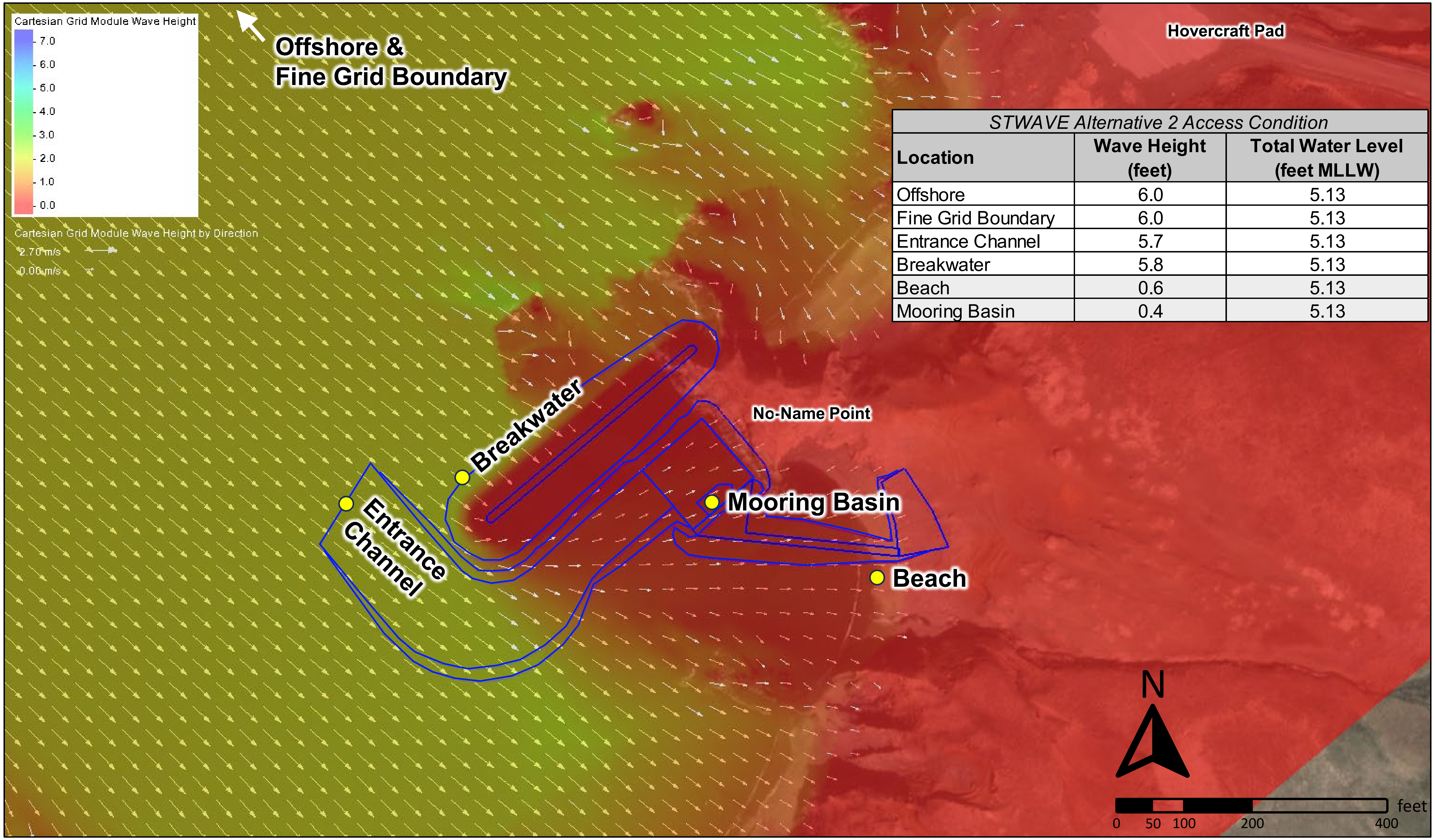
STWAVE simulations were also run for the ferry and skiff access condition to show the maximum wave heights the ferry and local skiffs could encounter in the entrance channel and dock. The maximum survivable condition for the ferry is expected to be Beaufort Sea State (SS) 5, with a significant wave height of 6 feet and maximum wave height of 8 feet and winds of 17 to 21 knots. Note that due to the limitations in STWAVE modeling at small wave heights, actual wave heights reported for the mooring basin or beach may be higher than those listed by STWAVE. If, for example, actual wave heights at the mooring basin dock were 3 times those predicted by STWAVE (0.4 feet x 3 = 1.2 feet), the ferry would still be expected to safely offload passengers and goods (Figure 37).

The maximum operation condition for a skiff is expected to be SS3, with a significant wave height of 2 feet and maximum wave height of 3 feet and winds of 7 to 10 knots. It was found that skiff operators would encounter negligible wave heights at the mooring basin and protected beach behind the breakwater during SS3 conditions, 0.1 foot and 0.2 foot waves respectively (Figure 38). This is contrasted to the modeled 1.4 to 2.4 foot or greater wave heights at exposed beaches to the north and south of the proposed harbor. The protection provided by the harbor would provide an estimate 4.5% increase in skiff accessibility of Akun, see section 4.1.2 Operational Conditions for more information.



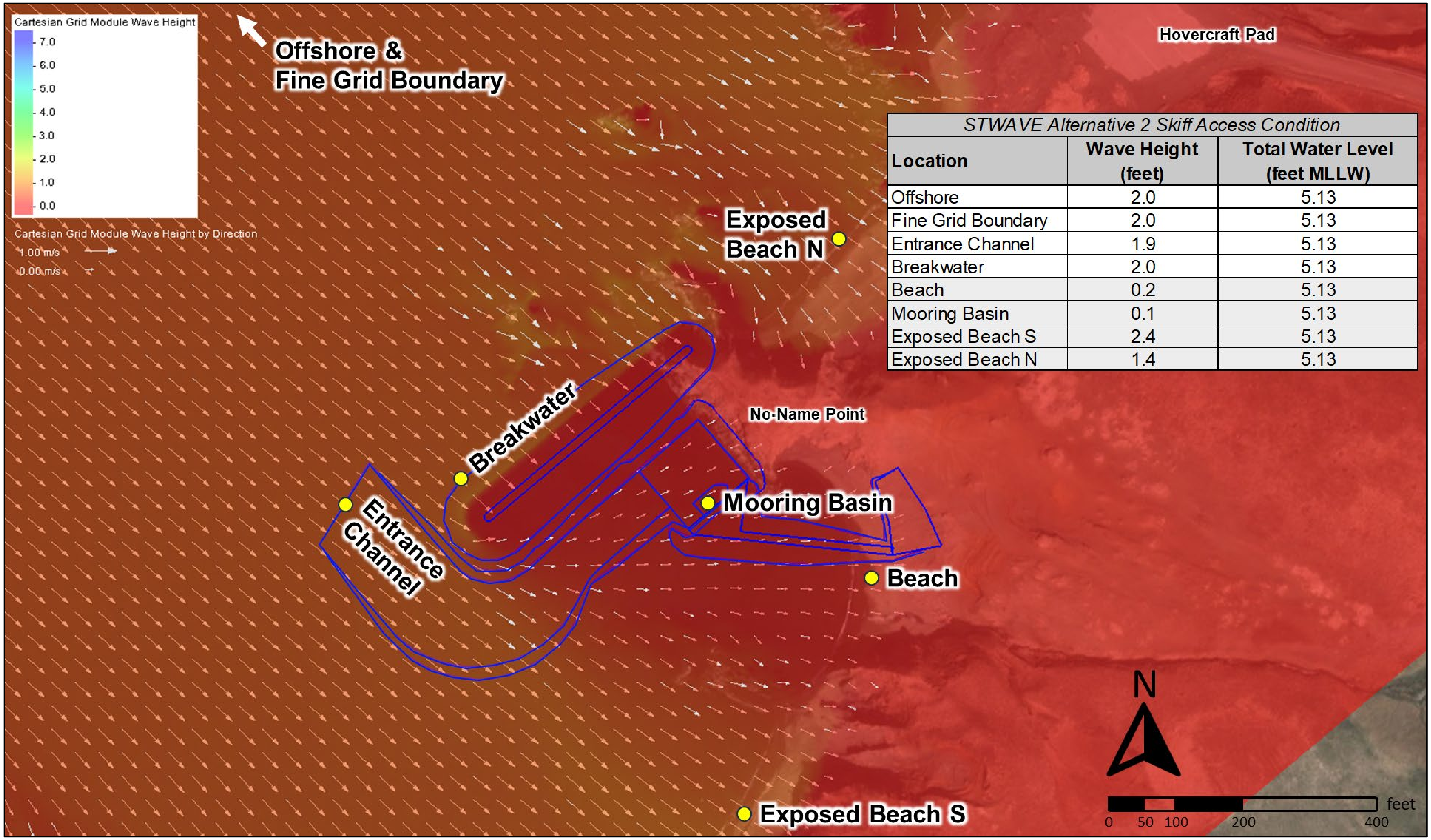
STWAVE Alternative 2 Design Condition		
Location	**Wave Height (feet)**	**Total Water Level (feet MLLW)**
Offshore	30.0	7.79
Fine Grid Boundary	30.0	7.79
Entrance Channel	14.8	7.79
Breakwater	12.5	7.79
Beach	1.2	7.79
Mooring Basin	1.0	7.79

Figure 36: STWAVE Results for Alternative 2, Design Condition



STWAVE Alternative 2 Access Condition		
Location	**Wave Height (feet)**	**Total Water Level (feet MLLW)**
Offshore	6.0	5.13
Fine Grid Boundary	6.0	5.13
Entrance Channel	5.7	5.13
Breakwater	5.8	5.13
Beach	0.6	5.13
Mooring Basin	0.4	5.13

Figure 37: STWAVE Results for Alternative 2, Ferry Access Condition



STWAVE Alternative 2 Skiff Access Condition		
Location	**Wave Height (feet)**	**Total Water Level (feet MLLW)**
Offshore	2.0	5.13
Fine Grid Boundary	2.0	5.13
Entrance Channel	1.9	5.13
Breakwater	2.0	5.13
Beach	0.2	5.13
Mooring Basin	0.1	5.13
Exposed Beach S	2.4	5.13
Exposed Beach N	1.4	5.13

Figure 38: STWAVE Results for Alternative 2, Skiff Access Condition

4.0 DESIGN CRITERIA

4.1 Design Vessel

The design vessel of this study is based upon two factors, regularly available vessels in the region and minimum size requirements to safely operate trips between Akutan and Akun in conditions that allow aircraft to land in Akun. It is anticipated that the ferry vessel would be a converted seiner, crabber, trawler, longliner or similar fishing vessel. The Aleutians East Borough (AEB) has indicated that they do not want to purchase a ferry vessel and will be contracting for ferry services, similarly to the current contract for the helicopter.

The design vessel chosen for this study is the F/V Magnus Martens, a 58-foot long twin screw steel monohull with a 26-foot beam and an 8-foot draft that operates across Alaska, including in the Aleutians. The Marine Design Center recommended that a 58-foot vessel operate in a 5-foot maximum wave height. Therefore, operational conditions and harbor accessibility were based off a 5-foot wave maximum height.

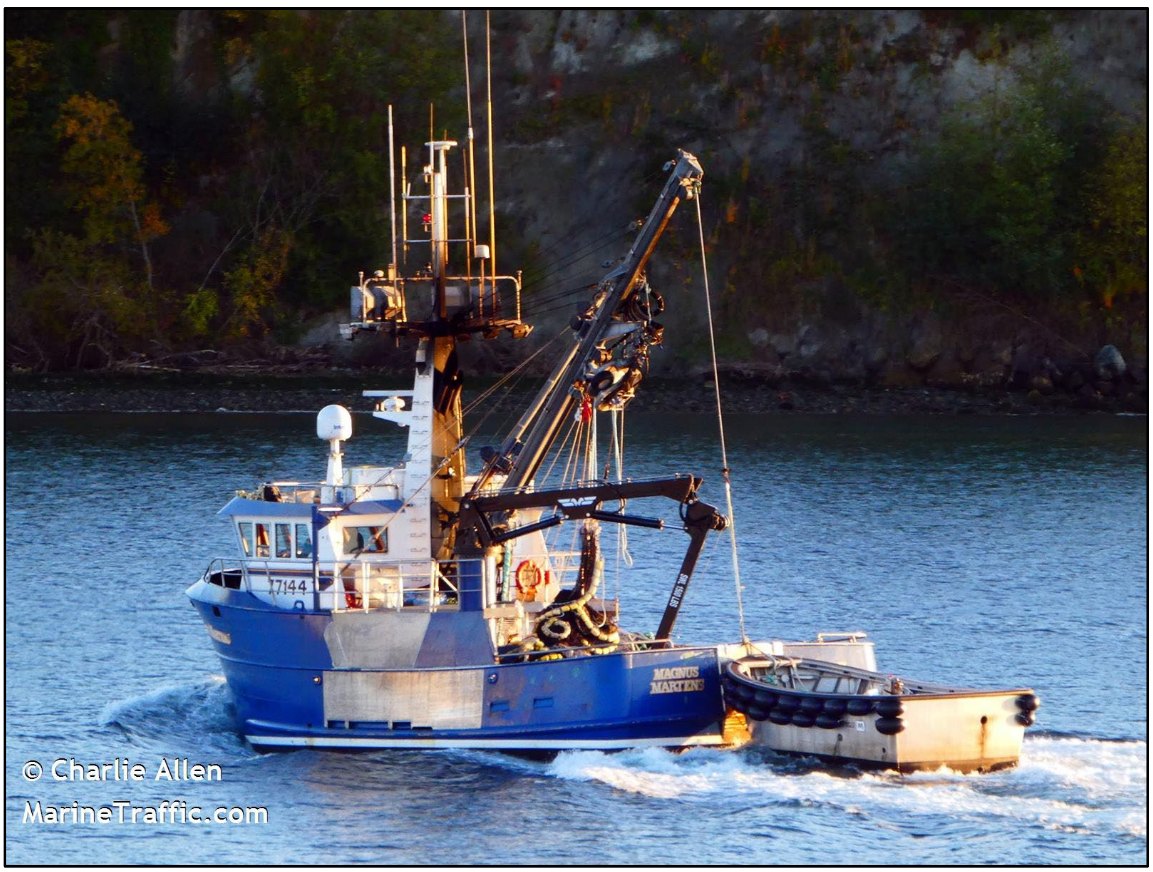


Figure 39: Design Vessel F/V Magnus Martens

Table 16: Design Vessel F/V Magnus Martens Parameters

Ship Parameter	Dimensions (feet)
Length Over All (LOA)	58
Beam	26
Loaded Draft	8

4.1.1 Design Vessel Evaluation Criteria

The North Pacific Fishery Management Council reported than in 2010, of the 2,736 vessels participating in federal managed fisheries off Alaska, 80% of those vessels were less than 60 feet in length (Witherell, Fey, & Fina, 2012). The Alaska Fisheries Development Foundation reported than in 2017, of the over 9,000 commercial fishing vessels licensed to operate in Alaska, 93% of those vessels were under 59 feet in length (AFDF, 2019). Longliners for groundfish, sablefish, and halibut frequent the Aleutian Islands and Bering Sea (Figure 40), the majority of which range from 30 to 59 feet in length (Figure 41). Vessels of 58-foot length were reliably found for sale online using Alaska marine brokerages.

