ENGINEERS, INC.

MEMORANDUM

To: Ken Nichols, P.E.
DOWL Engineers

Date: May 22, 2020
Project No: 192082

From: Alexander Khokhlov, PND Engineers
Subject: Sitka Seaplane Base – Metocean Conditions and Numerical Wave Model Study

This memo analyzes metocean (meteorological and oceanographic) criteria and provides numerical modeling results for the proposed Seaplane Base on the northern shore of Japonski Island in Sitka, Alaska. Included is an analysis of wind, wave and water elevation from measured and hindcast data. Desktop calculations and MIKE 21 numerical models have been applied to estimate the design wave conditions at the project site. The main purpose of this study was to identify the design environmental conditions (i.e., waves and water levels) that could have an impact on the design of the marine facilities.

Two proposed seaplane float and seaplane slip concepts have been evaluated. The initial concept (without wave attenuator) consists of a seaplane float, transient/loading drive down float and drive down gangway is presented in the Figure 2. An additional T-Dock concept with attached wave attenuator were analyzed in the latter stage of the study to estimate potential wave conditions at the project site and behind/around the proposed wave attenuator. This additional concept and numerical modeling results are presented in Appendix A at the end of this memo. The proposed marine structures are exposed to waves generated along relatively long fetch distances to the north, northwest, and southeast. The proposed drive-down ramp could be exposed to a large wave generated in Sitka Sound, penetrating through the gap between the south breakwater and Japonski Island at high tide. These waves can reach the project site on a straight-line fetch, as shown in Figure 1. Long-period swell waves from the west and southwest (Gulf of Alaska) and locally generated waves from the north can reach the proposed facility through the gaps in the breakwater but only by diffracting and refracting around headlands and islands.

This memo describes a numerical (computer) wave model study for the waves penetrating to the project site. Included is a description of the model setup, input conditions, analysis of the output, and interpretations. Locally generated wind waves were calculated using wave growth formulae included in the U.S. Army Corps of Engineers (USACE) Shore Protection Manual (USACE, 1984) and Coastal Engineering Manual (USACE, 2005).

PREVIOUS WAVE STUDY

USACE conducted several physical model studies of Sitka Harbor and entrances to establish the cause for wave action within the CBS inner harbors and to investigate potential engineering alternatives to reduce wave action to acceptable levels. A total of 179 tests were conducted in the Sitka physical model during four time periods between the completion of the model in September 2005 and February 2007.

The USACE physical model experiment shows excessive sensitivity to the wave period tested – almost 50% difference of wave height is recorded for 10- and 12-second waves, which suggests there could be an error in the physical modeling itself or the model result interpretations.

