SINCLAIR ISLAND DOCK REPLACEMENT

WAVE HINDCAST AND MET-OCEAN DESIGN CRITERIA

Prepared For

Skagit County, Washington

Prepared By

PND Engineers, Inc.

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PREFACE TO REPORT

This report has been prepared by PND Engineers Inc., (PND), for Skagit County Public Works. The report contains the results of a met-ocean study for the Sinclair Island Dock Replacement Project. Included is analysis of wind, water levels, waves and currents. The Delft3D-Wave numerical model has been applied to estimate the design wave conditions at the project site, in addition to desktop calculations. The work is needed for engineering and design of the replacement dock, including an approach pier, gangway, wave barrier and floating dock. The key questions answered by this met-ocean study include identifying the different combinations of incoming wave height, period and direction for which a wave barrier must provide protection, or a seasonal use float will need to survive.

PND's analysis and findings in this report are based the following:

1. Engineering calculations performed by PND, including numerical wave modeling.
2. Review and application of previously performed met-ocean analysis for other projects in the vicinity.
3. Engineering judgment and experience, including knowledge gained during design and construction of partially penetrating vertical wave barriers.

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1 INTRODUCTION

The dock is located on the east shore of Sinclair Island, approximately 5 miles north of Anacortes, Washington. Figure 1.1 and Figure 1.2 are aerial photos of the project site. Figure 1.3 is a nautical chart that shows relatively deep water close to shore. The dock, which dates to 1920, has been damaged by recent rough winter weather, has excessive maintenance costs, and a new dock is needed.

The existing dock includes an approach pier, gangway, wave barrier and floating dock. PND developed concept design alternatives in 2007 and did a hydrographic survey near the project site. This met-ocean study will establish the Design Environmental Conditions (DEC) needed for design. The met-ocean information is necessary for calculating wind and wave loads on marine infrastructure. It will be used to analyze dock replacement alternatives, including the length of breakwater needed for harbor protection, the size and orientations of floats and moorings.

The project site is exposed to waves generated along relatively long fetch distances. Waves from the west-southwest, south and the southeast can reach the project site as shown in and Figure 1.4. Measured wave data is not available for the project site. Wave numerical models have been used to analyze wind generated wave conditions. Desktop hindcast calculations have also been applied to check the numerical wave model results.

Wind data is available from different sources near the vicinity of the project site. Winds and storms are highly influenced by the local topography and are typically from the south. Wind data from different sources have been used to analyze return period wind events.

1.1 Criteria for Wave Conditions in a Small Boat Harbor

Recommended maximum allowable wave conditions inside marinas can vary. A typical criteria for small boat harbors is to allow a 1-foot wave height exceeded once per year on average, and a 2 feet wave height exceeded once every 50 years, on average. These criteria are from the “Criteria for Good Wave climate in a small craft harbor,” developed by the Canadian Department of Fisheries and Oceans, Small Craft Harbors branch (Table 1.1). The same criteria are also referenced in the manual “Planning and Design Guidelines for Small Craft Harbors” from the American Society of Civil Engineers.

These criteria are reasonable for use at the Sinclair Island Dock. The facilities should be designed in the future so that wave conditions at the dock do not exceed the criteria in Table 1.1.

Table 1.1 Criteria for "Good" Wave Conditions in a Small Boat Harbor

Design Wave		Return Period		
Direction	Peak Period	50 Year	1 year	1 Week
Head Seas	< 2 seconds	not applicable	<1 feet wave height	<1 feet wave height
	2 to 6 seconds	<2 feet wave height	<1 feet wave height	<0.5 feet wave height
	>6 seconds	<2 feet wave height	<1 feet wave height	<0.5 feet wave height
Beam Seas	< 2 seconds	not applicable	<1 feet wave height	<1 feet wave height
	2 to 6 seconds	<0.75 feet wave height	<0.5 feet wave height	<0.25 feet wave height
	>6 seconds	<0.75 feet wave height	<0.5 feet wave height	<0.25 feet wave height

[1]Reference: Small Craft Harbor Criteria, Canada Department of Fisheries and Oceans, Small Craft Harbors Branch.
[2]For "excellent" wave climate multiply by 0.75, for "moderate" wave climate multiply by 1.25.
[3] "Head seas are waves that approach from the bow or stern of the boat. "Beam seas" approach from the side.