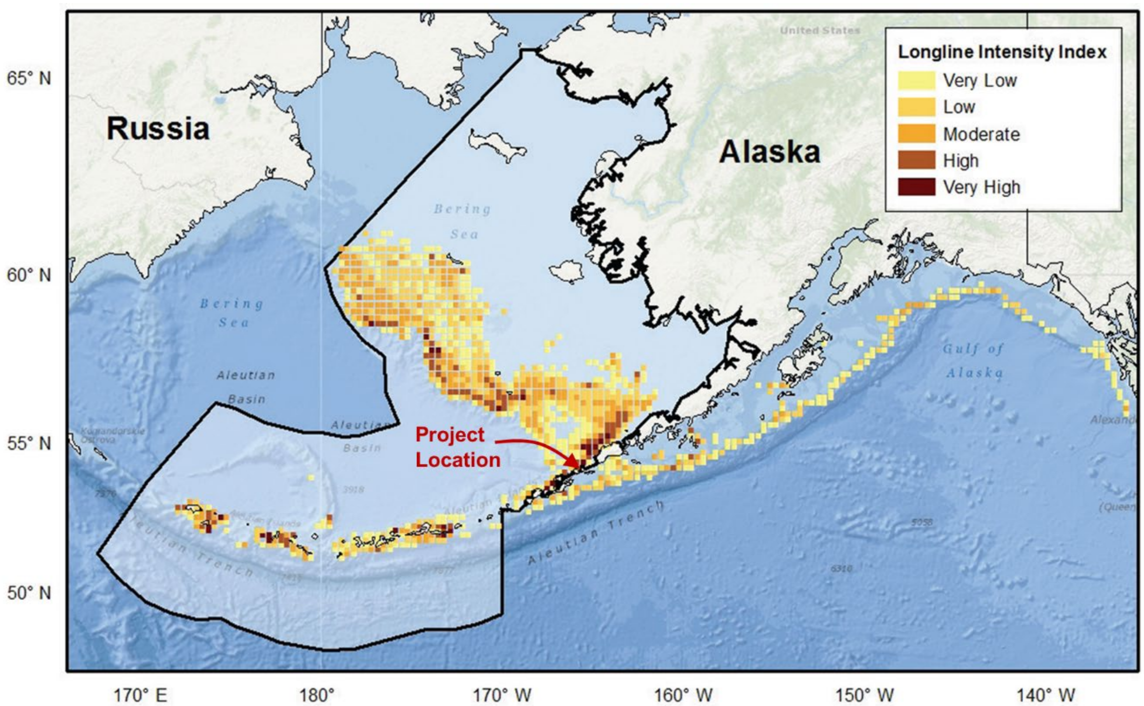


Figure 40: Observed Groundfish Longline Set Intensity Summarized from 1993-2012 (ABSI, 2015)

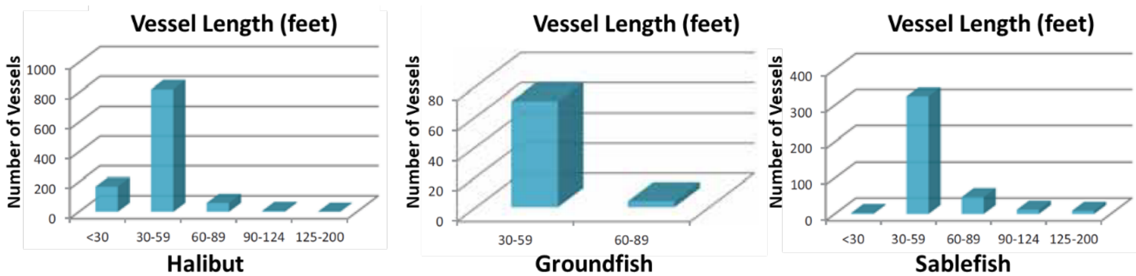


Figure 41: Longline Vessel Lengths (Witherell, Fey, & Fina, 2012)

Several previous studies have also evaluated a ferry route between Akutan and Akun. The vessels evaluated include a SWATH 80 feet long with a 42 foot beam and 9.5 foot draft and a monohull 80 feet long with a 19 foot beam and 6.5 draft (The Glosten Associates, 12 March 2009), a SWATH 78 feet long with a 39 foot beam and 12 foot draft and a 65 foot monohull with a 16.25 foot beam and 5.13 foot draft (The Glosten Associates, 24 February 2009), a landing craft 59 feet long with a 16 foot beam (Crescere Marine Engineering, 2012), and a 55 feet long with a 22 foot beam and 3.5 foot draft monohull with modified deep-vee (Alton Bay Design, 2015).

During the Charrette, lengths of 95 feet and 78 feet were recommended as the size of vessel would make the crossing from Akutan to Akun most comfortable for passengers. Larger vessels were also reported by the community to be more expensive to operate and harder to repair. The general consensus was that a 58-foot vessel would be the minimum recommended length to cross Akun Strait safely.

Other vessels that operate in the area that were recommended by Akutan were a Silver Bay Seafoods 75-foot transporter that operates between False Pass and Cold Bay and holds approximately 40 passengers. This route was reported to be similar to the future ferry route between Akutan and Akun. Crewboats that operate in the North Sea were also mentioned as suitable vessels, which typically range from about 45 feet to 140 feet. Crewboats are uncommon in Alaska as helicopter is the preferred method of transport to offshore oil rigs (Co. & ERE Systems, 1981), so this type of design vessel was not considered.

The design vessel was evaluated to match the operating parameters of the fixed-wing aircraft in order to minimize the cost of the harbor design and ferry operation. A ferry length of 58 feet was evaluated to most closely fulfill this condition. The harbor facilities were designed using conservative assumptions about the maneuverability of the 58-foot vessel. The ferry vessel is not restricted to 58 feet and a longer vessel may be utilized at the pilot’s discretion based on vessel handleability, wind, and currents. The entrance channel and turning basin dimensions are based on USACE conservative design guidelines, and a competent pilot could utilize the harbor with a vessel longer than 58 feet.

Considering the design vessel draft, many 58-foot fishing vessels in the Alaska have drafts ranging from 8 to 13 feet. A shallower draft of 8 feet allows the ferry to travel faster, reducing the amount of time passengers are exposed to waves that induce motion sickness. But a shallower draft vessel will experience greater motion in the waves which decreases passenger comfort. The shallower draft design vessel of 8 feet was chosen based on fishing vessels of this draft being available for purchase in Alaska and the advantage of minimizing harbor dredging depths. As with vessel length, a ferry vessel with a draft deeper than 8 feet may be utilized at the pilot's discretion based on vessel handleability, waves, and tides.

4.1.2 Operational Conditions

Operational conditions for the design vessel are described using the Beaufort Sea State (SS), a visual scale for estimating wind speed and sea state as described in Table 17. The design vessel can be expected to conduct operations in SS4. SS4 conditions include a significant wave height of 3 feet, maximum wave height of 5 feet, and wind speed of 11 to 16 knots. The 2015 conceptual vessel study for Akutan Airport stated that a 55-foot ferry with a 22 foot beam and 3.5 foot draft should be able to routinely operate in SS4 conditions (Alton Bay Design, 2015). The Bristol Harbor Group suggested that the design vessel for this project could conduct operations SS4 and possibly up to SS5 (significant wave height of 6 feet and maximum wave height of 8 feet and windspeeds of 17 to 21 knots) with a competent boat and pilot (Eling, 2023). The contracted ferry may be smaller than the design vessel and passenger comfort should be taken into account. Therefore, SS4 was used for the analysis with SS5 provided for information only.

Table 17: Beaufort Sea State Scale (NWS, 2023)

Estimating Wind Speed and Sea State with Visual Clues				
Beaufort number	Wind Description	Wind Speed	Wave Height	Visual Clues
0	Calm	0 knots	0 feet	Sea is like a mirror. Smoke rises vertically.
1	Light Air	1-3 kts	< 1/2	Ripples with the appearance of scales are formed, but without foam crests. Smoke drifts from funnel.
2	Light breeze	4-6 kts	1/2 ft (max 1)	Small wavelets, still short but more pronounced, crests have glassy appearance and do not break. Wind felt on face. Smoke rises at about 80 degrees.
3	Gentle Breeze	7-10 kts	2 ft (max 3)	Large wavelets, crests begin to break. Foam of glassy appearance. Perhaps scattered white horses (white caps). Wind extends light flag and pennants. Smoke rises at about 70 deg.
4	Moderate Breeze	11-16 kts	3 ft (max 5)	Small waves, becoming longer. Fairly frequent white horses (white caps). Wind raises dust and loose paper on deck. Smoke rises at about 50 deg. No noticeable sound in the rigging. Slack halyards curve and sway. Heavy flag flaps limply.
5	Fresh Breeze	17-21kts	6 ft (max 8)	Moderate waves, taking more pronounced long form. Many white horses (white caps) are formed (chance of some spray). Wind felt strongly on face. Smoke rises at about 30 deg. Slack halyards whip while bending continuously to leeward. Taut halyards maintain slightly bent position. Low whistle in the rigging. Heavy flag doesn't extended but flaps over entire length.
6	Strong Breeze	22-27 kts	9 ft (max 12)	Large waves begin to form. White foam crests are more extensive everywhere (probably some spray). Wind stings face in temperatures below 35 deg F (2C). Slight effort in maintaining balance against wind. Smoke rises at about 15 deg. Both slack and taut halyards whip slightly in bent position. Low moaning, rather than whistle, in the rigging. Heavy flag extends and flaps more vigorous.
7	Near Gale	28-33 kts	13 ft (max 19)	Sea heaps up and white foam from breaking waves begins to be blown in streaks along the direction of wind. Necessary to lean slightly into the wind to maintain balance. Smoke rises at about 5 to 10 deg. Higher pitched moaning and whistling heard from rigging. Halyards still whip slightly. Heavy flag extends fully and flaps only at the end. Oilskins and loose clothing inflate and pull against the body.
8	Gale	34-40 kts	18 ft (max 25)	Moderately high waves of greater length. Edges of crests begin to break into the spindrift. The foam is blown in well-marked streaks along the direction of the wind. Head pushed back by the force of the wind if allowed to relax. Oilskins and loose clothing inflate and pull strongly. Halyards rigidly bent. Loud whistle from rigging. Heavy flag straight out and whipping.
9	Strong Gale	41-47 kts	23 ft (max 32)	High waves. Dense streaks of foam along direction of wind. Crests of waves begin to topple, tumble and roll over. Spray may affect visibility.
10	Storm	48-55 kts	29 ft (max 41)	Very high waves with long overhanging crests. The resulting foam, in great patches is blown in dense streaks along the direction of the wind. On the whole, the sea takes on a whitish appearance. Tumbling of the sea becomes heavy and shock-like. Visibility affected.
11	Violent Storm	56-63 kts	37 ft (max 52)	Exceptionally high waves (small and medium-sized ships might be for time lost to view behind the waves). The sea is completely covered with long white patches of foam lying along the direction of the wind. Everywhere, the edges of the wave crests are blown into froth. Visibility greatly affected.
12	Hurricane	64+ kts	45+ ft	The air is filled with foam and spray. The sea is completely white with driving spray. Visibility is seriously affected.

4.1.1.1 Operational Conditions Comparison

A statistical analysis was conducted to compare the amount of time successful trips could theoretical be conducted at Akutan Airport for various methods of transportation craft. These included the existing Bell 206L4 helicopter, a larger Bell 412 helicopter, the existing Piper PA31-350 Navajo Cheiftan, and the proposed 58-foot ferry vessel.

The percent of time of inoperability was the preferred metric of comparison between the craft given the available meteorological data and the level of reasonable assumptions made for the operations of each type of craft. However, by not considering the timing of the delay to result in a cancelation, the anticipated values are over inflated. To help compensate for the optimistic data, a scaling factor was applied to the ferry weather operability. The scaling factor was the average of the helicopter and fixed-wing ratio of reported weather delays divided by the calculated anticipated weather delays. The resulting final values for comparison are listed as Scaled in Table 18.

Table 18: Percent of Time of Inoperability

	Craft	Weather	Mechanical	Total
Anticipated	Bell 206L4 Helicopter[1]	27.1%	0.9%	27.9%
Reported	Bell 206L4 Helicopter	29.6%	0.9%	30.4%
Scaled	Bell 206L4 Helicopter	29.6%	0.9%	30.4%
Anticipated	Bell 412 Helicopter[2]	24.9%	0.9%	25.8%
Scaled	Bell 412 Helicopter	27.2%	0.9%	28.1%
Anticipated	Piper PA31-350 Navajo Cheiftan[3]	31.4%	2.8%	34.2%
Reported	Piper PA31-350 Navajo Cheiftan	34.4%	2.8%	37.2%
Scaled	Piper PA31-350 Navajo Cheiftan	34.4%	2.8%	37.2%
Anticipated	58-foot Ferry (SS4)[4]	19.6%	0.9%	20.4%
Scaled	58-foot Ferry (SS4)	21.4%	0.9%	22.3%
Anticipated	58-foot Ferry (SS5)[5]	11.0%	0.9%	11.8%
Anticipated Scaled	58-foot Ferry (SS5)	12.0%	0.9%	12.8%

[1]Weather percentage includes winds greater than 30 knots, visibility less than 1 mile, ceiling less than 719 feet.

[2]Weather percentage includes winds greater than 35 knots, visibility less than 1 mile, ceiling less than 719 feet.

[3]Weather percentage includes crosswinds greater than 20 knots or winds greater than 40 knots, visibility less than 2 miles, and ceiling less than 719 feet.

[4]Weather percentage includes Beaufort Sea State 4 (SS4) conditions include significant wave heights greater than 3 feet originating from 290° to 330°degrees and tides less than 0 feet MLLW during marginal sea states.

[5]Weather percentage includes Beaufort Sea State 5 (SS5) conditions include significant wave heights greater than 6 feet originating from 290° to 330°degrees and tides less than 0 feet MLLW during marginal sea states.

4.1.1.1 Methodology

Accessibility metrics for fixed-wing and helicopter aircraft were based on Akutan Airport (PAUT) station data from 5/15/2014 to 4/18/2023 with an average of 3 readings per hour. Applicable data used for the analysis included wind speed, wind gust, wind direction, visibility, sky level coverage, and sky level altitude. Ceiling height was interpreted by identifying if the sky level coverage included any of the

3 cloud types considered as ceiling (overcast clouds, broken clouds, and vertical visibility). If a ceiling cloud type was reported, then the corresponding lowest sky level altitude was determined to be the ceiling.

The Akutan Airport instrument approach procedure (IAP) charts list the minimum descent altitude (MDA), or the minimum altitude to which the pilot may descend on approach without visuals. Calculations are based on the higher ceiling values of the east approach. For an east approach, the MDA ceiling is 719 feet and visibility 1 ¼ miles (FAA, 2023). The visibility reduction by helicopters for Akutan Airport is no less than 1 mile, with no reduction for ceiling. Note that these are minimum values and the authorized MDA may be further restricted for the pilot or the aircraft.