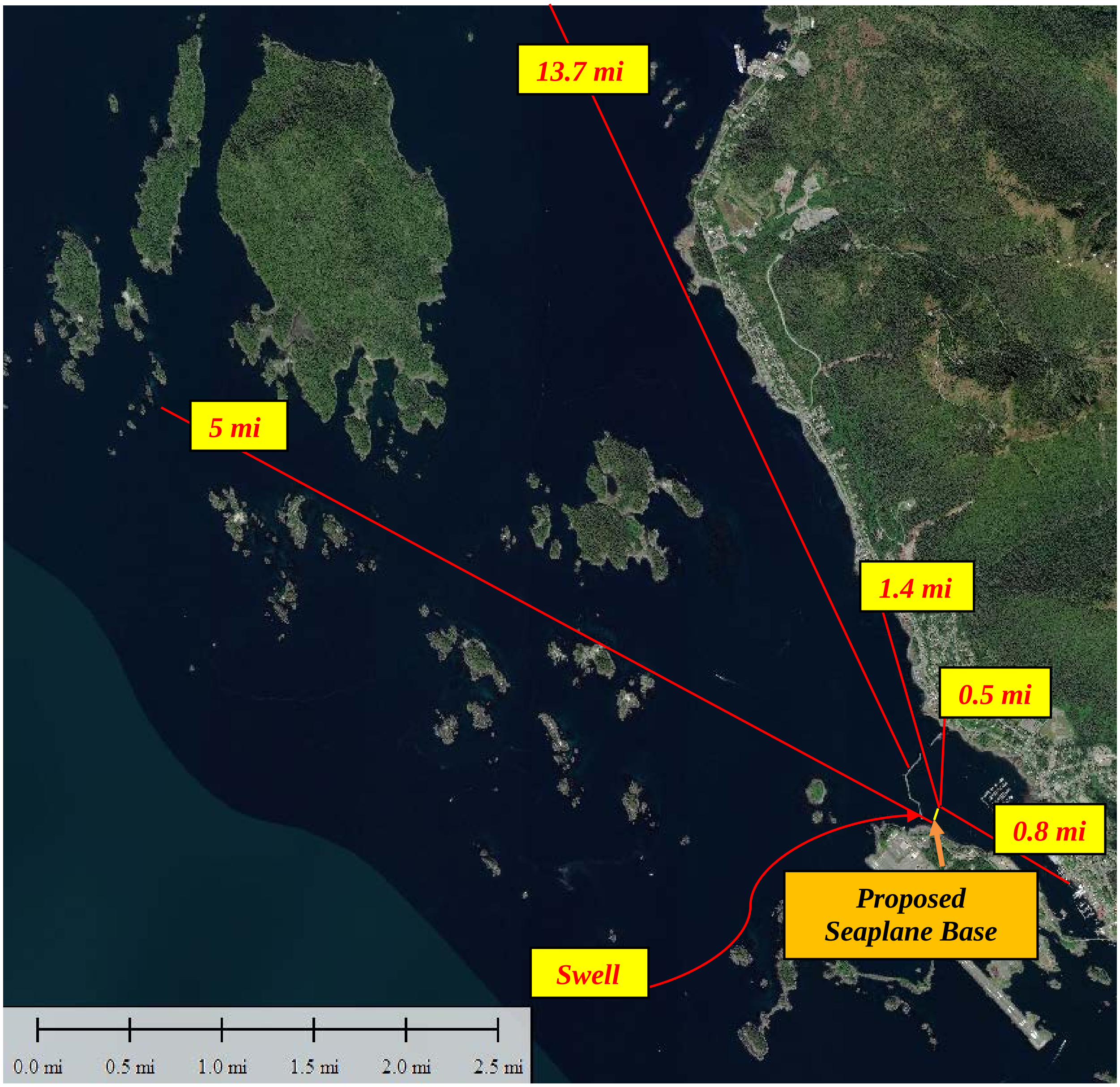

Figure 1. Sitka Area Map and Wave Directions

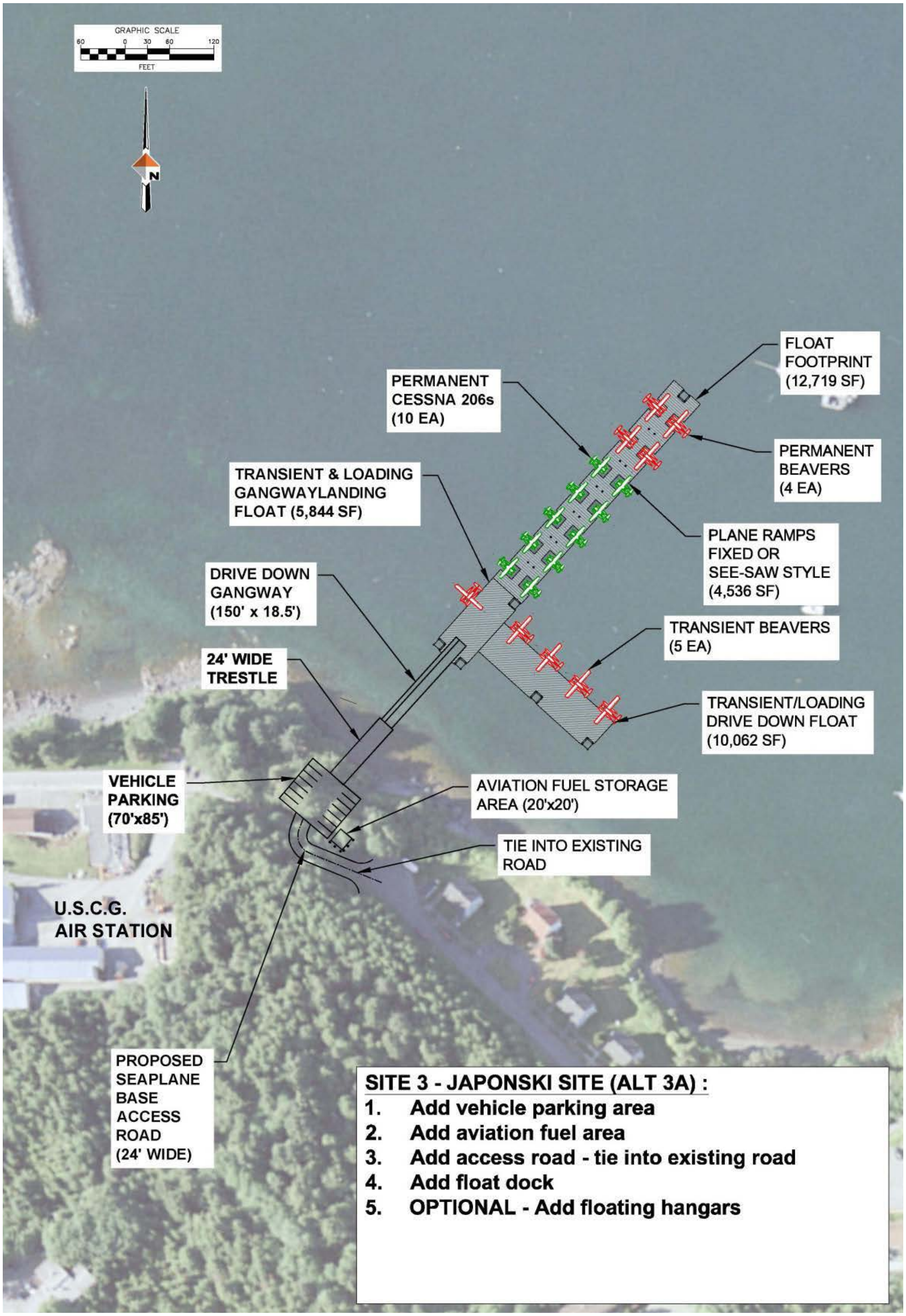

Figure 2. Proposed Seaplane Floating Dock Concept

TIDES AND WATER LEVELS

Tide and water level data are available from a National Oceanic and Atmospheric Administration (NOAA) tide station in Sitka (Station 9451600). Tidal datums at Sitka tide station are based on tidal epoch 1983-2001. Table 1 shows tidal datum information for the Sitka station.

The highest recorded tide in Sitka occurred on November 2, 1948, elevation +14.9 feet. The lowest observed water level of -4.1 feet was recorded on December 14, 2008. Tide elevations have been recorded in Sitka since 1924 and show a net falling sea level at a rate of -2.4 mm (0.09 inch) per year, with a 95% confidence interval of +/- 0.27 mm/year. This is equivalent to a change of -0.79 feet in 100 years (NOAA, 2019), as shown in Figure 3. The plot shows the monthly mean sea level without the regular seasonal fluctuations due to coastal ocean temperatures, salinities, winds, atmospheric pressures, and ocean currents. The Alaska coast has experienced variable sea level trends. The relative sea level is rising in some parts of Alaska, and falling in other areas based on analysis of NOAA tide gauge data. Relative sea level fall in Sitka is due to Glacial Isostatic Adjustment (GIA) related uplift from the last ice age, as well as more recent uplift due to glacier retreat over the last several decades and the averaged effects of tectonics over the observational record. For an assumed project design life of 50 years, it may be appropriate to design for a potential decrease in sea level of 0.5 feet.

The immediate recommended design high water elevation for Sitka is +15.0 feet mean lower low water (MLLW). The recommended design low water is -4.0 feet MLLW.

Table 1. Tidal Datum Information – Sitka Tide Station 9451600

Water Levels	Elevation (feet, MLLW)
Highest recorded water level (11/2/1948)	14.9
Mean Higher High Water (MHHW)	9.9
Mean High Water (MHW)	9.2
Mean Sea Level (MSL)	5.3
Mean Tide Level (MTL)	5.3
Mean Low Water (MLW)	1.5
Mean Lower Low Water (MLLW)	0.0
Lowest recorded water level (12/14/2008)	-4.1

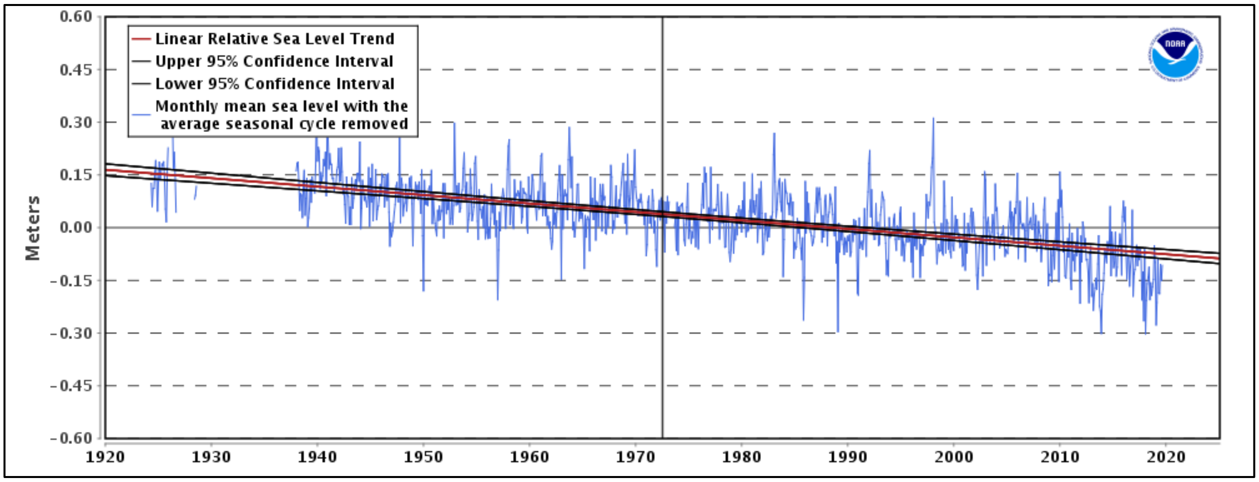

Figure 3. Sea Level Rise Trend – Sitka

WIND

Measured wind data are available from a number of sites in the region. The following organizations maintain the weather stations and buoys where the data was collected:

1. National Oceanic and Atmospheric Administration (NOAA)
2. National Data Buoy Center (NDBC)
3. United States Air Force (USAF)
4. National Climatic Data Center (NCDC)

Table 2 summarizes the data available from nearby stations. The wind data are 2-minute average wind speeds for land stations and 8-minute averages for offshore buoys. Wind direction is defined as the direction from which winds are traveling. The station locations and the corresponding wind roses are shown in Figure 4. The highest recorded wind speed was a westerly 64 knots at the Sitka Airport station.