Figure 1.1. Sinclair Island Dock – Aerial Image (Google Earth, 2011)

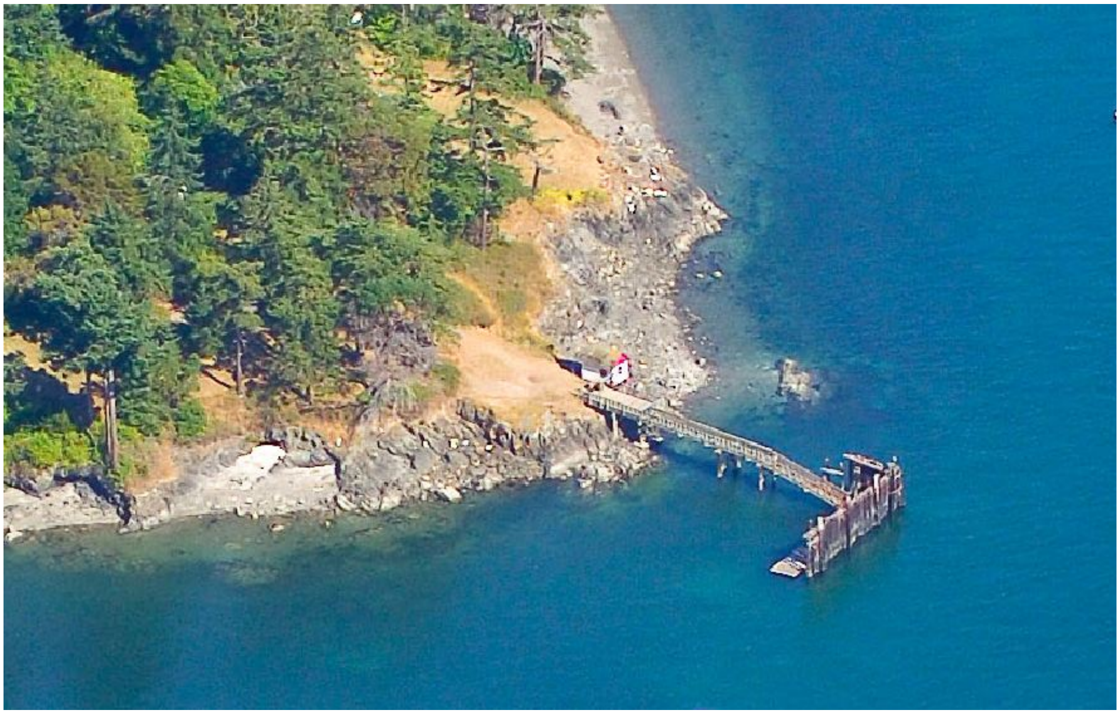

Figure 1.2. Project Site Aerial Photo (Washington Department of Ecology 8/14/2006)

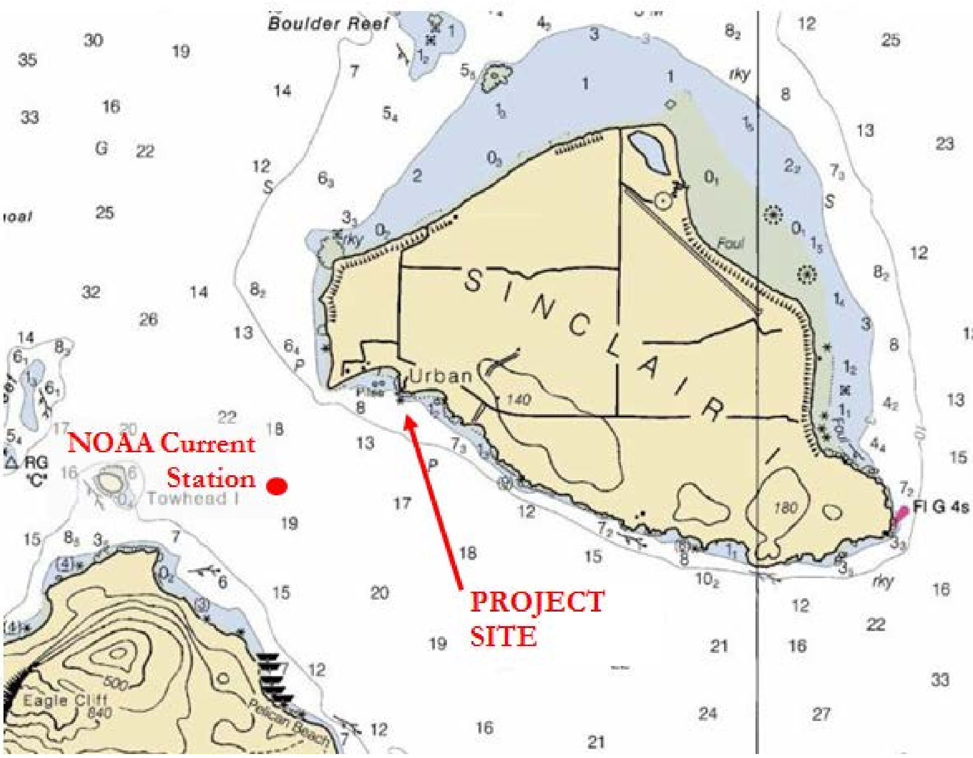

Figure 1.3. Sinclair Island– NOAA Chart 18424 (soundings in fathoms, 1 fathom=6 feet)