Winds of 40 knots or greater will cause cancelations of flights into Unalaska Airport and Akutan Airport. The maximum allowable tailwind or crosswind for hover operations of the existing Bell 206L4 helicopter are 30 knots and a larger Bell 412 helicopter are 35 knots. The maximum available crosswind for the existing Piper PA31-350 Navajo Cheiftan is 20 knots.

The Akutan Airport station does not record wave information, nor does the location adequately capture the weather that would pass from the Bering Sea to the ferry route. Accessibility metrics for the ferry were based on WIS Station 82327 data from 01/01/1985 to 01/01/2020 with 1 reading per hour. The WIS data was filtered to 290° to 330° to reflect the limited window of Bering Sea energy that could affect the ferry due to the coverage provide by the islands of Akutan and Akun as well as the island chain to the south. Applicable data used for the analysis included wave height and direction.

Fixed-wing flights currently arrive at Akutan Airport at 10:20 and 15:30 and depart at 10:35 and 16:05. It is assumed that all methods of airport transportation would cease during twilight hours of 23:00 to 06:00 April 1 to October 31 and 20:00 to 09:00 November 1 to March 31. The twilight hours were removed from all analysis except tide. Tide was not found to have a statistically significantly difference between daylight and twilight hours, so the unmodified value was used.

Delays due to mechanical/maintenance for the fixed-wing and helicopter were reported by the carriers from 2020 to 2023. A ferry would not inherently have more or less mechanical issues than a helicopter as the environmental operating conditions differ and the age and condition of the contracted ferry are unknown. Due to the uncertainties associated with mechanical/maintenance delays and the relatively small value of 0.9% (Maritime helicopter cancelations average from 2020 to 2022), mechanical/maintenance cancellations was assumed to be the same for the ferry vessel.

The proposed harbor depth of -14 feet MLLW is designed to be accessed at tides greater than 0 feet MLLW. Approximately 1% of the time, a combination of marginal sea state conditions nearing SS4 in the harbor entrance channel occurring at tides lower than 0 feet MLLW would cause the harbor to be inaccessible. This percentage is included in the ferry calculations. At other times, calmer sea states occurring at tides lower than 0 feet would result in a ship response to waves smaller than 4 feet, and the additional depth allowance would compensate for the lower tide. Additionally, if the intermediate sea level change scenario of -0.92 feet is not realized, the additional 1 foot of dredging incorporated design depths at construction would reduce the 1% joint tide probability to 0.15%.

4.1.2 Results

The total amount of time that the ferry and existing Bell 206 helicopter are anticipated to be inoperable due to weather and mechanical issues is 22.3% and 30.4% respectively (Table 18). The improvement in access between the helicopter and ferry can bet seen in the simple equation below.

$$(1 - Ferry\ Cancelation_{FWP}) - (1 - Helicopter\ Cancelation_{FWOP}) = Improvement\ in\ Access$$

$$(1 - 0.223) - (1 - 0.304) = 0.081 = 8.1\%\ Improvement\ in\ Access$$

The resulting 8.1% improvement in access of the ferry verses the helicopter is between the Native Village of Akutan and Akun. Travel from Akutan Airport (on Akun) to Dutch Harbor and onward would not be improved.

All accessibility statistics as presented do not include human judgement. Pilots and Captains may elect to operate more or less conservatively in practice than presented by this analysis. The scaling factor applied to each percent of time of inoperability factors in some degree of human judgement, but all statistics presented in this analysis contain a level of uncertainty caused by human judgement.

Improvement in access anticipated by the project was also determined for skiffs. Akutan airport station wind data was used to evaluate conditions at the project site in which skiffs can land. It was found that approximately 20% of the time, conditions under SS3, wind speeds under 7 knots, occur at the project site. During these conditions, skiff operators could likely access Akun without the harbor project, although at least one community member typically stays behind with the vessel. Approximately 19% of the time, SS3 conditions, wind speeds of 7 to 10 knots, occur at the project site. During these conditions, skiff operators may be able to make the crossing from Akutan but would likely not be able to safely land on the beach due to waves. A broad comparison between the two conditions is that approximately 50% of the time, a skiff operator could theoretically make the crossing to Akun but not be able to land on Akun without the protection provided by the project.

WIS station 82327 directionally filtered from 290° to 330° was used to estimate how often skiff operators could safely make the crossing to Akun. It was found that approximately 9% of the time, SS3 or lower conditions, wind speeds 10 knots or lower and significant wave heights 2 feet or lower, occur in the crossing to Akun. During these conditions, skiff operators would likely be able to make the crossing from Akutan to Akun. Additional factors such as tides and currents, skiff size, and operator judgement would also affect the decision to cross and are not reflected in the statistics.

Evaluating the percent of time that skiff operators can make the crossing to Akun but only land due to the protection provided by the harbor, the project would provide an estimated 4.5% increase in skiff accessibility of Akun. This was determined using the following simple formula.

$$(Akutan\ to\ Akun\ Crossing) * (Land\ at\ Akun_{FWP}) = Improvement\ in\ Access$$

$$(9\%) * (50\%) = 4.5\%\ Improvement\ in\ Access$$

4.2 Breakwaters

4.2.1 Design Wave

The design wave was developed for the three alternatives by transmitting the 2% AEP deepwater WIS station 82327 wave of 30.0 feet from the 310° direction to the toe of each breakwater using STWAVE modeling. The resulting design wave for each alternative is given in Table 19 below.

4.2.2 Stone Sizing

Breakwater stone size was calculated using the 1977 Hudon's equation, where M_{50} is the medium mass of rock, ρ_s is the density of rock, p_w is the density of water, H is the wave height, K_D is the stability coefficient, and α is the slope angle.

$$M_{50} = \frac{\rho_s {H_s}^3}{K_D \left(\frac{\rho_s}{p_w} - 1\right)^3 \cot\alpha}$$

With p_s of 165lb/ft^3, p_w of 64 lb/ft^3, H_s of 12.5 feet, K_D of 3.5 for rough angular stone with random placement, and α of 2 for a 2 horizontal to 1 vertical (2:1) slope, the medium weight of armor stone is 6 tons. Ice is not present at the project area and was not considered for armor stone sizing.

Table 19: Breakwater Armor Stone Weight

Alternative	Design Wave (feet MLLW)	Armor Stone (tons)
Alternative 1	14.5	10.5
Alternative 2	12.5	6.5
Alternative 3	15.0	11.5

4.2.3 Breakwater Dimensions

4.2.3.1 Crest Height

CEM run-up calculations were initially used to determine breakwater height. The following equations determine the runup height with 2% exceedance level for a permeable rock armored slope with irregular head-on waves.

$$R_{2\%} \begin{array}{ll} = 0.96\xi_{om} \times H_s & for\ 1.0 < \xi_{om} \le 1.5 \\ = 1.17(\xi_{om})^{0.46} \times H_s & for\ 1.5 < \xi_{om} \le 3.1 \\ = 1.97 \times H_s & for\ 3.1 < \xi_{om} < 7.5 \end{array}$$

where ξ_{om} is the mean surf-similarity parameter and is dependent on the mean wave period, significant wave height, and slope of the structure, and H_s is the significant wave height. For alternative 2 with a wave height of 12.5 feet and period of 12 seconds and breakwater slope of 2H:1V, the run-up with 2% exceedance level was calculated to be 24.6 feet. Added to the total water level, this results in a breakwater crest elevation of 32.7 feet MLLW. A breakwater of this height is not feasible, and an overtopping breakwater design was pursued.

The overtopping breakwater crest height was determined using the EurOtop equation below (Van der Meer, 2018). A reduction factor C_r was applied due to the breakwater crest width, G_c, being greater than the significant wave height. Solving for freeboard R_c, or the difference between the crest of the breakwater and the total water level, can be used to determine the breakwater height.

$$q = C_r \left[0.1035 \times \exp\left(-\left(1.35 \frac{R_c}{H_s \gamma_f \gamma_\beta}\right)^{1.3}\right)\right] \sqrt{g H_s^3}$$

$$C_r = 3.06 \ \times \exp\left(\frac{-1.5 G_c}{H_s}\right)$$

$$R_c = \frac{H_s \gamma_f \gamma_\beta}{1.35} \left[-\ln\left(\frac{q}{0.1035 C_r \sqrt{g H_s^3}}\right)\right]^{\frac{1}{1.3}}$$

Structural damage for an unpaved revetment is anticipating to occur at a mean overtopping discharge q between 0.05 and 2 meters^3/s (50 and 200 liters/s) per meter length of breakwater (Figure 42). A q value of 115 l/s/m (0.115 m^3/s/m) was chosen for design due to the limited infrastructure behind the breakwater and not being a safe harbor of refuge. Reduction factor C_r was determined to be 0.63 from the breakwater crest, G_c, of 13.2 feet (4.0m) and H_s of 12.5 feet (3.8m). Influence factor for the permeability and roughness of the slope, γ_f, is 0.40 for a 2 rock armor layer with a permeable core. Influence factor for oblique wave attack, γ_β, is 1.0 for worst-case perpendicular wave attack.

Solving for crest height,

$$C_r = 3.06 \ \times \exp\left(\frac{-1.5 \times 13.2}{12.5}\right) = 0.63$$

$$R_c = \frac{3.8 \times 0.4 \times 1}{1.35}\left[-\ln\left(\frac{0.05}{0.1035 \times 0.63\sqrt{9.81 \times 3.8^3}}\right)\right]^{\frac{1}{1.3}} = 2.34\, meters$$

R_c equals 2.34 meters or 7.67 feet. The total water level is 7.79 feet MLLW (see Section 3.2.2 Water Level). The sum of these values results in a breakwater crest height of 15.46 feet, rounded to 15.5 feet for design. For comparison, a q value of 50 l/s/m was also evaluated, the point at which structural damage is anticipated to begin, resulting in a breakwater crest height of 17.3 feet. A flume study will be performed in PED to determine if the allowable overtopping discharge is appropriate and if the crest height and stone size is sufficient.

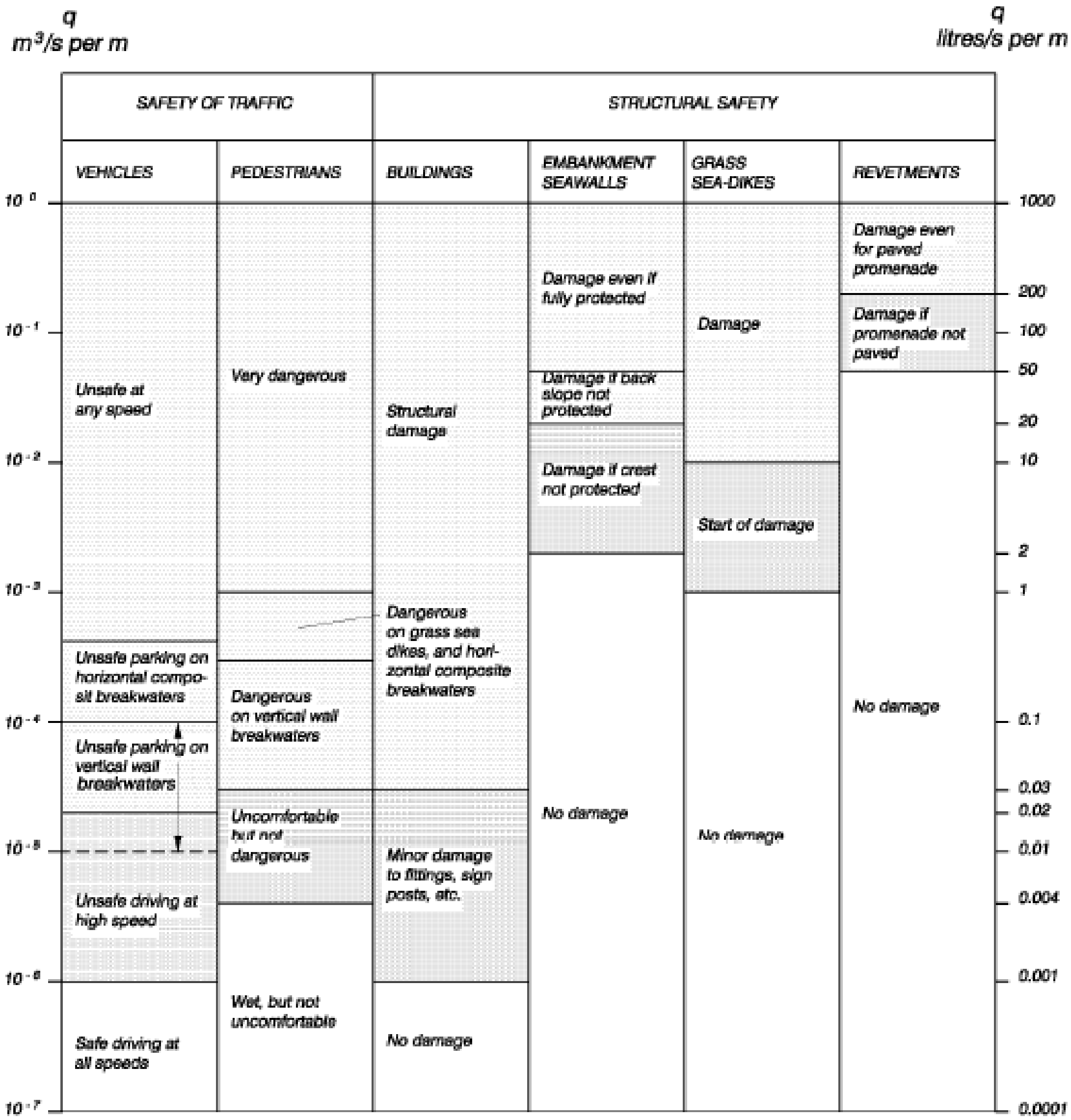


Figure 42. CEM Table VI-5-6 Critical Values of Average Overtopping Discharges (USACE, Coastal Engineering Manual, 2008).

Table 20: Breakwater Crest Heights

Alternative	Design Wave (feet MLLW)	Crest Height (feet MLLW)
Alternative 1	14.5	15.5
Alternative 2	12.5	16.5
Alternative 3	15.0	17.0

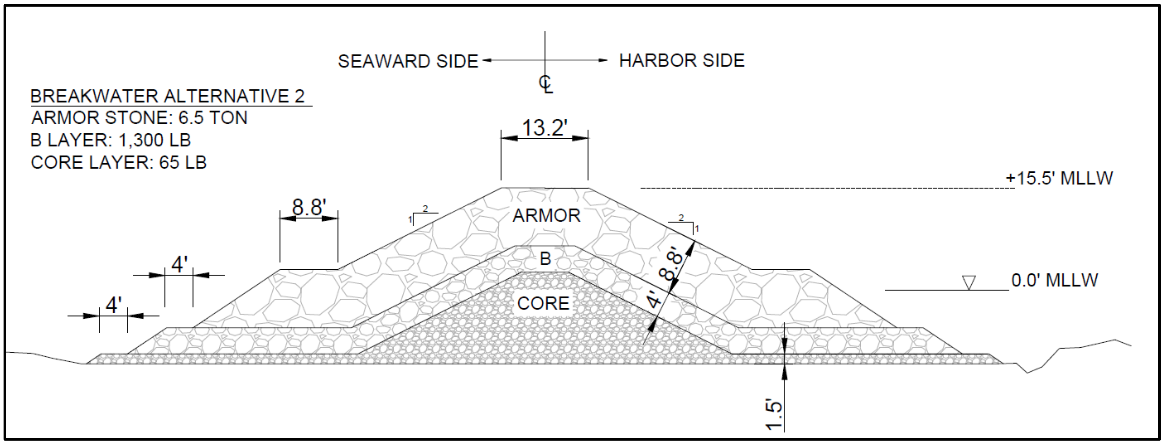


Figure 43: Breakwater Typical Cross Section (Alternative 2)

4.3.2.2 Crest Width and Armor Stone Layer Thickness

Breakwater crest width is equal to the combined width of three armor stones. Breakwater armor stone layer thickens is equal to the combined width of two armor stones. All alternatives were designed as overtopping breakwaters.