Table 2. Wind Data Summary

No.	Site	Distance from Site (miles)	Start-End Years	No. of Years*	Max Wind Speed (knots)
1	Sitka Airport	0.7	1948-2019	71	64
2	Sitka Harbor – SHXA2	0.5	2017-2019	1.5	29
3	Sitka AML – STXA2	4.2	2017-2019	1.5	25

*Number of years of data with gaps removed

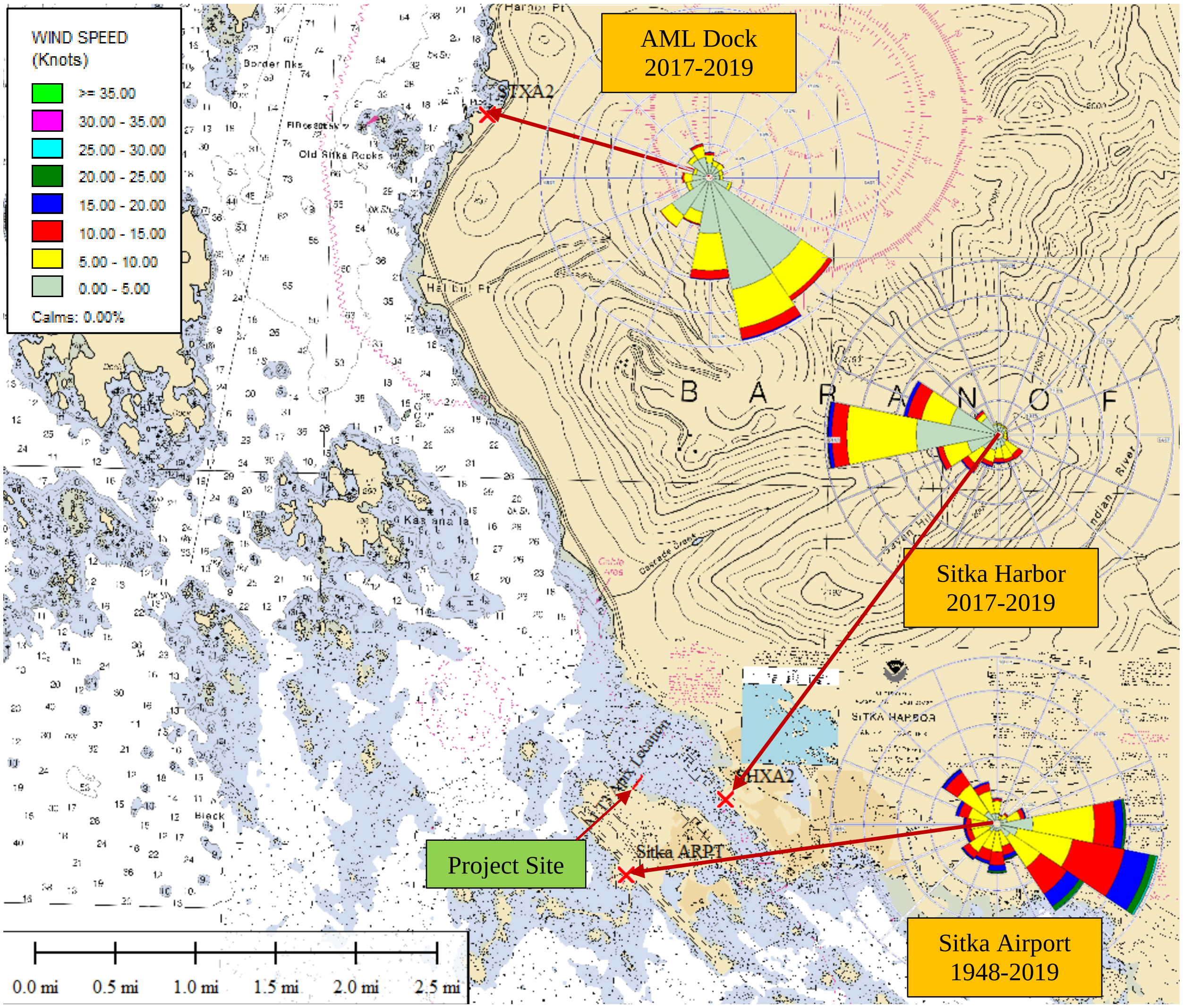

Figure 4. Sitka Wind Rose Comparison

The wind roses show that the wind distribution is highly variable and appears to be strongly influenced by the local topography. Winds from the southeast and northwest are prevailing at the Airport station.

Wind data from the Sitka Airport station was selected for extremal wind analysis due to its location and data availability. Given the length of wind record for the Sitka Airport station (71 years), the return-period statistics are reliable up to 180 years. The data from the AML Dock station (1.5 years) and Sitka Harbor station (1.5 years) are not long enough for estimating 100-year return-period wind speeds reliably.

Table 3 shows the 10 largest wind speeds from all directions measured at the Sitka Airport station.

Table 3. Largest Recorded Annual Wind Speeds – All Directions

Rank	Sitka Airport (1948-2019)		
	Date	Speed (knots)	Dir (deg)
1	11/2/1948	64.1	135
2	11/30/1990	60.1	20
3	7/16/1981	59.9	10
4	10/24/1980	58.9	100
5	10/29/1983	57.0	20
6	8/12/1975	56.0	30
7	11/12/1987	55.0	180
8	3/27/1988	55.0	250
9	5/16/1984	54.0	N/A
10	1/27/1989	54.0	290

The analysis of wind speeds in this report focuses on the extremes. The top 200 winds for all years were used to calculate the 2-year, 10-year, 50-year, and 100-year return wind speeds. These wind speeds were then used to predict the wave environment at the site. The extremal analysis was carried out according to the Automated Coastal Engineering System (ACES) technical reference.

Table 4 shows the ranked wind speeds for Sitka Airport filtered by fetch directions. The return period wind speeds are summarized in Table 5.

The estimated 100-year return period wind speed is 59 knots for winds from the north, 67 knots for winds from the east-southeast, and 57 knots for winds from the west-northwest.

Table 4. Largest Recorded Wind Speeds – Filtered by Fetch Direction (Sitka Airport Station)

Rank	North (330°-30°)			East-Southeast (90°-150°)			West-Northwest (270°-330°)		
	Date	Speed knots	Dir deg	Date	Speed knots	Dir deg	Date	Speed knots	Dir deg
1	11/30/1990	60.1	20	11/2/1948	64.1	135	1/27/1989	54.0	290
2	7/16/1981	59.9	10	10/24/1980	58.9	100	8/2/1978	50.9	280
3	10/29/1983	57.0	20	6/19/1983	53.8	110	7/17/1979	50.9	290
4	8/12/1975	56.0	30	5/25/1996	52.9	130	5/2/1979	50.0	270
5	12/27/1994	51.9	20	2/8/1979	50.0	120	8/8/1981	50.0	290
6	2/20/1982	50.9	30	4/2/1979	50.0	150	6/22/1970	49.0	320
7	12/2/1983	50.9	10	3/20/1981	50.0	120	8/13/1991	41.0	270
8	6/26/1984	45.1	10	9/30/1992	50.0	140	10/25/2008	40.0	300
9	2/28/1954	36.0	338	12/7/1955	48.0	113	11/12/2011	40.0	280
10	1/4/1973	31.9	10	3/10/1956	48.0	135	11/10/1955	35.0	315

Table 5. Return Period Wind Speed Analysis Summary

Direction	Sitka Airport			
	2-yr Wind Speed (knots)	10-yr Wind Speed (knots)	50-yr Wind Speed (knots)	100-yr Wind Speed (knots)
All Directions	44	56	70	77
North (330°-30°)	26	38	53	59
East-Southeast (90°-150°)	38	49	61	67
West-Northwest (270°-330°)	29	39	51	57

WAVES

The only reliable measured wave data are available from the NOAA offshore buoy 46084, located 41 miles southwest of the project site. Offshore wave information is also available from a numerical model hindcast study at points offshore of Alaska (USACE, 2019).

The MIKE 21 wave numerical model was applied to predict the wave environment near the project site. The inputs for the wave models included the 100-year return period, wind and offshore waves, and existing water depths from recent nearshore bathymetric surveys (DOWL 2020) and NOAA offshore survey data. A simplified wave hindcast calculation using measured wind data was also used to estimate waves at the project site and is discussed in the following sections. Note that tsunami effects in the area are significant and are beyond the scope of this study.

Measured Wave Data

Directional measured wave data are available from NOAA Buoy 46084 from 2002 to 2019 (NDBC, 2019), approximately 41 miles southwest from the project site. The wave data extremes were analyzed to determine the wave height associated with a return period event. Table 6 shows the 10 largest wave heights and periods measured from the offshore buoy. Wave data from Buoy 46084 were selected for extremal wave analysis. This information was used as the boundary condition for the MIKE 21 model to evaluate large wave storms propagating from the Gulf of Alaska inside Sitka Sound.

Table 7 shows the results of the extremal analysis. The estimated 100-year return period significant wave height is approximately 55 feet at the NOAA Buoy 46084.