Table 21: Breakwater Crest Width and Armor Stone Layer Thickness

	Crest Width (feet)	Armor Stone Layer Thickness (feet)
Alternative 1	15.5	10.2
Alternative 2	13.2	8.8
Alternative 3	16.0	10.6

4.3.2.3 Breakwater Length

Breakwater length was determined by assuming an initial length and then integrating the geometry of the breakwater into the STWAVE model bathymetry. The model was rerun with the breakwater and checked to ensure that a 1 foot or less wave was in the harbor basin footprint. Actual wave heights of up to 2 feet in the harbor should be expected due to the limitations in STWAVE modeling at small wave heights. The 2-foot maximum wave height in the basin is intended to protect mooring infrastructure. The maximum wave height expected in the harbor basin during ferry operations (SS4 or less) is less than 1 foot.

Table 22: Breakwater Lengths

	Length (feet)
Alternative 1	715
Alternative 2	400
Alternative 3	400

4.2.4 Life-Cycle Breakwater Design

Armor stone for the proposed breakwaters at Akun was sized using the 2% AEP design wave forces expected to impact the structure. This was determined to be the most cost-effective means of protection for port alternatives considered. Rock for the project would likely be barged to the project location. Replacement costs are estimated to be relatively high because the project location is very remote and mobilization costs are substantial. A 1% AEP design would reduce the frequency and magnitude of needed maintenance, however design conditions for these events are not well known due to the period of record of data available at the site and there is less certainty that basing the design on a lower frequency event would produce a structure that would be capable of withstanding events of greater severity than those observed and studied. A 2% AEP design provides the optimum balance between minimizing maintenance requirements and the cost of procuring the stone for repairs.

Maintenance of breakwater armor stone is estimated at 5 percent replacement every 25 years. A flume study will be performed in PED to determine if this estimate is sufficient or if it should be increased or decreased.

4.2.5 Earthquake Risk

The project is located along the Aleutian megathrust, one of the earth's most active subduction zones (Buurman, Nye, West, & Cameron, 2014). Earthquakes pose a risk for stone movement on the breakwater slope as well as seabed liquefaction. Tsunamis caused by earthquakes would overtop the breakwater and potentially damage the dock and mooring facilities inside the harbor.

A geological investigation was performed on Sedanka Island, 35 miles to the southwest of the project location, to study the history of past tsunamis. It was found that large tsunamis occur on average every 300 to 340 years in the eastern Aleutian Islands (USGS, New Geological Evidence Aids Tsunami Hazard Assessments from Alaska to Hawaii, 2016). The most recent large tsunamis were in 1946 and 1957, caused magnitude 8.6 earthquakes located 140 and 450 miles from the project location, respectively.

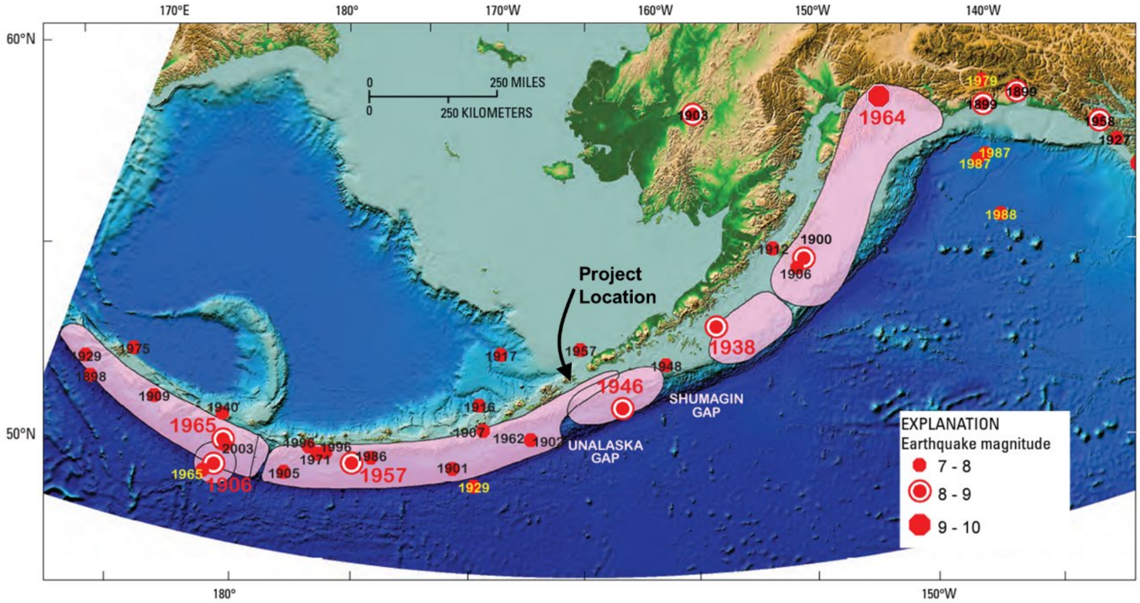


Figure 44: Rupture Zones (Pink) and Epicenters of Aleutian Megathrust Earthquakes During 20th Century (USGS, 2011)

Earthquake and tsunami risks will better be understood during the PED phase once the geotechnical boring investigation and the integrated numerical and physical coastal models are completed.

4.3 Channel and Basin Widths

Considerations for channel design follow the standards of USACE EM1110-2-1613 Hydraulic Design of Deep Draft Navigation Projects and EM 1110-2-1615 Hydraulic Design of Small Boat Harbors and were checked against globally used PIANC guidance (USACE, 2008).

4.3.1 Entrance Channel

Section 3-11 of EM 1110-2-1615 Hydraulic Design of Small Boat Harbors was used to design the entrance channel and turning basin widths. The design vessel is a 58-foot long with 26-foot beam monohull and is assumed to have good controllability. The width of the entrance channel turn was designed to 560% of the beam using the following calculation.

$$560\% = 440\% + (2 * 60\%)$$

The width of the entrance channel straight sections were designed to 300% of the beam using the following calculation.

$$300\% = 180\% + (2 * 60\%)$$

Table 23: Minimum Channel Element Widths (Committee on Tidal Hydraulics, 1965)

Minimum Channel Widths Needed in Percent of Beam			
Location	Vessel Controllability		
	Very Good	*Good*	*Poor*
Maneuvering Lane, Straight Channel	160	180	200
Bend, 26-degree Turn	325	370	415
Bend, 40-degree Turn	385	440	490
Vessel Clearance	80	80	80
Bank Clearance	60	60 plus	60 plus

Note that quantity calculations are based off a previous design iteration of a 120 foot wide turn and 60 foot wide straight section. Many 58-foot fishing vessels in Alaska have beams less than 26-feet, typically ranging from 18 to 24 feet. Channel shape and dimensions may be updated in PED due to optimization of design vessel and numerical modeling and geotechnical site investigation results.

4.3.2 Turning Basin

Section 3-14 of EM 1110-2-1615 Hydraulic Design of Small Boat Harbors recommends the turning basin be designed based on observation of vessel turning radius. Because the ferry vessel will be contracted and the turning radius is unknown, PIANC guidance was utilized. PIANC recommends the turning basin to be twice the length of the design vessel, or 120 by 120 feet. Since ship simulation was not performed for this study, it was deemed appropriate to use the PIANC turning basin dimensions.

The mooring basin is located within the dimensions of the turning basin, as only the ferry vessel will utilize the mooring basin. In the rare instance that another vessel is utilizing the mooring basin, the conservatively sized turning basin should provide enough room for the design vessel to maneuver. Local skiffs utilizing the harbor can either pull up and anchor on the beach or utilize the ferry mooring when the space is not occupied.

4.3.3 Circulation

The circulation aspects of the proposed harbors at Akun were evaluated based on guidance given in the Coastal Engineering Manual Part II Chapter 7. Tidal variation, storm surge, wave driven currents, and wind stresses are factors that would affect water circulation in the proposed harbor. The harbor basin design aspect ratio is 120-foot by 120-foot square for all alternatives. This results in a very high spatial average exchange coefficient of 0.48 to 0.5 (Figure 45).

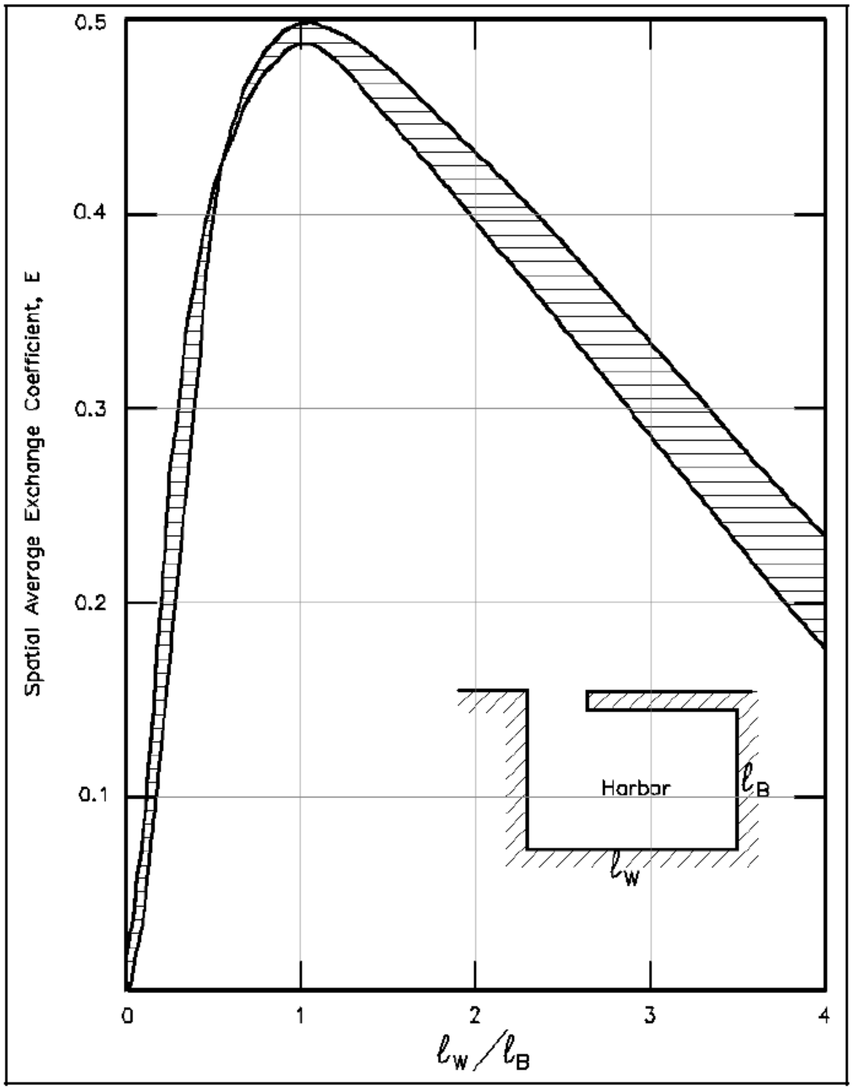


Figure 45: Exchange Coefficients – Rectangular harbor (USACE, 2008)

A second circulation check was performed by calculating the basin flushing time.

$$T_f(tidal\ cycles) = \frac{\ln D}{\ln\left(\frac{V_t - V_m + 2V_m(1-\varepsilon)}{V_t + V_m}\right)}$$

where D is the dilution factor, $V_t - V_m$ is the low-tide volume, $V_t + V_m$ is the high tide volume, $2V_m$ is the tidal prism, and $1-\varepsilon$ is the amount of "return flow", i.e., the volume of "dirty" water that gets drawn back into the basin in each tide cycle. A dilution factor of 1.5 was chosen because there are no significant sources of water inflow to the harbor other than tidal action. A typical return flow of 30% was also chosen. Using the 120-foot by 120-foot basin with a tide range of 3.47 feet, the basin flushing time is approximately 2.5 hours. This is well above the EPA recommended residence time of 4 days. Additionally, pollutants in the harbor are expected to be a low concern. Anticipated usage of the harbor is one ferry vessel making one to two trips daily with no permanent mooring. Circulation issues with the proposed harbor design are not anticipated at this time but will be further verified in PED with numerical and physical modeling.

4.4 Channel and Basin Depths

A vessel moving in the entrance channel and turning basin must maintain clearance between its hull and channel bottom. Navigational design parameters were analyzed including squat, safety clearance, and vessel motion due to waves. Storm surge was not included as it increases water depth that would benefit depth calculations. An allowance for RSLC was included. Minimum gross underkeel clearance was calculated from the sum of the depth requirement from each design parameter.

Considerations for channel design follow the standards of the CEM and were checked against globally used PIANC guidance (USACE, 2008).

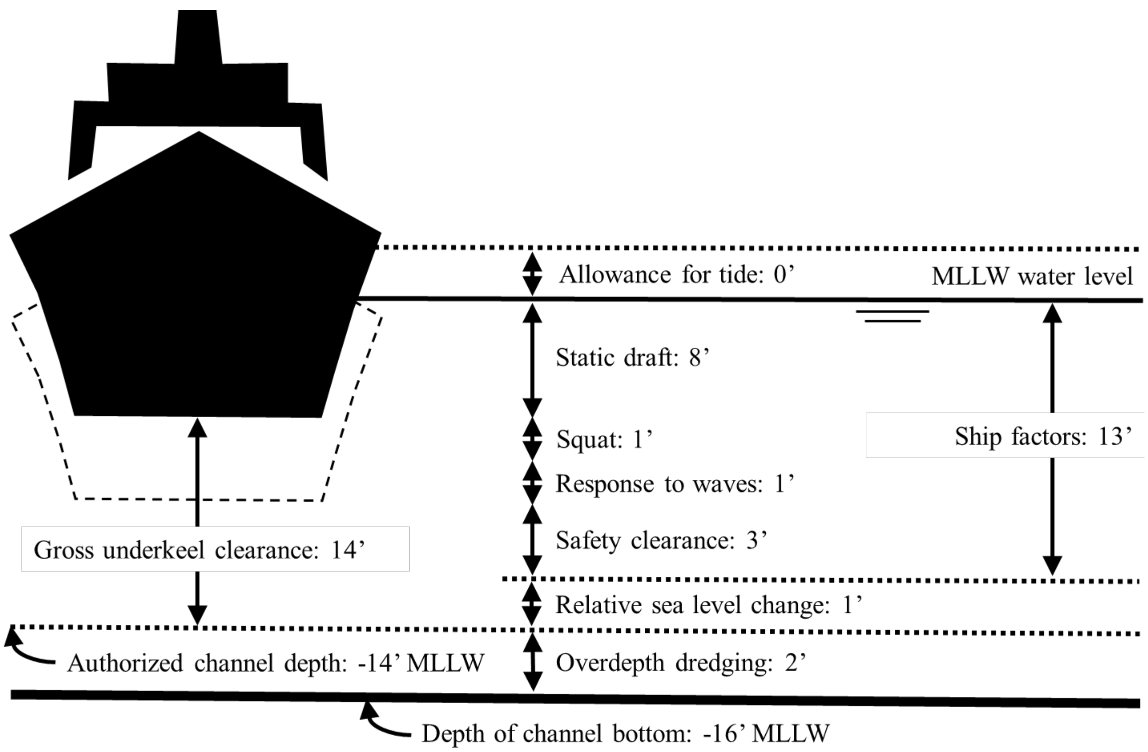


Figure 46: Channel Design Parameters

4.4.1 Environmental Factors

4.4.1.1 Tide.

The harbor is designed to allow access at tides above 0.0 feet MLLW. During favorable weather conditions, the harbor may be accessed at tides lower than 0.0 feet MLLW per the pilot's discretion.

4.4.1.2 Relative Sea Level Change

From Section 2.9 Relative Sea Level Change, in order to maintain the project depth at year 50, 1 foot of dredging will be incorporated in the harbor and entrance channel design depths at construction.

4.4.1.3 Set-Down

Set-down is a lowering of the water surface elevation due to wind stresses. The lowest observed water level at Unalaska (9462620) is -2.78 feet which indicates that set-down can occur in the area, but information is not available for how often they occur. Set-down was not included in the design depth as the ferry would not operate during the strong wind conditions associated with set-down.

4.4.2 Ships Factors

4.2.2.1 Squat

Vessel draft increases when vessel sailing depth adjusts to the energy balance between hydrostatic and kinetic energy due to the fluid velocity around and under the vessel hull. It is pulled down into the water column by the hydrodynamic pressure gradient. This phenomenon and related vertical hydrodynamic effects are defined here as "squat," which varies with vessel speed, water depth beneath the keel, and the ratio of the vessel cross-section area to the cross-section area of the channel.

Ship squat is difficult to accurately predict, with the best available method being imperial formulas. USACE guidance for the Hydraulic Design of Small Boat Harbors (EM 1110-2-1615 section 3-12) describes ship squat based on the vessel's blockage ratio and the Froude number. The channel's dimensionless blockage ratio S is defined as

$$S = \frac{A_s}{A_c}$$

where A_s is the cross-sectional area of the ship and A_c is the cross-sectional area of the channel. A beam of 26 feet multiplied by a draft of 8 feet results in an A_s value of 28 feet^2. A channel depth of 14 feet multiplied by a width of 120 feet results in an A_c value of 1,680 feet^2. Therefore S is equal to 0.12.

The Froude number F is defined as

$$F = \frac{V_s}{\sqrt{gH_c}}$$

where V_s is vessel speed in feet/sec, g is acceleration due to gravity at 32.2 ft/sec^2, and H_c is the channel water depth in feet. With V_s ranging from 4 to 8 knots (6.8 to 13.5 feet/sec) and a channel depth of 14 feet, dimensionless squat is read from Figure 47 below.

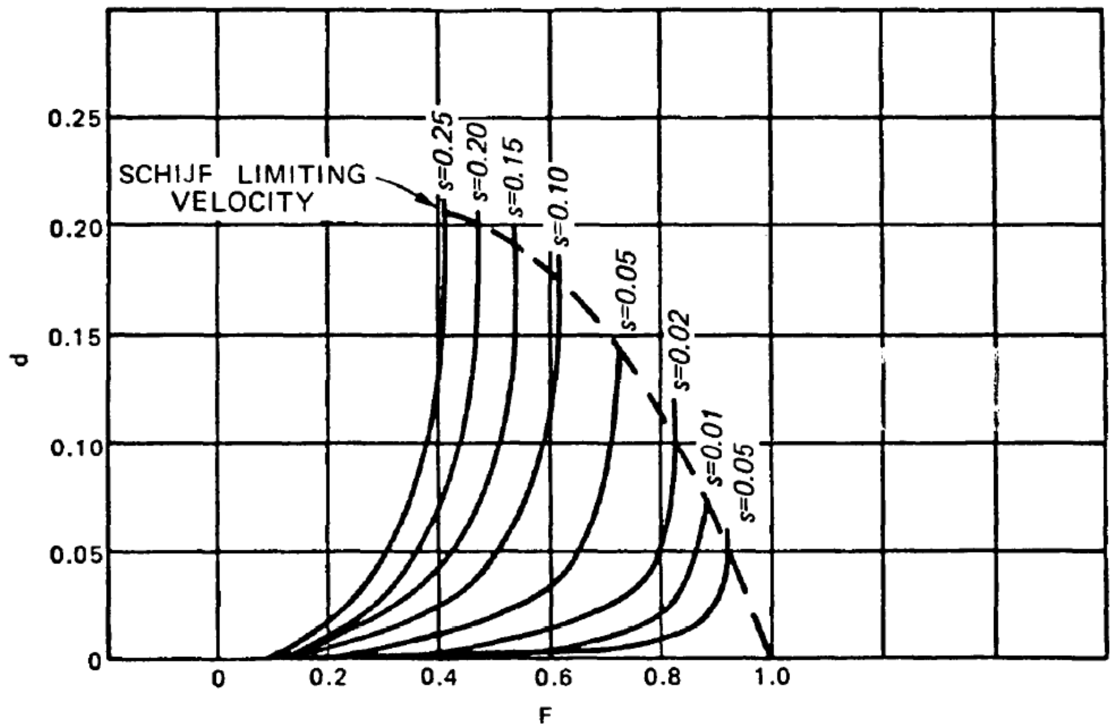


Figure 47: Dimensionless Squat (EM 1110-2-1615 Figure 3-10)

Dimensionless squat was multiplied by the depth of channel water (14 feet) to produce ship squat. Results for EM 1110-2-1615 squat calculations are shown in Table 24 below.

Table 24: Squat Calculations

Vessel Speed (knots)	**Squat** *EM 1110-2-1615* (feet)	*EM 1110-2-1613* (feet)	*PIANC* (feet)
4	0.3	0.4	0.1
5	0.4	0.7	0.1
6	1.0	1.0	0.2
7	1.8	1.4	0.3
8	2.5	1.8	0.4

USACE guidance for the Hydraulic Design of Deep Draft Navigation Projects (EM 1110-2-1613 section 6-3) was also used to check squat using the Norrbin equation

$$z_{max} = \frac{C_B B T V^2}{4.573 L h}$$

where z_{max} is ship squat in feet, C_B is block coefficient, B is max beam, T is fully loaded draft, V is ship velocity in knots, L is length of vessel, and h is channel depth. C_B coefficients range from 0.5 for fine form ships to 0.9 for very full tankers and bulk carriers, with 0.5 used for the design vessel (see Table 25, tuna seiner). Computations for prediction of squat assume a typical container vessel C_B of 0.5, B of 26 feet, T of 8 feet, V of 4 to 8 knots, L of 58 feet, and h of 14 feet. Results for EM 1110-2-161 squat calculations for are shown in Table 24 above.

Table 25: Block Coefficients from EM 1110-2-1613

Table 3-1
General Typical Ship Hull Form Coefficients

Type	C_B	L/B	B/T	Speed V, knots, ft/sec	Length Froude No.[1] $F_l = \frac{V}{\sqrt{gL}}$	Number of Propellers/ Rudders	Rudder Area Ratio[2]
Harbor tug	0.50	3.3	2.1	10 (16.8)	0.25	1/1	0.025
Tuna seiner	0.50	5.5	2.4	16 (26.9)	0.31	1/1	0.025
Car ferry	0.55	5.1	4.5	20 (33.6)	0.34	2/2	0.020
Container high speed	0.55	8.3	3.0	28.5 (47.9)	0.53	2/2	0.015
						2/1	0.025
Cargo liners	0.58	6.9	2.4	21 (35.3)	0.29	1/1	0.015
RO/RO[3]	0.59	6.9	3.0	22 (37.0)	0.26	1/1	0.015
Barge carrier	0.64	7.5	2.9	19 (31.9)	0.20	1/1	0.015
Container med. speed	0.70	7.1	2.8	22 (37.0)	0.25	1/1	0.015
Offshore supply	0.71	4.7	2.75	13 (21.8)	0.28	2/2	0.016
General cargo low speed	0.73	6.7	2.4	15 (25.2)	0.20	1/1	0.015
Lumber low speed	0.77	6.7	2.6	15 (25.2)	0.20	1/1	0.025
LNG (125,000 m^3)	0.78	6.8	3.7	20 (33.6)	0.20	1/1	0.015
OBO[4] (Panamax)	0.82	7.5	2.4	16 (26.9)	0.17	1/1	0.01
OBO (150,000 dwt)	0.85	6.4	2.4	15 (25.2)	0.15	1/1	0.017
OBO (300,000 dwt)	0.84	6.0	2.5	15 (25.2)	0.14	1/1	0.015
Tanker (Panamax)	0.83	7.1	2.4	15 (25.2)	0.16	1/1	0.015
Tanker (100,000 to 350,000 dwt)	0.84	6.2	2.4	16 (26.9)	0.15	1/1	0.015
Tanker (350,000 dwt)	0.86	5.7	2.8	16 (26.9)	0.13	1/1	0.015
U.S. river towboat	0.65	3.5	4.5	10 (16.8)	0.25	2/2	...

[1] $\frac{V}{\sqrt{gL}}$ where V = ship speed, ft/sec ; g = acceleration due to gravity, ft/sec^2; and L = ship length, ft. To convert feet to meters, multiply by 0.3048.
[2] RUDDER AREA/SHIP LENGTH * DRAFT
[3] Roll-on, roll-off type ships
[4] Oil-, Bulk-, Ore-type ships

USACE guidance value was checked against PIANC guidance recommended Barrass (B3) equation

$$S_{Max,B3} = \frac{C_B V_k^2}{100/K}$$

where $S_{Max,B3}$ is ship squat, C_B is the block coefficient, V_k is ship speed, and K is a dimensionless coefficient. K is defined as

$$K = 5.74S^{0.76}$$

where S is the channel's dimensionless blockage factor, previously calculated as 0.12. Therefore K is equal to 1.17. For a C_B previously established as 0.5 and a V_k of 4 to 8 knots, results PIANC squat calculations are shown in Table 24 above.

As a check, USACE guidance (EM 1110-2-1615 Section 3-12 b.) recommends a smaller vessel generalization for squat of 1 foot in entrance channels. An allowance for vessel squat of 1 foot was chosen for design, which equates to a maximum ferry speed of 6 knots in the entrance channel and mooring and turning basins.

4.2.2.2 Response to Waves

Vessel response to waves, or the vertical movement of pitch, roll, and heave, is difficult to estimate accurately and is still being researched. Best available USACE guidance (EM 1110-2-1613) estimates the effect of pitch, roll, and heave using the Noble equation

$$P_{avg} = 0.57 + 0.99\left(\frac{H_S T_{\emptyset}}{T_e}\right)$$

where P_{avg} is average ship motion in waves, H_S is significant wave height, $T_{\emptyset}$ is natural ship pitch period, and T_e is encounter period. The natural pitch period for the design vessel is not known but is estimated at 4 seconds based on a similar study of a 65 foot fishing vessel in Newfoundland, Canada (Akinturk, Cumming, & Bass, 2007).

The design vessel can be expected to conduct operations in SS4 and survive in SS5. Calculations for the vessel response to waves were based of SS5 conditions. An offshore significant wave of 6 feet with an 8 second period was modeled in STWAVE to find the wave height at the entrance channel and basin. Modeled water level was MHHW of 3.76 feet. Results were a 6 foot 8 second period wave at the entrance channel and 0.5 foot 8 second period wave in the basin. The wave in the basin was rounded to a 1 foot 8 second period wave due to the limitations in STWAVE modeling at small wave heights. Vessel speed was calculated for a range of 4 to 8 knots.

Utilizing Figure 48 below, waves originating from the Bering Sea to the north would have an encounter angle Ɵ, or the difference between the wave angle and ship heading, of 180° for the inbound ferry heading to Akun and 0° for the outbound ferry heading to Akutan. Outbound vessels travel in head seas, or against the direction of wave propagation, which causes a larger ship motion due to waves than inbound vessels. Therefore, outbound ship motion due to waves was used for calculations. Vessel speed V_k multiplied by the dimensionless factor F is the input and wave period of encounter is the output. Using the Noble equation with a 5 foot and 0.5 foot significant wave height, natural ship period of 4 seconds, and a wave encounter period for outbound ferry ranging from 4 to 8 knots, the ship response to waves is given in Table 26. USACE guidance (EM 1110-2-1615 Section 3-12 c.) recommends a smaller vessel generalization for ship response to waves of one-half the design wave height. This equates to 0.5 feet for the mooring and turning basin, and 3 feet for the entrance channel. The generalization and calculated values were compared, and the more conservative calculated values were utilized in the design.