Table 6. Largest Recorded Wave Heights – All Directions – Buoy 46084

Rank	Buoy 46084		
	Date	Wave Height (feet)	Wave Period (seconds)
1	3/29/2004	46.1	17
2	12/16/2004	40.6	14
3	12/29/2006	39.3	17
4	11/12/2011	38.4	15
5	12/20/2006	37.5	14
6	2/6/2006	34.8	14
7	12/2/2016	34.2	16
8	12/18/2006	34.0	17
9	1/1/2008	33.6	14
10	11/1/2010	33.1	12

Table 7. Return Period Significant Wave Height (Hs), Non-Directional

Return period	Buoy 46084
	Hs (feet)
2 years	34
10 years	41
50 years	50
100 years	55

<u>Offshore Waves – Wave Information Study (WIS)</u>

Offshore wave information is available from a numerical model hindcast study at points offshore of Alaska (USACE, 2019).

The wave rose for WIS Station 81039, 58 miles southwest from the proposed site, is presented in Figure 5. It shows the dominant wave direction is from the southwest. Figure 6 shows analysis of return period wave heights at Station 81039 with associated peak period and direction tabulated for the 10 largest events during the 32-year hindcast. The 100-year return period significant wave height offshore is estimated to be about Hs = 41 feet (12.5 meters). A peak wave period of Tp = 15 to 18 seconds is a reasonable assumption for the 100-year return wave period.

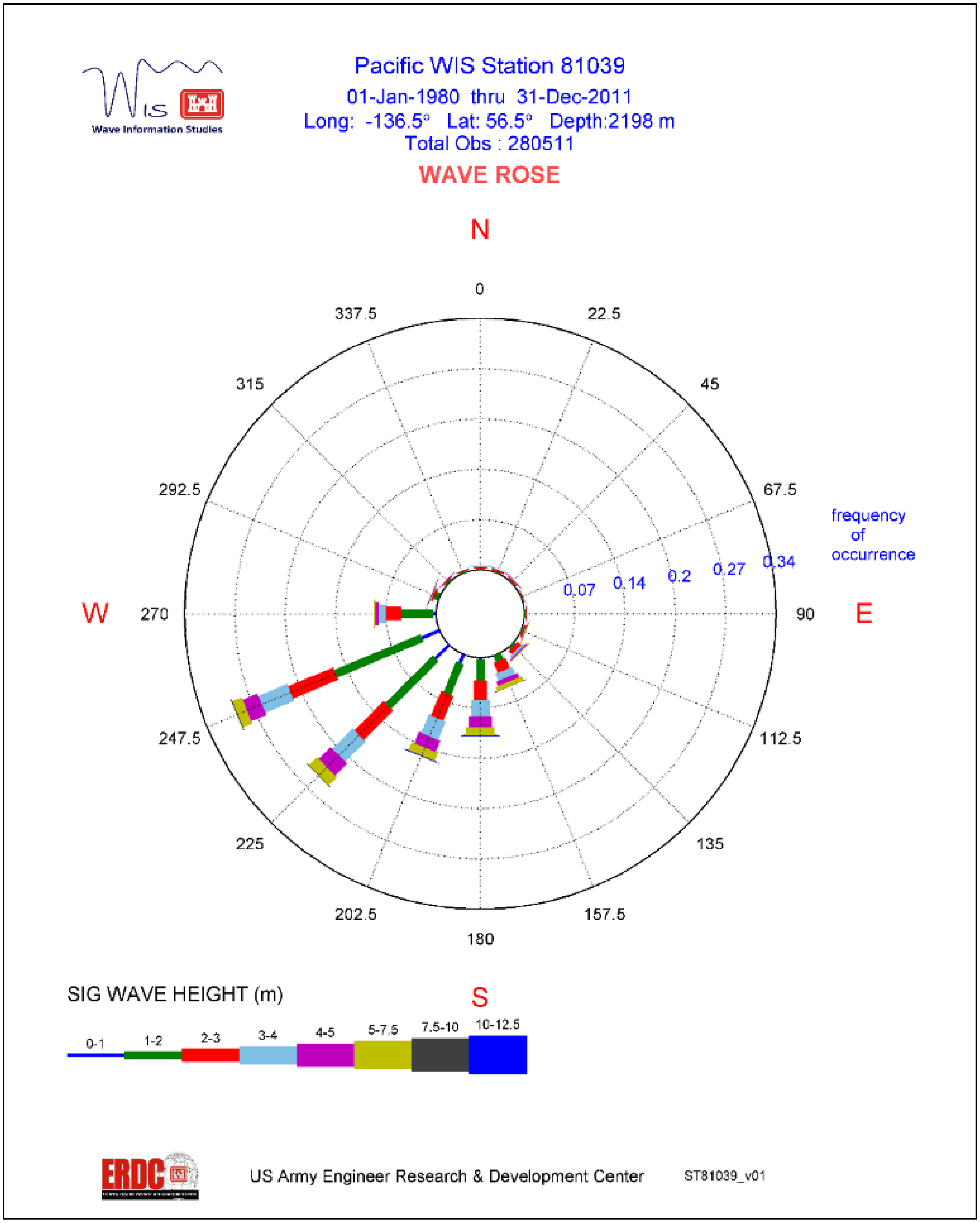

Figure 5. Wave Rose – WIS Station 81039, 58 Miles Southwest from Proposed Site (USACE, 2019)

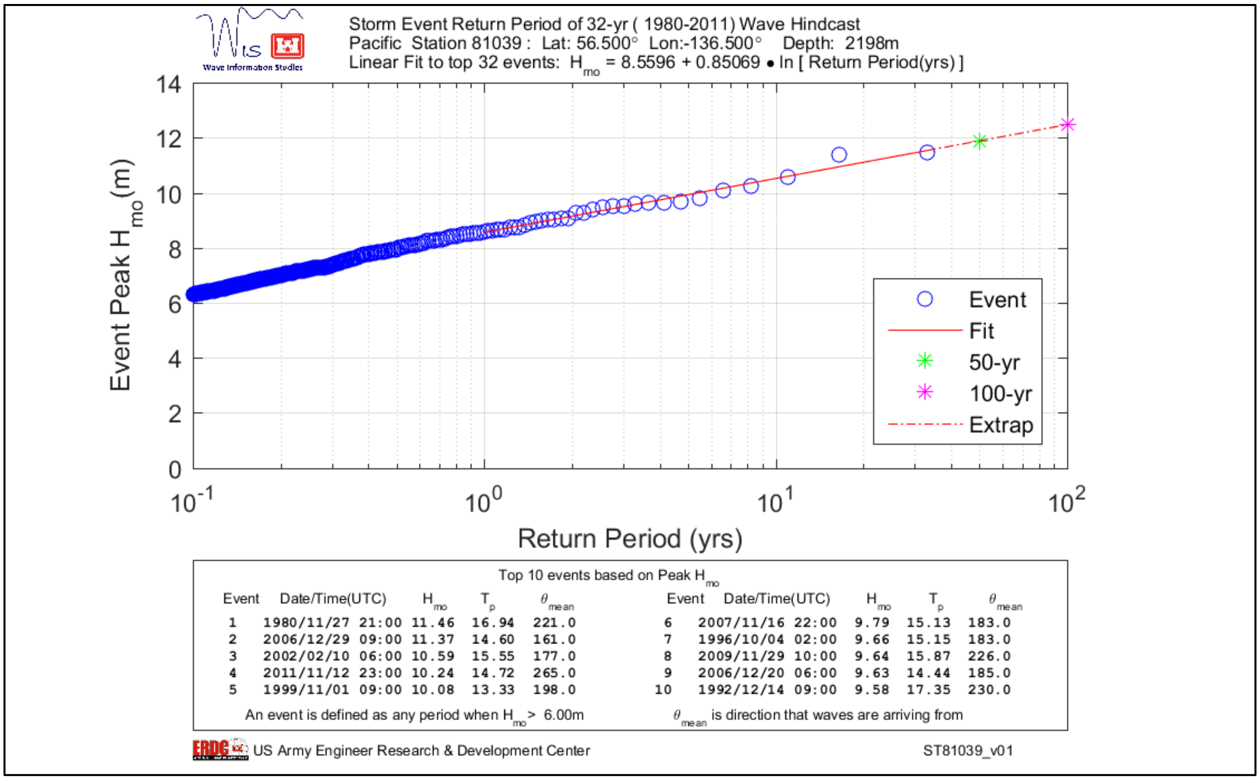

Figure 6. Return Period Wave Height – WIS Station 81039, 58 Miles Southwest from Proposed Site (USACE, 2019)

<u>Wave Hindcast Calculations</u>

Waves at the project site were estimated using wind data and hindcast formulae found in the U.S. Army Corps of Engineers Coastal Engineering Manual (USACE, 1984). The proposed seaplane float and seaplane slips (Figure 2) are exposed to waves generated along relatively long fetch distances to the north, northwest, and southeast. The proposed drive-down ramp could be exposed to a large wave generated in the Sitka Sound, penetrating through the gap between the south breakwater and Japonski Island at high tide. Long-period swell waves from the west and southwest (Gulf of Alaska) can reach the proposed dock site only by diffracting and refracting around headlands and islands.