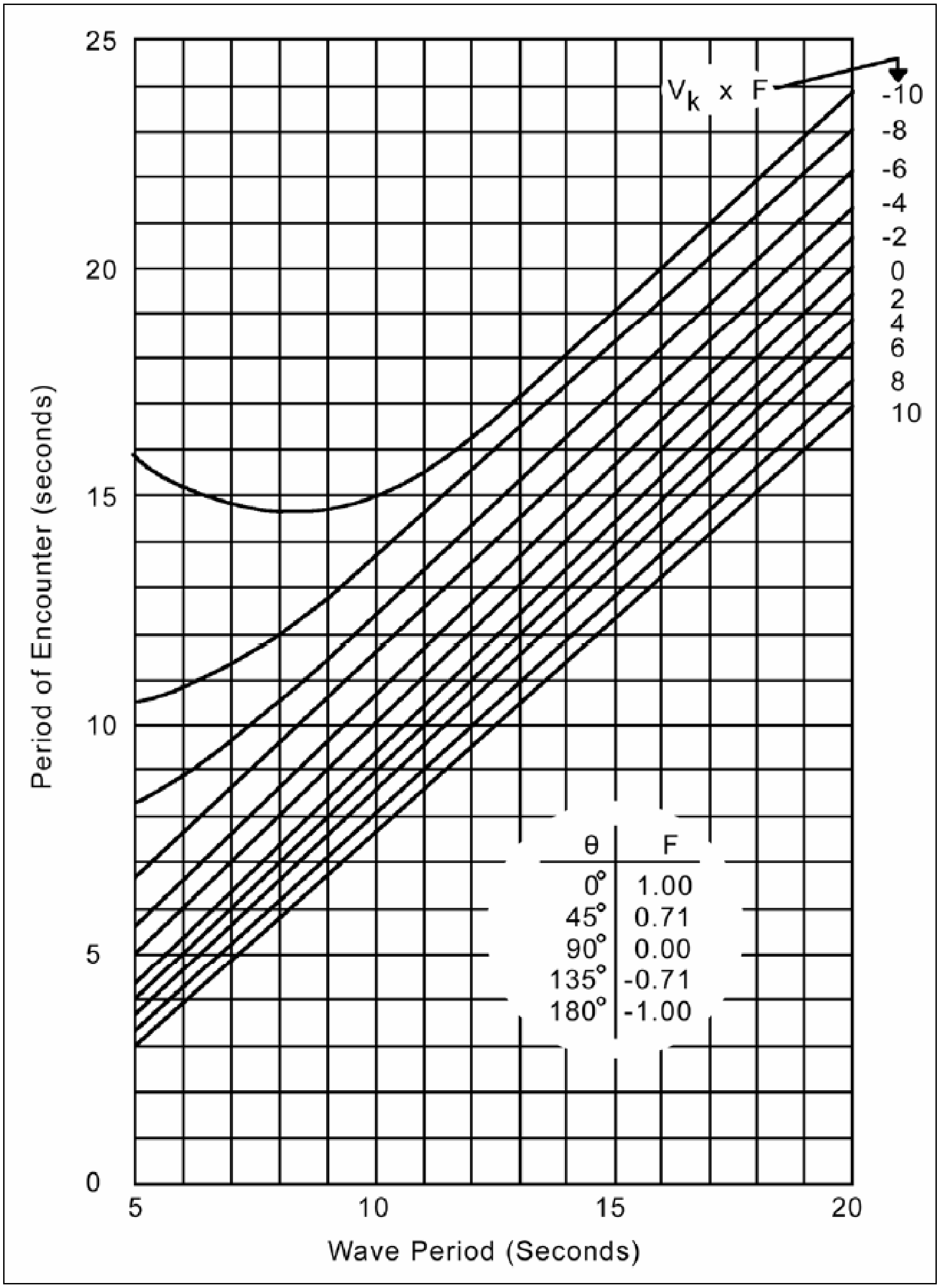


Figure 48: EM 1110-2-1613 Wave Encounter Period (Figure 6-15)

USACE guidance (EM 1110-2-1615 Section 3-12 c.) recommends a smaller vessel generalization for ship response to waves of one-half the design wave height. This equates to 0.5 feet for the mooring and turning basin, and 3 feet for the entrance channel. The generalization and calculated values were compared in Table 26 below, and the more conservative calculated values were utilized in the design.

Table 26: Vessel Motion Due to Waves

Vessel Speed (knots)	Basin Calculated (feet)	Basin Generalization (feet)	Entrance Channel Calculated (feet)	Entrance Channel Generalization (feet)
4	0.85	0.50	3.4	3.0
5	0.86	0.50	3.5	3.0
6	0.87	0.50	3.6	3.0
7	0.88	0.50	3.7	3.0
8	0.89	0.50	3.8	3.0

An allowance for vessel motion due to waves of 1 foot for the mooring and turning basin and 4 feet for the entrance channel chosen for design.

4.4.3 Safety Clearance

USACE guidance (EM 1110-2-1613) suggests a minimum net underkeel clearance of 2 feet; however, for hard bottom conditions such as rock, consolidated sand or clay, 3 feet of net underkeel clearance is recommended. Based on bedrock being present in the dredging area, a safety factor of 3 feet was used for this analysis.

4.4.4 Gross Underkeel Clearance

The subtotal of squat, response to waves, RSLC, and safety clearance for the entrance channel and turning basin provides a gross underkeel clearance of 6.0 feet for the mooring and turning basin and 9.0 feet for the entrance channel. This results in a design depth of -14 feet MLLW and -17 feet MLLW respectively. USACE guidance (EM 1110-2-1613 Section 6-4) recommends the PIANC rule of thumb for preliminary design of entrance channel depths of 1.3 times the maximum shift draft, which results in a design depth of -10.4 feet MLLW. The entrance channel design depth far surpasses the rule of thumb.

It is anticipated that a percentage of the turning basin and entrance channel dredging will encounter bedrock and blasting will likely be required. Dredging equipment and procedures for blasting cannot provide a smoothly excavated bottom at a precisely defined elevation. Two feet of allowable overdepth dredging was added to for a maximum dredge depth of -16 feet MLLW for the mooring and turning basin and -19 feet MLLW for the entrance channel.

Table 27: Design Parameters for Gross Underkeel Clearance Calculation

Design Parameter	Depth Allowance	
	Basin (feet MLLW)	*Entrance Channel* (feet MLLW)
Storm Surge	0	0
Tide Level	0	0
Relative Sea Level Change	-1	-1
Vessel Draft	-8	-8
Squat	-1	-1
Response to Waves	-1	-4
Safety Clearance	-3	-3
Design Depth	-14	-17
Allowable Overdepth	-2	-2
Max Payline	-16	-19

4.5 Dredging

4.5.1 Dredging Limits

Dredging limits were determined based on vessel maneuvering characteristics as a function of length, beam, turning radii, and wind conditions. Side slopes of 2H:1V were assumed based on the rocky material anticipated, and further geotechnical analysis will likely allow for even steeper side slopes.

A minimum offset bench width distance of 15 feet horizontal between the top of the dredge cut slope and the toe of any causeway or breakwater structure is recommended. For purposes of dredging adjacent to the proposed dock faces, the required depth can abut to the dock faces.

The maximum dredging depth determined for the site was to -16 feet MLLW. Previous studies have indicated a need to drill and blast 2 feet below the design depth to produce an efficient pattern to loosen the material for excavation. Dredging tolerances were assumed to be 2 feet due to the coarse nature of the material around the island and the potential need for blasting to remove it. Payment includes dredging allowable overdepth to a maximum of -16 feet MLLW.

4.5.2 Dredging Quantities

Table 28 displays dredge quantities associated with each alternative. Alternative 1 was laid out beyond the anticipated bedrock and would likely not require blasting. Alternatives 2 and 3 are located within known bedrock prisms and will require blasting. The quantities presented include grading a 2:1 sideslope to daylight.

Table 28: Estimated Dredging Quantities

	Initial Dredging (cy)	Maintenance Dredging (cy)
Alternative 1	23,800	2,380
Alternative 2	27,400	2,740
Alternative 3	23,000	2,300

4.5.2 Dredging Methods

It is anticipated that the mouth of the entrance channel will not need blasting and will be mechanical dredged by an in-water barge. A transition zone in the entrance channel behind the breakwater is expected in which mechanical dredging and blasting will occur from in-water from a barge. At depths shallower than -6 feet MLLW, it is expected that blasting will need to occur by land by building up a pad to +5 feet MLLW. This area is too shallow to be blasted by barge as this area contains many exposed rock pinnacles. The blasting pad material is expected to be sourced from the material generated by constructing the harbor access road. Anticipated dredging methods will be investigated further and refined in PED once the geotechnical site investigation is performed.

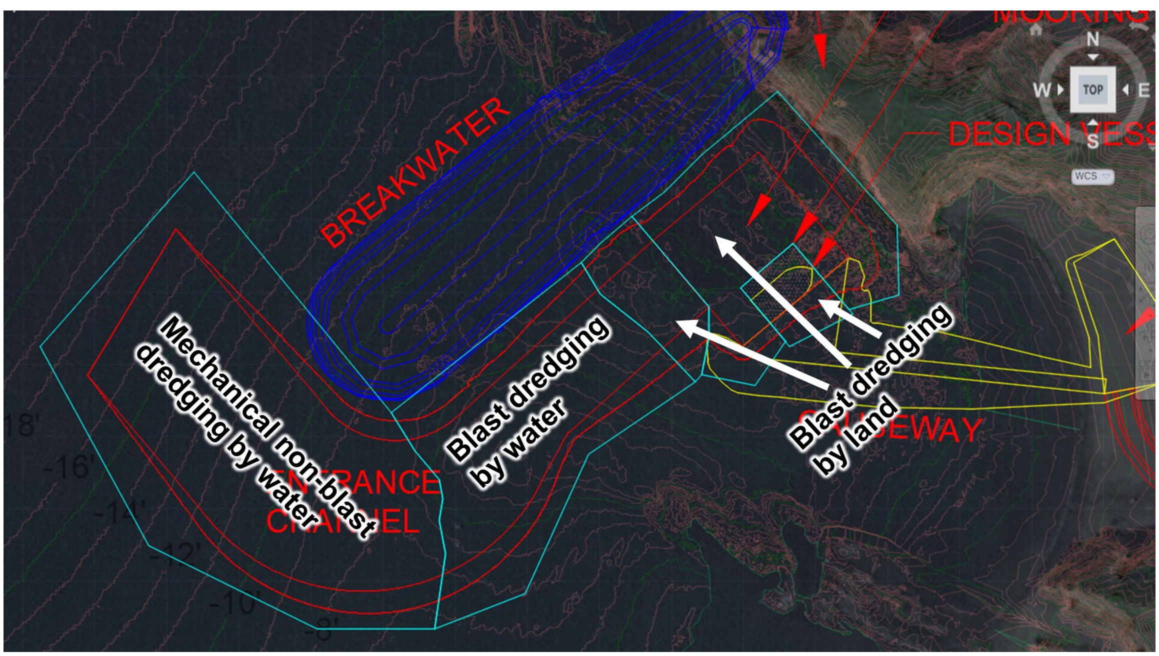


Figure 49: Anticipated Dredging Methods

4.6 Channel Navigation

4.6.1 Navigation Aids

As part of the construction of the project, concrete navigation marker bases would be constructed at locations determined by the U.S. Coast Guard, typically at the heads of the new breakwaters. Coordination with the U.S. Coast Guard Aids to Navigation Office will be conducted to ensure adequate base construction to support installation of navigational aids.

4.6.2 Allowable Wave Heights

The maximum wave height inside the harbor was estimated to be 3 feet or greater using STWAVE analysis and will be further refined during additional modeling efforts in PED. The ferry will return to Akutan small boat harbor after each trip to Akun as the Akun harbor is not a safe moorage harbor.

The crest height elevation of the breakwater is 15.5 feet MLLW and will begin to overtop with a significant wave height of 6 feet and MHHW tide of 3.7 feet. The ferry is not expected to be able to make the crossing through Akun Strait in conditions greater than those stated, so it is unlikely the ferry will encounter overtopping breakwater conditions at Akun harbor.

4.7 Local Service Facilities

For each of the three alternatives, it is assumed that the LSF would be constructed under the same contract for the Federal features of the project. LSF includes the non-Federal dredging at the mooring area, docks, mooring dolphins and bollards, and access roads. Upland staging and laydown areas are also LSF. The non-Federal dredging portions of the project are represented by the area adjacent to the proposed dock faces out to an offset distance of approximately one and a half vessel beams in width (40 feet) and one vessel length (60 feet). LSF design will be performed by an AE Contractor during PED. LSF are the sole responsibility of the Non-Federal Sponsor for construction, operation, and maintenance cost.

4.7.1 Access Road

The access road connecting the proposed harbor on Akun to the airport is 12 feet wide with 2-foot shoulders at an average grade of 8.5%. The road is designed to allow for 1-way vehicle or 2-way ATV traffic. This design was chosen to match the parameters of the Akutan road that is under construction from the Native Village of Akutan to the Akutan small boat harbor. Currently only one vehicle resides on Akun Island. If in the future more vehicles are utilized on Akutan and Akun islands, both roads would need to be widened.

The proposed harbor location is too shallow and rocky to receive barges, therefore the access road will be a haul route during construction for barges arriving at the former hovercraft pad. The LSF access road will be excavated at the same time as the breakwater is being built and material from excavation will be useable and used to build causeway, as well as building up a pad from which blasting will occur.

4.7.2 Causeway, Dock, and Uplands Pad

The elevation of the causeway, dock, and uplands pad is +8 feet MLLW (see section 2.11.4 RSLC for Local Service Facilities). Further analysis in PED may change the elevation of the LSF. Numerical and physical modeling in PED will help determine wave heights in the harbor during different scenarios, such as ferry operation and 0.2% AEP design event, which will inform design elevation. Adjustments to the ferry vessel in PED may require changes in elevation or design of the dock and causeway.

4.8 Dredge Material Placement

Material will be generated both from the road cut to access Alternatives 1 and 2, and the dredging of the entrance channel and turning basin for all alternatives. It is anticipated that the dredge material, especially blasted rock, will be of good quality and could be utilized by the sponsor. In which case an uplands placement area will be identified for dredge material storage rather than in water disposal. If in water disposal of dredge material is required, a preferred disposal area will be identified by the Environmental team based on biological productivity levels identified at each site.

5.0 SITE SELECTION

5.1 Features for All Alternatives

5.1.1 Akutan Facilities

Any facility upgrades necessary on Akutan Island will be the same for Alternatives 1 – 3. The sites considered were discussed in Section 5.5.1. At this time, it is assumed that the ferry vessel will moor in the Akutan Harbor when not in use. Before each ferry trip, the crew to pilot the ferry vessel would transit to the ferry at the Akutan Harbor using the road that has been funded and is currently in development. Two options exist for loading passengers and freight. Either the vessel and crew would travel back to the City Dock where passengers and freight will board the vessel, or passengers and freight would travel to the Akutan Harbor where loading would occur. The ferry will then travel to the proposed harbor on Akun and offload passengers and freight to meet a connecting flight on a fixed-wing aircraft. The ferry will travel back to either the City Dock or the Akutan Harbor with any passengers, freight, and crew from Akun Island. Once all runs for the day are completed, the ferry will be moored at the Akutan Harbor.

The existing depths at Akutan Harbor given in Table 29. The entrance channel and mooring basin depth of the 3 proposed harbor alternatives are -17 feet and -14 feet MLLW. The ferry vessel would be limited by the depths of the proposed harbor, not the existing Akutan Harbor.

Table 29: Existing Akutan Harbor Depths

Harbor Area	Depth (feet MLLW)
Entrance Channel	-18
Vessels > 150 ft	-18
Vessels 120-150 ft	-16
Vessels 20-120 ft	-14

Upgrades will need to be applied to the City Dock to accept the ferry vessel. At a minimum, the catwalk with mooring dolphins could be replaced to the appropriate elevation for easy boarding of the ferry vessel.

5.1.2 Akun Facilities

The facility upgrades on Akun will vary for each alternative based on the length of road needed to reach existing infrastructure.

5.1.3 Updated Design Features

5.2 Alternative 1

The harbor would be sized to accommodate a design vessel with a length of 58 feet and draft of 8 feet. The 715-foot-long rubble mound breakwater would protect a 120 foot by 120 foot turning basin. The entrance channel and turning basin dredge depths are -17 feet MLLW and -14 feet MLLW respectively. It is anticipated that blasting would not be required for the turning basin or entrance channel at this location. The entrance channel would vary from a minimum width of 60 feet to a maximum width of 120 feet.