Waves generated along a fairly long fetch (13.7 miles) from the north cannot reach the project site directly; however, this fetch was considered for calculations of the waves outside of the breakwater. Waves calculated outside of the breakwater were used as an input in the MIKE 21 model to predict diffracted waves that could affect the project site from the north direction.

Fetch-limited wave calculation methods were applied to determine the wave height and period associated with the wind speeds and fetch lengths. The hindcast significant wave height (Hs), peak period (Tp), and maximum wave height (Hmax) are calculated and listed in Table 8. The wave heights estimated are for deepwater, meaning they originate in a depth offshore before they can feel the bottom and shoal or refract.

The 100-year return period significant wave height calculated at the drive-down ramp is approximately 6.2 feet for winds blowing from the west-northwest. These waves can penetrate through the gap between the existing south breakwater and Japonski Island to the ramp area at high tide. The maximum calculated 100-year wave height that is expected at the seaplane float location is approximately 3.5 feet for winds blowing from the north and 3.2 feet for winds from the east-southeast. The maximum calculated 100-year wave height that is expected outside of the breakwater is approximately 10.3 feet. These results would be a worst-case wave height as it does not account for wave height shoaling and refraction (reduction) as the waves transform around land forms to the project site.

The significant wave height is the average wave height of the highest one-third of all waves measured. The maximum wave height is the largest single wave during a storm event and is assumed equal to 1.7 times the significant wave height. The wind speed analysis for hindcast calculations was directional, meaning the return period winds aligned with the associated fetch direction were used to calculate the return period wind speed. The simple wind wave desktop calculation methods are limited by their underlying assumptions and appear slightly larger compared with the MIKE 21 spectral wave model results (discussed in the following section). The MIKE21 model output is generally considered a better estimate of wave heights than calculations based on fetch distance and wind speed formulae.

Table 8. Wave Hindcast Analysis – Sitka Seaplane Base Site

No.	Direction – Fetch	Wind Speed (knots)	H_s (feet)	H_{max} (feet)	T_p (s)
2-Year Return Period					
1	North – 1.4 mi	26	1.3	2.4	2
2	East-Southeast – 0.8 mi	38	1.6	2.9	2
3	West-Northwest – 5 mi	29	2.7	5.0	3
4	Outside BW North – 13.7 mi	26	3.7	7.0	3
10-Year Return Period					
1	North – 1.4 mi	38	2.0	3.8	2
2	East-Southeast – 0.8 mi	49	2.1	4.0	2
3	West-Northwest – 5 mi	39	3.9	7.2	3
4	Outside BW North – 13.7 mi	38	5.9	11.0	4
50-Year Return Period					
1	North – 1.4 mi	53	3.1	5.7	2
2	East-Southeast – 0.8 mi	61	2.8	5.2	2
3	West-Northwest – 5 mi	51	5.4	10.1	3
4	Outside BW North – 13.7 mi	53	9.0	16.7	5
100-Year Return Period					
1	North – 1.4 mi	59	3.5	6.6	2
2	East-Southeast – 0.8 mi	67	3.2	5.9	2
3	West-Northwest – 5 mi	57	6.2	11.6	3
4	Outside BW North – 13.7 mi	59	10.3	19.2	5

WAVE NUMERICAL MODELING

The MIKE 21 Spectral Wave (SW) numerical wave model was applied to estimate the design wave conditions at the project site in addition to the desktop calculations to compare the output results. The model was developed by the Danish Hydraulic Institute and is widely used in the industry for the analysis and design of coastal structures. The SW model is capable of simulating the growth, decay, and transformation of wind-generated waves and swell in offshore and coastal areas. The model takes into account important physical processes, including wave growth by action of winds, shoaling and refraction due to depth variations, diffraction and reflection near structures, wave breaking in the surf zone, wave dissipation (including bottom friction, white-capping, and quadruplet- and triad-wave interaction), and some non-linear wave-current interactions.

Bathymetry data obtained from the NOAA National Geophysical Data Center were used to develop the model grid for the project site. The model domain includes the entire southwest part of Sitka Sound and part of the north section of the sound including the islands due northwest of Japonski Island. Bathymetry in close vicinity of the project site was based on a hydrographic survey conducted by DOWL (2020).

The mesh resolution varies throughout the model domain with a very dense resolution near the project area and behind the breakwater. This nodal spacing is sufficient to resolve the bathymetry for wave transformation over a large area and to keep computational times reasonable. The mesh contains a total of 17,294 nodes. The detail of the model domain, bathymetry, and location of the observation stations (wave parameters output) are shown in Figure 7.

Modeling Approach

Wind input used in the model was based on the results of the return period analysis presented in Table 5. Wave input at the MIKE 21 model sea boundary was based on offshore buoys wave return period analysis, shown in Table 7.

The MHHW of +9.9 feet from chart level was used for the modeling exercises to predict extreme events at the site. Ten offshore conditions associated with the deepwater wind and wave climate were propagated within the MIKE 21 model to predict waves near the proposed Seaplane Base location (Concept No.1). Additional runs for 2-year and 10-year return periods and proposed T-Dock configuration are presented in Appendix A.

The significant wave height and wave period were calculated at every grid point. The output includes color map plots; examples are shown in Figure 8 through Figure 11. The plots show the wave height distribution and the peak wave direction. Five output points were placed along the initial proposed float facilities to represent maximum wave conditions at various locations at the Seaplane Base. The input and output conditions for the MIKE 21 model are summarized in Table 9.

Figure 9 demonstrates how the wave refraction and shoaling are responsible for the substantial wave height reduction when propagating from the open ocean to the project site. Model results show that the large long-period swell waves originated in the Gulf of Alaska are greatly reduced in height at the entrances to the Sitka Sound and at the proposed location due to refraction and shoaling around headlands and islets. The maximum 100-year swell waves of 1.1 feet could penetrate to the project site through the gap in the breakwater. Nevertheless, even small long-period waves are an important component for the design of floating dock structures due to their great ability to transmit energy and affect the motion of the floating structures.

Based on the MIKE 21 model output, the 100-year return period wave height at the planned dock is 2.6 feet for local wind waves from the north and northwest direction.

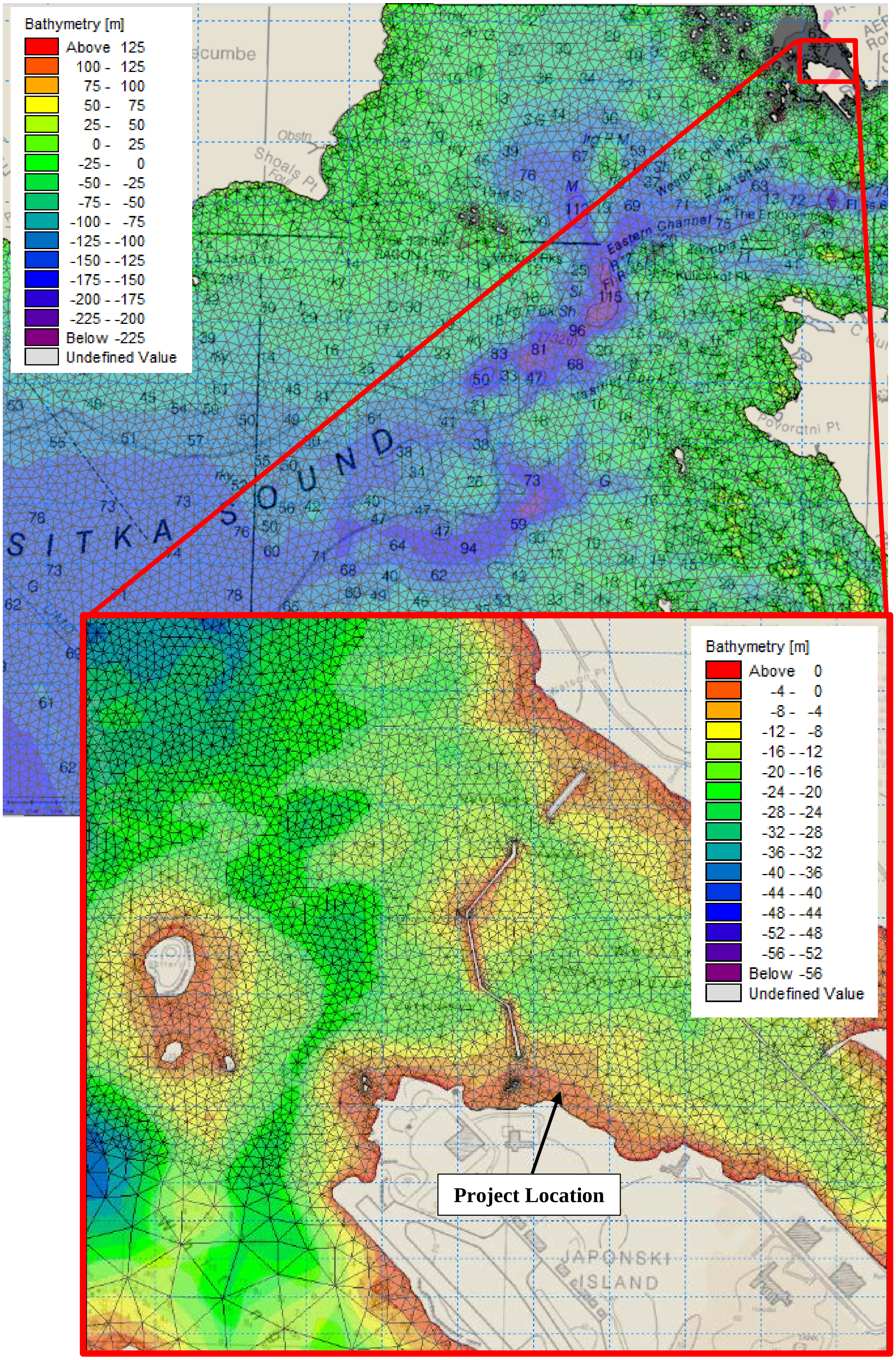

Figure 7. MIKE 21 Numerical Model Domain and Bathymetry

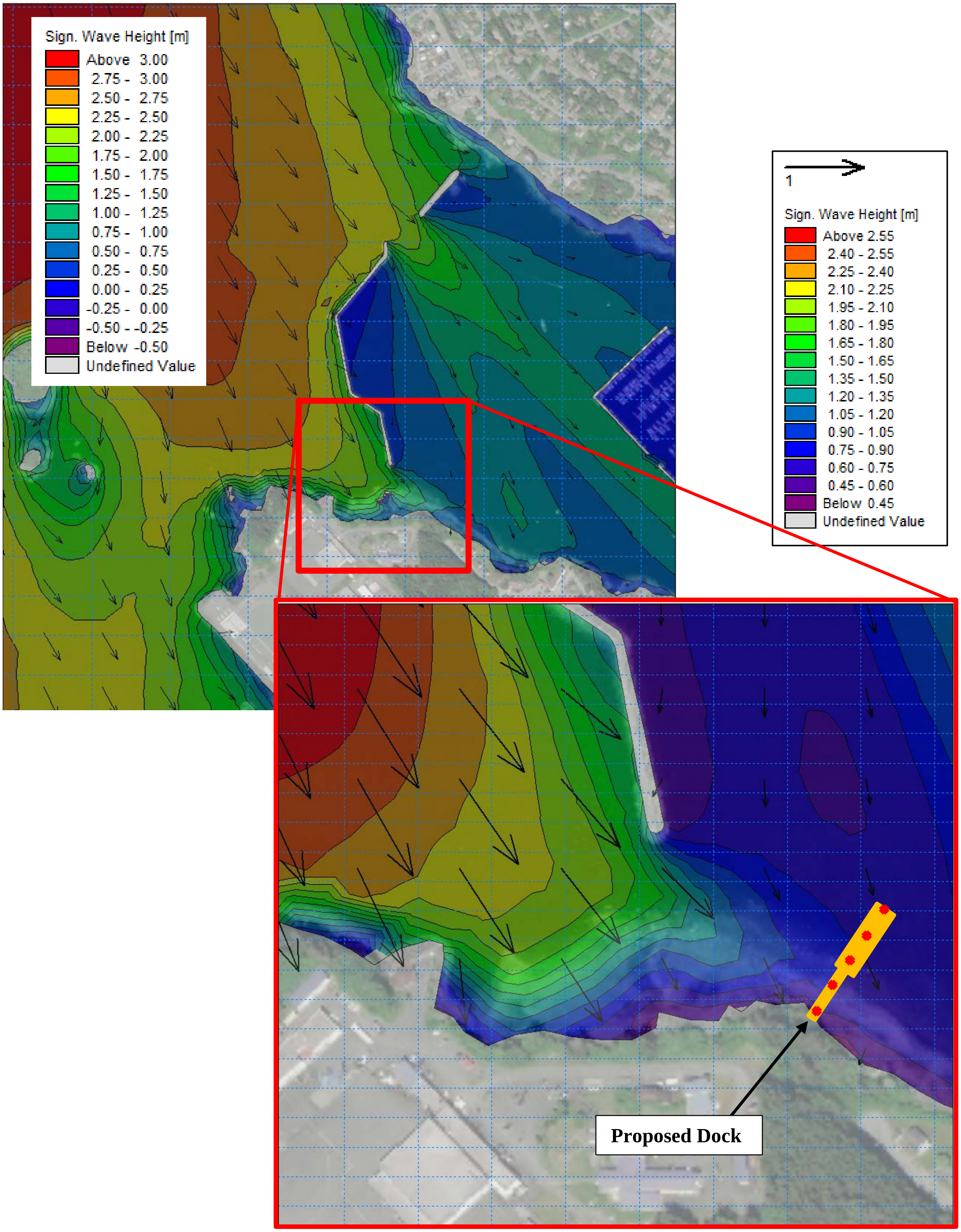

Figure 8. MIKE 21 Model Run No. 1 Results – 100-Year North Wind (59-knots wind and 10.3-foot wave input). Red Dots Show Approximate Model Output Locations.