Table 30: Alternative 1 Features

		Unit	Dimension
Breakwater	**Armor Stone Weight**	(tons)	10.5
	Armor Stone Thickness	(feet)	10.2
	Crest Height	(feet MLLW)	16.5
	Crest Width	(feet)	15.5
	Length	(feet)	715
Entrance Channel	**Width Straight**	(feet)	60
	Width Bend	(feet)	120
	Depth	(feet MLLW)	-17
Turning Basin	**Width**	(feet)	120
	Length	(feet)	120
	Depth	(feet MLLW)	-14
Quantities	**Armor Stone**	(cubic yards)	33,600
	Harbor Dredging	(cubic yards)	23,800
	Road Excavation	(cubic yards)	59,500

Local service facilities required would include a 560-foot-long by 12-foot-wide rubble mound causeway, sheet pile dock, 60-foot by 40-foot mooring basin with mooring dolphins, 7,000 square foot pad for loading/unloading freight, and a 1,100-foot-long road connecting the harbor areas with the existing hotel pad. The road would have an average grade of 9.4%. The road would consist of a 12-foot-wide surface with 6 inches of aggregate surface over 2 feet of borrow material. Two 6% grade shoulders would extend 2 feet from the edge of road. Two 2H:1V slope drainage ditches would extend from the shoulders before daylighting to existing ground at a 1.5H:1V slope.

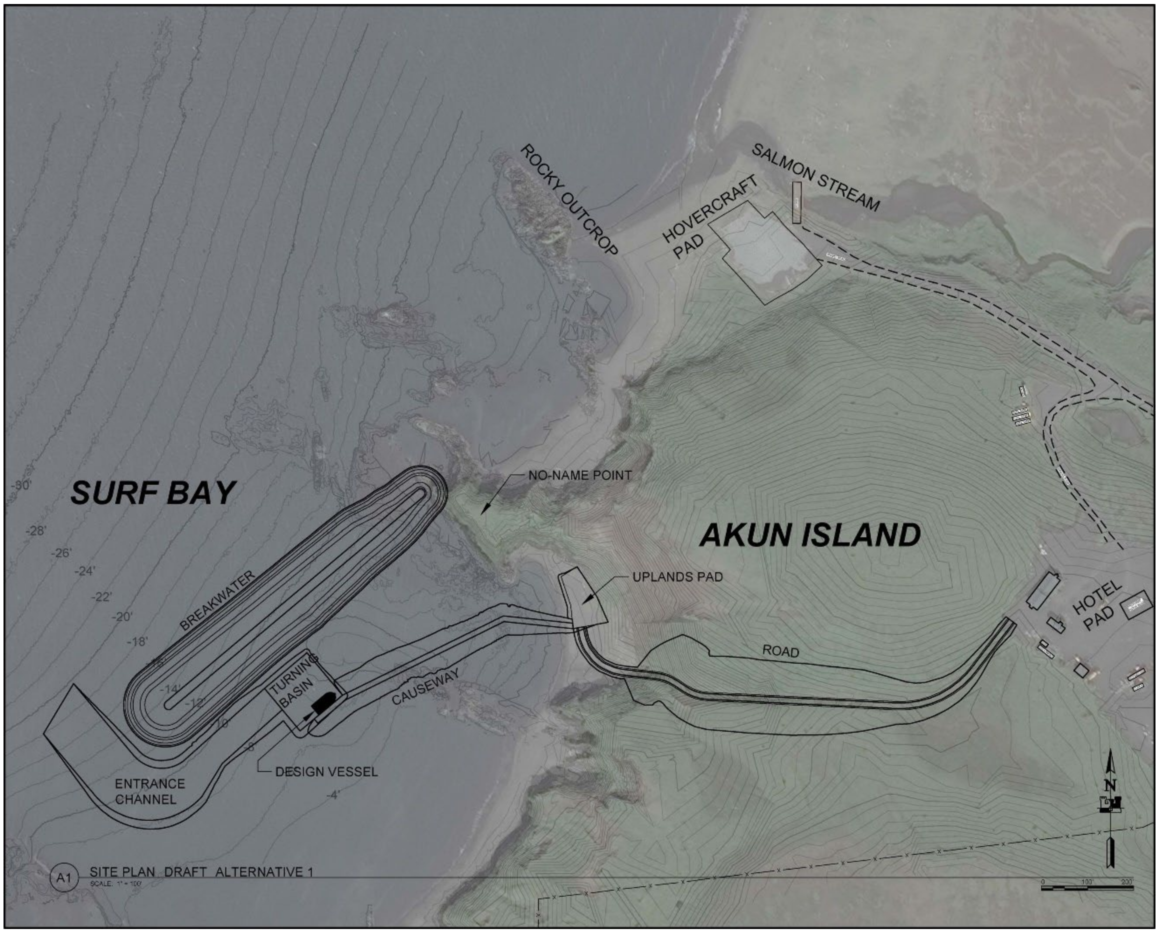


Figure 50: Alternative 1 Concept Plan

Alternative 1 explores the tradeoff of having the harbor located in deeper water to utilize soft material dredging equipment rather than blasting. The cost savings of avoiding blasting are not expected to outweigh having a larger breakwater with heavier armor stone and a longer dock to reach the mooring basin. Only a slight decrease in dredge quantity is realized by alternative 1 as it is located in a similar depth as the harbor in alternative 2.

Figure 51: Looking West From No-Name Point Towards Daryl's Point (Alternatives 1&2)

Figure 52: Looking East Towards Proposed Road Alignment Through Valley (Alternatives 1&2)

5.3 Alternative 2 (TSP)

The harbor would be sized to accommodate a design vessel with a length of 58 feet and draft of 8 feet. The 400-foot-long rubble mound breakwater would protect a 120-foot by 120-foot turning basin. The entrance channel and turning basin dredge depths are -17 feet MLLW and -14 feet MLLW respectively. It is anticipated that blasting would be required for the turning basin and entrance channel at this location. The entrance channel would vary from a minimum width of 60 feet to a maximum width of 120 feet.

Table 31: Alternative 2 Features

		Unit	Dimension
Breakwater	**Armor Stone Weight**	(tons)	6.5
	Armor Stone Thickness	(feet)	8.8
	Crest Height	(feet MLLW)	15.5
	Crest Width	(feet)	13.2
	Length	(feet)	400
Entrance Channel	**Width Straight**	(feet)	60
	Width Bend	(feet)	120
	Depth	(feet MLLW)	-17
Turning Basin	**Width**	(feet)	120
	Length	(feet)	120
	Depth	(feet MLLW)	-14
Quantities	**Armor Stone**	(cubic yards)	12,700
	Harbor Dredging	(cubic yards)	27,400
	Road Excavation	(cubic yards)	59,500

Local service facilities required would include a 560 foot long by 12-foot-wide rubble mound causeway, sheet pile dock, 60-foot by 40-foot mooring basin with mooring dolphins, 7,000 square foot pad for loading/unloading freight, and a 1,100-foot-long road connecting the harbor areas with the existing hotel pad. The road would have an average grade of 9.4%. The road would consist of a 12-foot-wide surface with 6 inches of aggregate surface over 2 feet of borrow material. Two 6% grade shoulders would extend 2 feet from the edge of road. Two 2H:1V slope drainage ditches would extend from the shoulders before daylighting to existing ground at a 1.5H:1V slope.

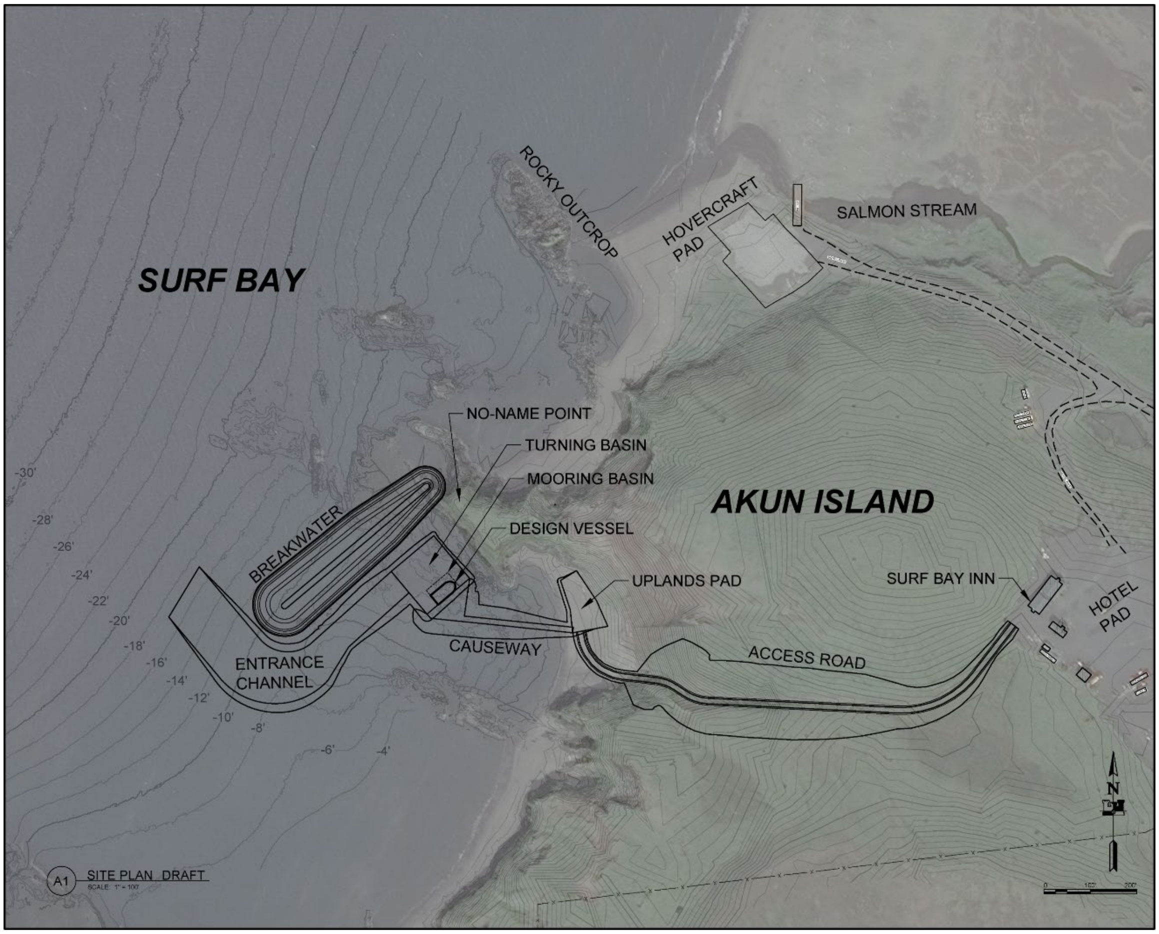


Figure 53: Alternative 2 Concept Plan

Alternative 2 attempts to optimize quantities of dredging for the entrance channel and turning basin by bringing them closer to shore than alternative 1. This also decreases both the length, height, and armor stone size required for the breakwater. Dock length also decreases as the mooring basin is located closer to shore. Road access is the same as alternative 1.

5.4 Alternative 3: Harbor Located North of No-name Point (with blasting)

The harbor would be sized to accommodate a design vessel with a length of 58 feet and draft of 8 feet. The 400-foot-long rubble mound breakwater would protect a 120-foot by 120-foot turning basin. The entrance channel and turning basin have a dredge depth of -17 feet MLLW and -14 feet MLLW respectively. It is anticipated that blasting would be required for the turning basin or entrance channel at this location. The entrance channel would have a minimum width of 60 feet to a maximum width of 120 feet when turning around the nose of the breakwater.

Table 32: Alternative 3 Features

		Unit	Dimension
Breakwater	Armor Stone Weight	(tons)	11.5
	Armor Stone Thickness	(feet)	10.6
	Crest Height	(feet MLLW)	17
	Crest Width	(feet)	16
	Length	(feet)	400
Entrance Channel	Width Straight	(feet)	60
	Width Bend	(feet)	120
	Depth	(feet MLLW)	-17
Turning Basin	Width	(feet)	120
	Length	(feet)	120
	Depth	(feet MLLW)	-14
Quantities	Armor Stone	(cubic yards)	14,700
	Harbor Dredging	(cubic yards)	23,000
	Road Excavation	(cubic yards)	600

The harbor would be sized to accommodate a design vessel with a length of 58 feet and draft of 8 feet. The 400-foot-long rubble mound breakwater would protect a 120-foot by 120-foot turning basin. The entrance channel and turning basin have a dredge depth of -17 feet MLLW and -14 feet MLLW respectively. It is anticipated that blasting would be required for the turning basin or entrance channel at this location. The entrance channel would have a minimum width of 60 feet to a maximum width of 120 feet when turning around the nose of the breakwater.

The shoreline along Alternative 3 is flanked by narrow headlands of volcanic rock (Golder, 2022). This provides some natural protection but will make dredging difficult as the rock extends under the water surface throughout the area.

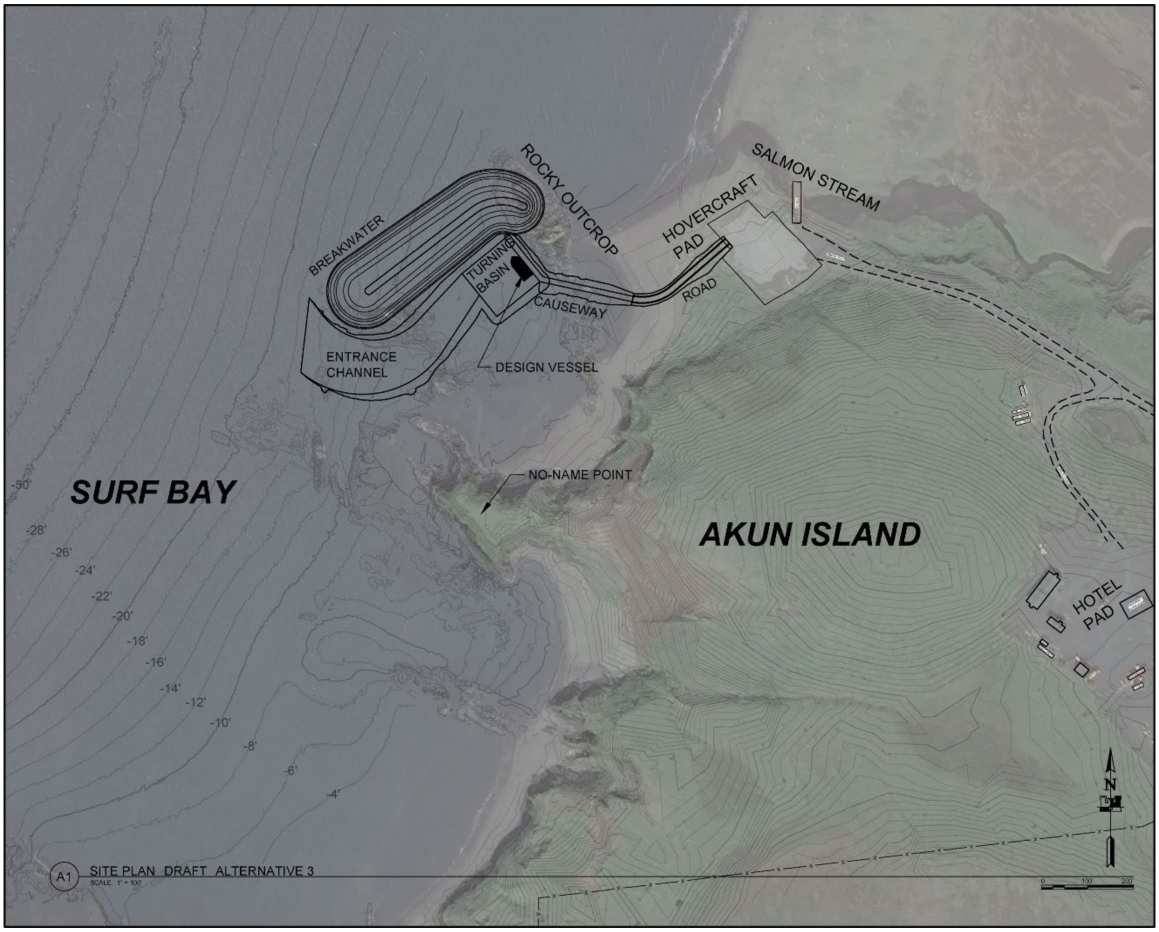


Figure 54: Alternative 3 Concept Plan

Local service facilities required would include a 320 foot long by 12 foot wide rubble mound causeway, 60 foot by 40 foot mooring basin with mooring dolphins, and a 250 foot long road connecting the harbor areas with the existing hovercraft pad. The existing hovercraft pad would function as an area for loading/unloading freight. The road would have an average grade of 3.3%. The road would consist of a 12 foot wide surface with 6 inches of aggregate surface over 2 feet of borrow material. Two 6% grade shoulders would extend 2 feet from the edge of road. Two 2H:1V slope drainage ditches would extend from the shoulders before daylighting to existing ground at a 1.5H:1V slope.

Figure 55: Looking North From No-Name Point Towards Rocky Outcrop (Alternative 3)

6.0 CHANNEL MAINTENANCE

The non-Federal operator of the harbor would be responsible for operation and maintenance of the completed mooring areas and local service facilities portion of the project. The Federal Government would be responsible for maintenance of the breakwaters, entrance channels and maneuvering basin portions of the project. The Alaska District, U.S. Army Corps of Engineers would visit the site(s) periodically to inspect the breakwaters and perform hydrographic surveys at 3- to 5-year intervals for the dredged areas. The hydrographic surveys would be used to verify whether the predicted maintenance dredging was warranted for the entrance channel and maneuvering areas. Maintenance requirements for breakwaters would be determined from the surveys and inspections. Local and Federal dredging requirements, if necessary, would probably be combined, so there would be only a single mobilization and demobilization cost.

The breakwaters were designed to be stable for the 2% AEP predicted wave conditions and no significant loss of stone from the rubble mound structures is expected over the life of the project. Stone quality is strictly specified in construction contracts to control stone degradation. However, it is anticipated that up to 5 percent of the armor stone could need to be replaced every 25 years. This results in an average of 1,300 cubic yards of Armor Rock required for replacement for the three alternatives at year 25.

Maintenance dredging would be conducted on an estimated 10-year cycle. The entrance channel and turning basin would require dredging of approximately 3,200 cubic yards. A dredged material management plan would be developed for the project in which a long-term disposal option would be identified. For purposes of this study, it is assumed that the entrance channel and maneuvering area material would be disposed of in the offshore. Clamshell bucket dredging equipment with a scow barge would likely be used for maintenance dredging. Dredged material characteristics should be easier to remove than construction dredging of the area and no blasting would be required for maintenance.

7.0 RISK AND UNCERTAINTY

7.1 Construction Considerations

Construction is expected to be phased over 3 years of 6-month construction seasons. In-water work will likely occur during the summer due to frequent winter storms. The type of dredge equipment used to perform the work will not be specified in the contract. It is anticipated that the bidders on the project will have experience blasting since it will likely be used in this project, although the government will not require blasting so long as the contractor provides a plan to remove the hard material using mechanical means. To attract a number of bidders, it is recommended that the project be advertised early to interest dredging contractors in bidding on this project. The work season length, wave climate, remote site location, and hard material removal are just some of the conditions that a contractor would need to consider when proposing on this contract.

7.2 Future Work to be Completed in PED

To more accurately determine the amount of blasting required for the selected plan, borings are required to ground-truth the geophysical investigation that was performed during the Feasibility Study. Once the geophysical investigation is complete, the harbor footprint may be shifted to minimize blasting quantities.

An integrated numerical model such as ERDC Coastal Modeling System (CMS) coupled with ADCIRC will be required in PED in order to determine a more accurate design wave, currents at the toe of the structure for scour analysis, and currents inside the harbor for sediment transport analysis to better define maintenance dredging. A flume study will need to be performed to verify breakwater armor stone stability. Since the breakwater is designed as overtopping, a flume study is particularly important for the lee side (rear slope) armor stone stability as most armor layer testing has been performed for seaward size armor stone. Lastly, a physical model will also be performed to verify currents along the toe of the breakwater structure for scour analysis and to verify wave climate and resonance within the harbor.

7.3 Resiliency

ECB-2018-2 describes resilience principles to be implemented in the engineering and construction community of practice (USACE, Implementation of Resilience Principles in the Engineering & Construction Community of Practice, 2018). Wind, wave, and currents in and around Akun are not anticipated to change in the 50-year project life. The anticipated changing condition at the site is RSLC. Harbor entrance channel, mooring, and turning basins include an additional one foot of depth at construction RSLC. Conversely, the armor stone size and breakwater length and crest height are designed for the worst-case RSLC high scenario. These design conditions are to ensure resiliency in the face of uncertain RSLC scenarios.

REFERENCES

(AFSC), A. F. (2021, 8 30). *Alaska Longline Survey Data Map*. Retrieved from NOAA Fisheries: https://www.fisheries.noaa.gov/resource/map/alaska-longline-survey-data-map

“LICENCIAS”, D. “. (2013). *“PIPER NAVAJO PA-31-310” “CC–AJB”.* Dirección General de Aeronáutica Civil.

ABSI. (2015). *Aleutian and Bering Sea Islands Landscape Conservation Cooperative: Strategic Science Plan Appendicies B-H.* Landscape Conservation Cooperative Network.

AEB. (2012). *Grant Aviation Provides Scheduled Air Service to Akutan Airport.* Anchorage: Aleutians East Borough.

AFDF. (2019). *Social Responsibility Onboard Commercial Fishing Vessels in Alaska.* Alaska Fisheries Development Foundation, Inc.

Akinturk, A., Cumming, D., & Bass, D. (2007). *Mapping motion responses for the Newfoundland fishing fleet.* St. John's: NRC Publications Archive.

Alton Bay Design, L. (2015). *Conceptual Vessel Study for Akun Airport Transportation.* Alton Bay: Schrider, Michael L.

Buurman, H., Nye, C. J., West, M. E., & Cameron, C. (2014). *Regional controls on volcano seismicity along the Aleutian arc.* Geochemistry, Geophysics, Geosystems.

Carlowicz, M. (2015, August 4). *El Niño conditions are growing stronger*. Retrieved from NASA Global Climate Change Vitals Signs of the Planet: https://climate.nasa.gov/news/2319/el-nino-conditions-are-growing-stronger/

Center, W. R. (2023). *Cold Bay, Alaska*. Retrieved from Western Regional Climate Center: https://wrcc.dri.edu/cgi-bin/clilcd.pl?ak25624

Co., P. M., & ERE Systems, L. (1981). *Petroleum Development Scenarios Transportation Systems Analaysis.* Alaska OCS Socioeconomic Studies Program.

Crescere Marine Engineering, I. (2012). *Akutan Monohull Ferry Seakeeping Study Appendix A, Seakeeping Data.* Columbia City: Celano, Tullio III P.E.

D'Oro, R. (2013). *Grant Aviation begins service to Akutan airport.* Fairbanks: The Associated Press Fairbanks Daily News-Miner.

Drewes, H., Fraser, G. D., Snyder, G. L., & Barnett Jr., H. F. (1961). *Geology of Unalaska Island and Adjacenet Insular Shelf, Aleutian Islands, Alaska.* Washington D.C.: U.S. Department of the Interior.

Eling, D. (2023). *Ferry Notional Sizing, Acquisition Cost, and Recurring Annual Costs Estimates.* Bristol: Bristol Harbor Group.

EPA. (2023, August 16). *United States Environmental Protection Agency*. Retrieved from Climate Change Indicators in the United States: https://www.epa.gov/climate-indicators

FAA. (2023, 10 25). *Instrument Approach Procedure (IAP) Charts: AKUTAN (7AK)(PAUT)*. Retrieved from SkyVector: https://skyvector.com/airport/7AK/Akutan-Airport

Golder. (2022). *Geophyiscal Survey Report Akutan Harbor Navigation Improvements.* Golder Associates USA Inc.

Gray, S., Berman, M., Eerkes-Medrano, L., Hennessy, T., Huntington, H., Littell, J., . . . Trainor, S. (2018). *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II [.* Washington, D.C.: U.S. Global Change Research Program.

Hamlington, B., Strassburg, M., Leben, R., Han, W., Nerem, R., & Kim, K.-Y. (2014). *Uncovering an anthropogenic sea-level rise signal in the Pacific Ocean.* Nature Climate Change.

Hesser, D. T. (2018). Wave Information Studies. Vicksburg, MS, USA.

J.R. Riehle, M. F. (1996). *Digital Shaded-Relief Image of Alaska.* Washington, D.C.: U.S. Department of the Interior.

Jensen, R. (2022). *Akun-Akutan Island Study: Wind and Wave Estimates used for Ferry Operation and Planning Desing of New Harbor on Akun Island.* CEERD-HFC.

Johnson, L. (2012). *Akutan Airport: Good News for Trident Seafoods – Long-term Benefits for Alaska?* Seattle: Stacy & Jacobsen, PLCC.

Joyce, S. (2013). *Hovercraft Running, Despite Challenges.* Unalaska: KUCB.

Miller, D. L., Phillips, W. T., & Wilson, S. Y. (2005). *Geotechnical Exploration Akutan Airport Master Plan.* Anchorage: Duane Miller & Associates.

NASA. (2023, August 17). *Dueling climate cycles may increase sea level swings*. Retrieved from Global Climate Change: https://climate.nasa.gov/news/2414/dueling-climate-cycles-may-increase-sea-level-swings/

NASA. (2023, August 18). *GNSS Time Series*. Retrieved from NASA Jet Propulsion Laboratory California Institute of Technology: https://sideshow.jpl.nasa.gov/post/series.html

NAVFAC. (2013). *Preliminary Assessment Report for Naval Defense Sea Area: Unalaska Island.* Silverdale: Naval Facilities Engineering Command Northwest.

NOAA. (1977). *United States Coast Pilot 9, Pacific and Arctic Coasts: Alaska, Cape Spencer to Beaufort Sea.* Washington, D.C.: U.S. Department of Commerce.

NOAA. (2022). *U.S. Coast Pilot 9, Alaska: Cape Spencer to Beaufort Sea.* Washington, D.C.: NOAA.

NOAA. (2023, 06 13). *Tides & Currents*. Retrieved from Annual Exceedance Probability Curves 9462620 Unalaska, AK: https://tidesandcurrents.noaa.gov/est/curves.shtml?stnid=9462620

NWS, N. W. (2023). *Beaufort Scale*. Retrieved from Estimating Wind Speed and Sea State: https://www.weather.gov/pqr/beaufort

Paek, H., Yu, J.-Y., & Qian, C. (2017). *Why were the 2015/2016 and 1997/1998 extreme El Niños different?* Geophysical Research Letters.

Pan, F. a. (1999). Gap Winds and Wakes: SAR Observations and Numerical Simulations. *J. Atm. Sciences*, pp. Vol. 56, No. 7, 905-923.

Peterson, M. (2003). *Hydraulic Design: Navigation Improvements Akutan, Alaska.* Anchorage: USACE.

PIANC. (2014). *Harbour Approach Channels Design Guidelines.* Brussels: The World Association for Waterborne Transport Infrastructure.

Sepez, J., Package, C., Malcolm, P. E., & Poole, A. (2007, December 20). Unalaska, Alaska: Memory and Denial in the Globalization of the Aleutian Landscape. *Polar Geography*, pp. 193-209.

Survey, U. C. (2017, September 26). *Historical Map & Chart Collection*. Retrieved from https://historicalcharts.noaa.gov/historicals/preview/image/9008-9-1937

The Glosten Associates, I. (12 March 2009). *Technical Memorandum: Akun Island to Akutan Island, Alaska Feasibility-Level Ferry Terminal Engineering Design.* Edmonds: Coast & Harbor Engineering.

The Glosten Associates, I. (24 February 2009). *Conventional Vessel Service from Akutan Island to Surf Bay Initial Feasibility Assessment Report – Phase II, Rev. A.* Seattle: The Glosten Associates, Inc.

United States Army Corps of Engineers. (2002, April 30). Coastal Engineering Manual. *(EM 1110-2-1100)*. Department of Army.

USACE. (2008). *Coastal Engineering Manual.* Washington, DC: EM 1110-2-1100.

USACE. (2015). *Recent US Climate Change and Hydrology Literature Applicable to US Army Corps of Engineers Missions.* Washington, D.C.: USACE Climate Preparedness and Resilience.

USACE. (2018). *Implementation of Resilience Principles in the Engineering & Construction Community of Practice.* ECB-2018-02.

USGS. (2011). *History of Earthquakes and Tsunamis Along the Eastern Aleutian-Alaska Megathrust, with Implications for Tsunami Hazards in the California Continental Borderland.* Washington, D.C.: USGS.

USGS. (2016). *New Geological Evidence Aids Tsunami Hazard Assessments from Alaska to Hawaii.* Reston: USGS.

Van der Meer, J. W. (2018). *Manual on wave overtopping of sea defenses and related structures. An overtopping manual largely based on European research, but for worldwide application.* EurOtop.

Wendler, G. C. (2014, August). Recent Sea Ice Increase and Temperature Decrease in the Bering Sea Area, Alaska. *Theoretical and Applied Climatology*, pp. 393-398.

Witherell, D., Fey, M., & Fina, M. (2012). *Fishing Fleet Profiles.* Anchorage: North Pacific Fishery Management Council.

Woods Hole Oceanographic Institution. (2023, August 17). Retrieved from El Niño & Other Oscillations: https://www.whoi.edu/know-your-ocean/ocean-topics/how-the-ocean-works/ocean-circulation/el-nio-other-oscillations/

WRCC. (2023). *DUTCH HARBOR, ALASKA (502587)*. Retrieved from Western Regional Climate Center: https://wrcc.dri.edu/cgi-bin/cliMAIN.pl?ak2587

Wuebbles, D. J., Fahey, D. W., Hibbard, K. A., Dokken, D. K., Stewart, B. C., & Maycock, T. K. (2017). *Climate Science Special Report: Fourth National Climate Assessment, Volume I.* Washington, D.C.: U.S. Global Change Research Program.

Zautner, J. (2017). *Extreme Value Analysis.* 14th Weather Squadron.