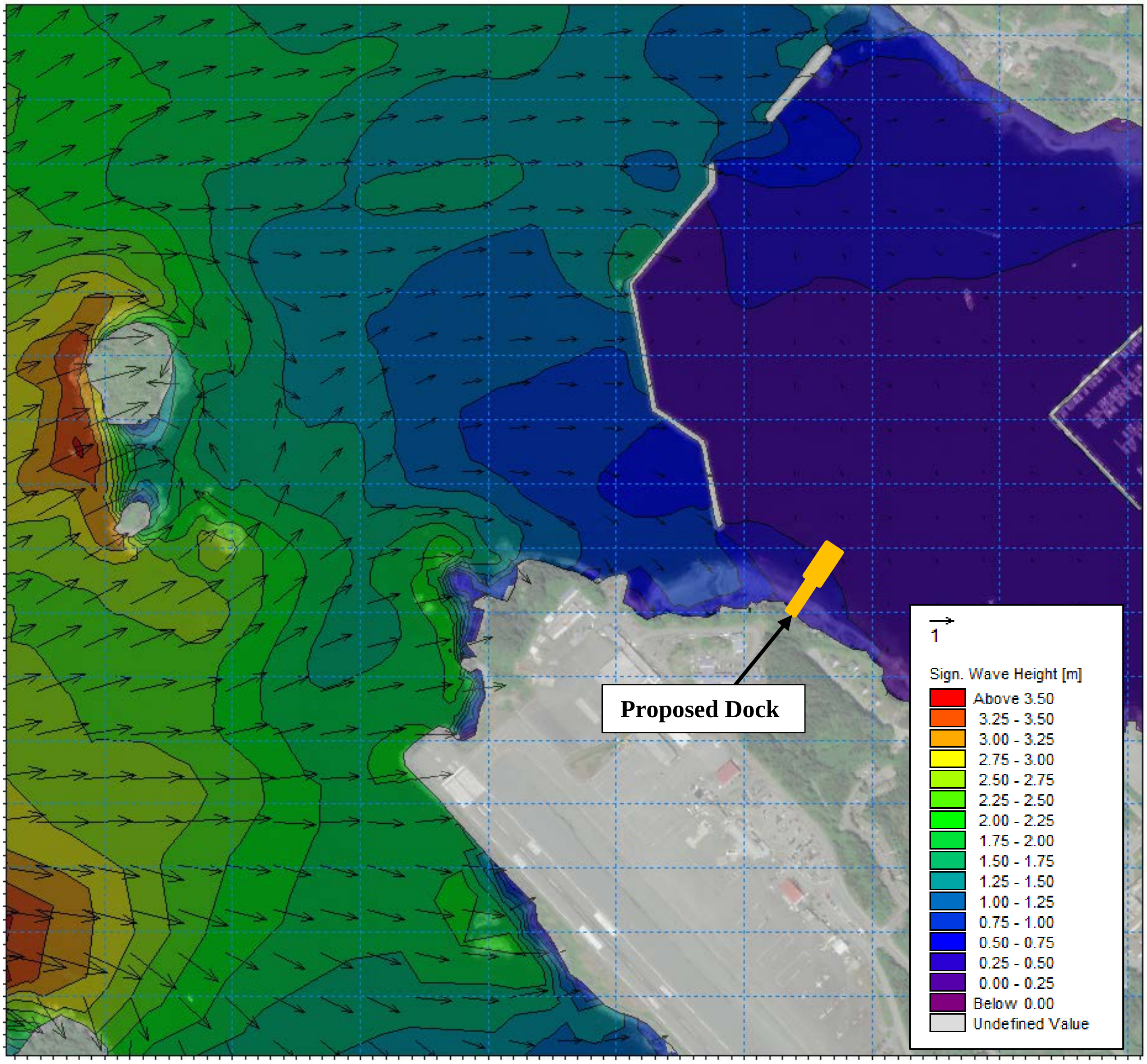

Figure 9. MIKE 21 Model Run No. 4 Results – 100-Year Southwest Swell (55-foot swell wave input)

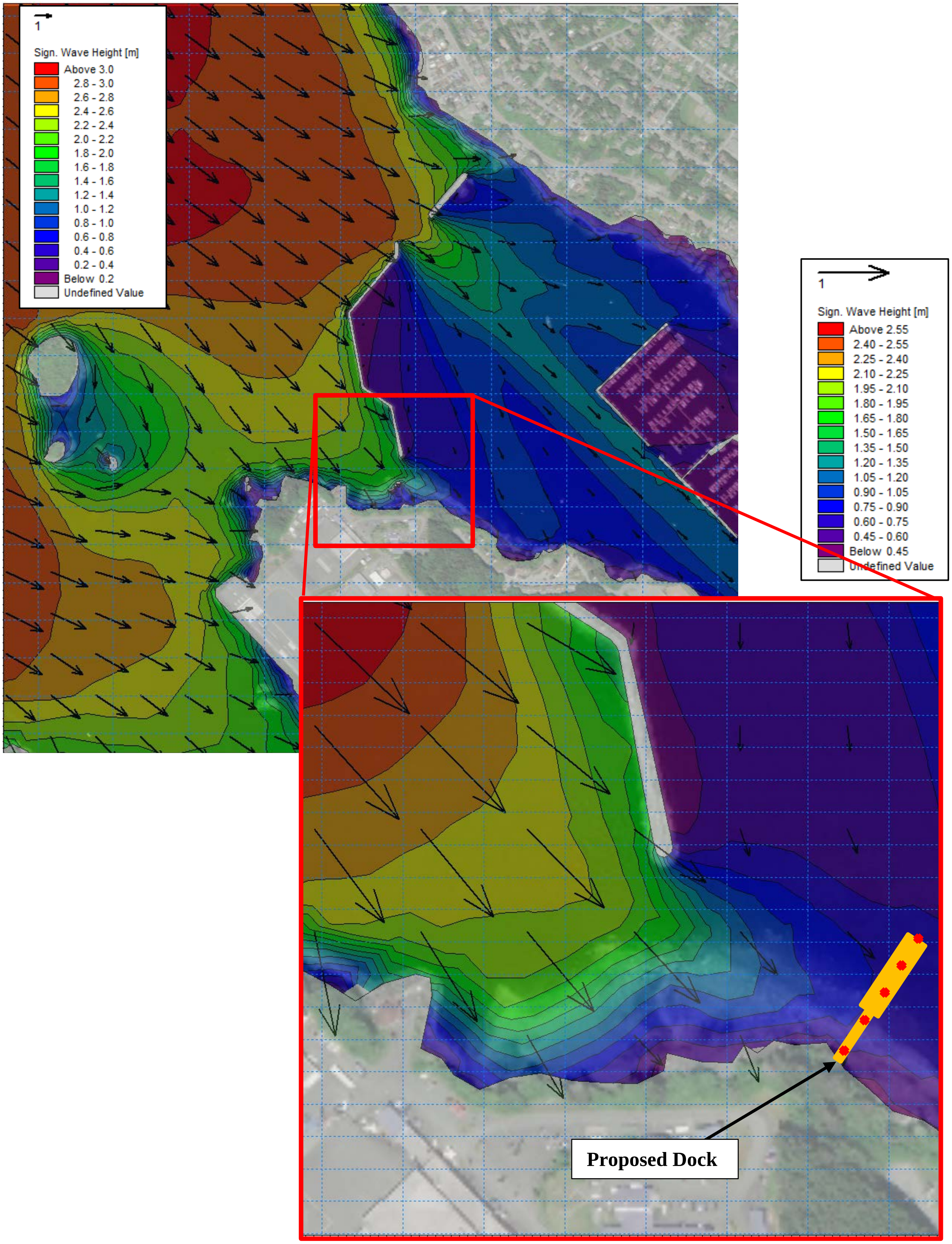

Figure 10. MIKE 21 Model Run No. 7 Results – 100-Year West-Northwest Wind (57-knots wind and 6.2-foot wave input). Red Dots Show Approximate Model Output Locations.

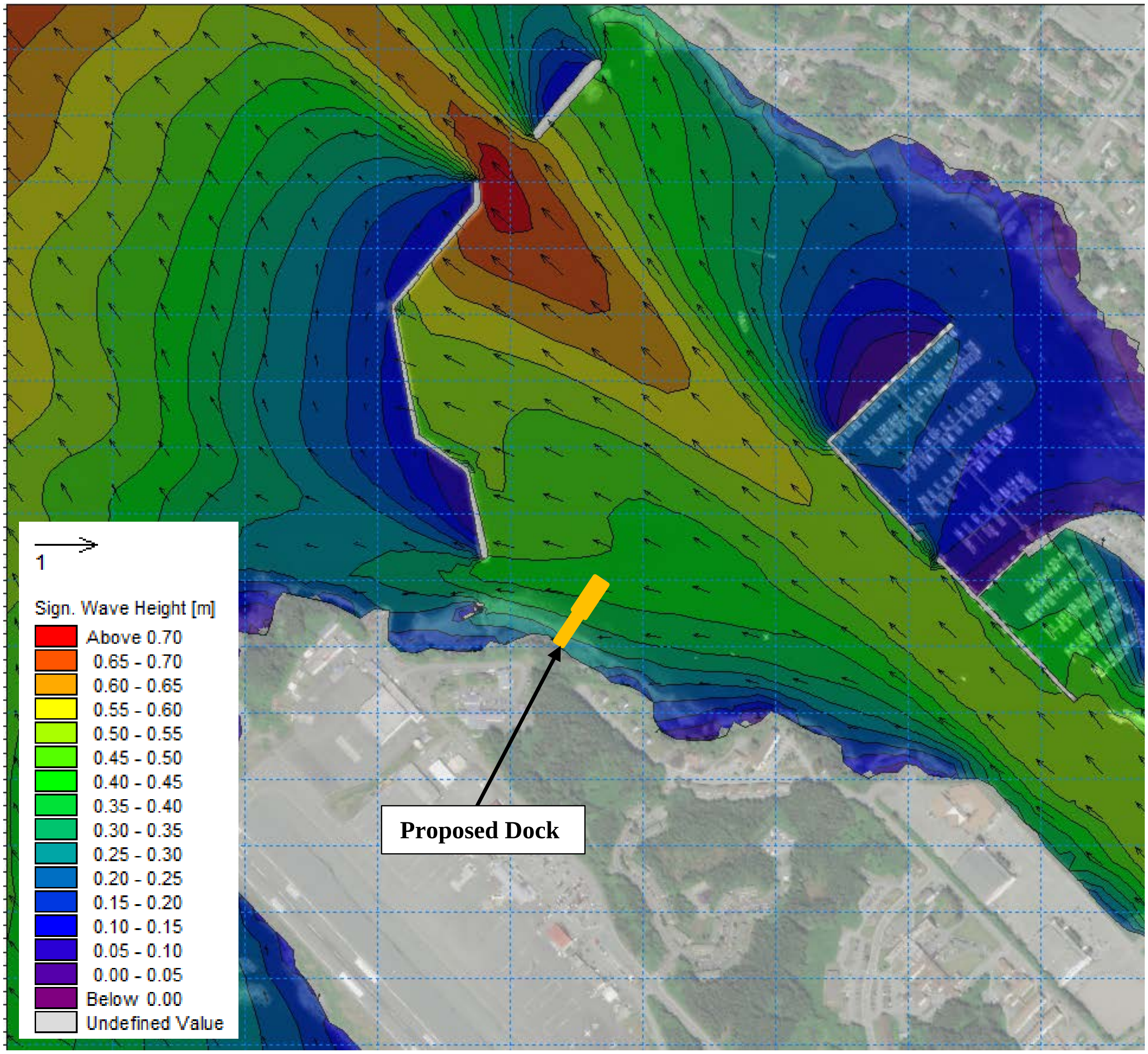

Figure 11. MIKE 21 Model Run No. 8 Results – 100-Year East-Southeast Wind (67-knots wind input)

Table 9. Initial Concept MIKE 21 Wave Model Results

Run #	Run Description	MIKE 21 INPUT						MIKE 21 OUTPUT		
		Tide	Wind		Wave			Maximum Along The Dock		
		Feet MLLW	Speed (knots)	Dir.	Wave Height Hs (feet)	Period (sec.)	Dir.	Wave Height Hs (feet)	Wave Period (sec.)	Wave Dir.
1	100-yr North Wind	9.9	59	345°	10.3	5	345°	2.6	5	340°
2*	100-yr North Wind @ Highest WL	14.9	59	345°	10.3	5	345°	2.8	5	331°
3*	100-yr North Wind @ MLLW	0	59	345°	10.3	5	345°	2.1	5	345°
4	100-yr Southwest Swell 15 sec	9.9	-	-	55	15	230°	1.1	13	340°
5**	100-yr Southwest Swell 12 sec	9.9	-	-	55	12	230°	1.0	11	338°
6	100-yr Southwest Swell + Southwest Wind	9.9	57	230°	55	15	230°	1.4	9	335°
7	100-yr West-Northwest Wind	9.9	57	300°	6.2	5	300°	2.4	5	331°
8	100-yr East-Southeast Wind	9.9	67	115°	-	-	-	1.5	2	107°
9***	50-yr North Wind	9.9	53	345°	9.0	5	345°	2.3	5	338°
10***	50-yr East-Southeast Wind	9.9	61	115°	-	-	-	1.3	2	107°

*Water level sensitivity check
**Wave period sensitivity check
***Return period sensitivity check

A series of sensitivity tests were also run to check the influence of different parameters (e.g. water level and wave period) in the model. The results of the sensitivity tests were compared with original model runs to understand the effect of the different input parameters in the model.

MIKE 21 Spectral Wave model output is generally considered a better estimate of wave heights than calculations based on fetch distance-wind speed formulae. Results based on fetch-limited wave calculations would be a worst-case wave height as it does not account for wave height shoaling and refraction (reduction) as the waves transform around land forms and through the gap in the breakwater to the dock.

CONCLUSIONS AND RECOMMENDATIONS

Prevailing winds recorded at Sitka Airport weather station are from the southeast and northwest. The wind distribution is highly influenced by the regional topography. The 100-year return period omnidirectional wind speed is 77 knots. The 100-year return period wind speed is 59 knots for winds from the north, 67 knots for winds from the east-southeast, and 57 knots for winds from the west-northwest.

The 100-year return period wave height at the planned Seaplane Base is 2.6 feet for wind waves from the north and northwest directions. The project site is relatively protected from the large, long-period wave storms approaching from the Gulf of Alaska. The largest predicted 100-year swell wave height from the south penetrating the site at high tide was found to be 1.1 feet. Long-period waves are an important design consideration because they influence the motion of floating structures more than smaller wavelength wind waves.

An extreme high water elevation of +15 feet above MLLW is appropriate for design. Water surface elevation strongly influences wave energy to the lee of the existing breakwaters. However, water levels of +9.9 MHHW feet were used for wave modeling exercises since the combination of the 100-year wind speed and the largest recorded water level would be a higher return period.

The work outlined in this memo is limited in scope. Due to budget constraints, the model was run for a limited combination of conditions at the proposed development site only. Due to the complexity of the study area, a higher-resolution numerical model and direct wind and wave field measurements are both recommended prior to final design. The measured data would be used for verifying assumptions, calibrating numerical models, and refining the design to reduce risk. Determination of optimum wave protection at the proposed site would be done with the aid of a phase-resolving wave numerical model (i.e. Boussinesq Wave Module) that can show the movement of individual wave crests and troughs as they refract, diffract, and reflect around the breakwater.

Additional wave protection measures may include closing the gap between the existing south breakwater and shore to protect against the west and northwest wind exposures and long period ocean swell waves. Other measures may include floating wave attenuators to protect against north and southeast wind exposures. Relocating the proposed facility somewhat easterly from its current location along the Japonski Island shoreline may also prove more favorable wave conditions. Placing seasonal operational restrictions on the facility at the proposed site without additional wave protection measures will leave the facility and seaplanes vulnerable given that high winds can be expected from any direction nearly anytime of the year. Further design development and wave modeling is required to refine these options.

REFERENCES

NOAA (2019). "NOAA Tides and Currents Online." http://tidesandcurrents.noaa.gov.

NOAA (2019). "Office of Coast Survey." National Ocean Service. https://www.nauticalcharts.noaa.gov/.

NDBC (2019). "National Data Buoy Center." https://www.ndbc.noaa.gov/.

NOAA (2019). "National Climatic Data Center." http://www.ncdc.noaa.gov.

USACE (2015). "Coastal Engineering Manual," Engineering and Research Development Center, Vicksburg, Mississippi.

USACE (1992). "Automated Coastal Engineering System (ACES)," Technical Reference v. 1.07, 1992.

USACE (1984). "Shore Protection Manual," two volumes, USACE Waterways Experiment Station, Vicksburg, Mississippi.

USACE (2019). "Alaskan 20 Year Wind and Wave Hindcast Study."