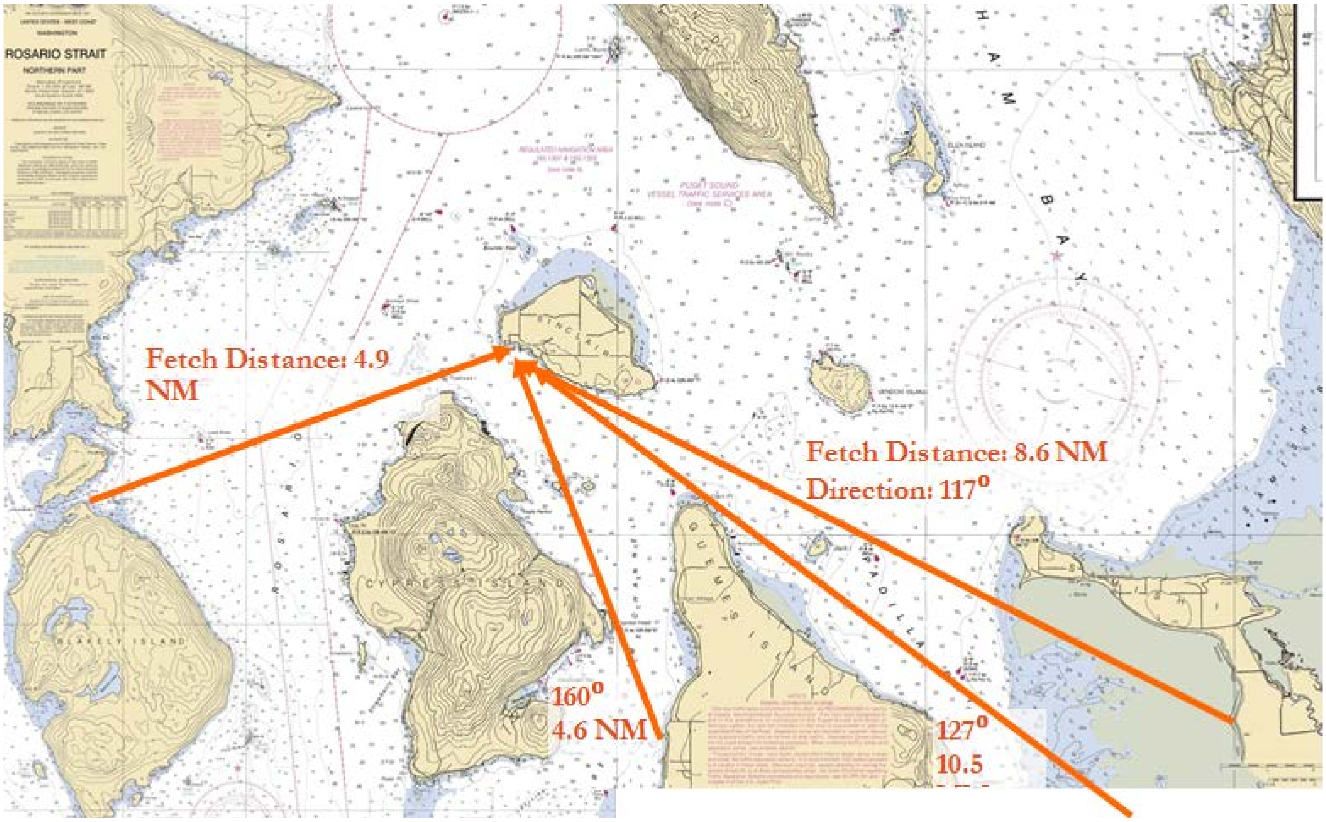

Figure 1.4. Area Map - NOAA charts No. 18424 and 18430

2 TIDES AND WATER LEVELS

Water levels strongly influence the design of marine facilities. Tide data near the project site are included in Table 2.1. The information is from NOAA nautical charts 18424 and 18430 for Eagle Harbor and Tide Point. Predicted tides for Eagle Harbor and Tide Point were also obtained using a tide prediction software (http://www.flaterco.com/xtide) and were analyzed. Tide information from NOAA Tides and Currents (http://tidesandcurrents.noaa.gov) for Anacortes, Armitage Island, Friday Harbor and Cherry Point is also included in Table 2.1.

“King tide” or extreme high tide events can affect the design of the dock significantly. The highest recorded tide in Seattle occurred recently, on December 17, 2012, elevation +14.48 feet, which was 1.64 feet higher than the predicted (astronomic) tide. This same tide elevation of +14.48 feet, MLLW was also recorded on January 27, 1983. The weather on December 17, 2012 was calm and it is not known what caused the tide elevation to be larger than predicted by 1.64 feet. The deck of an existing pier was submerged during December 17, 2012 as shown in Figure 2.1.

Tide elevations have been recorded at Seattle since 1898 and show a net trend of sea level rise of 2.1 mm per year, or 0.07 feet every 10 years (NOAA, 2001), as shown in Figure 2.2. A NOAA primary tide gage is also located at Port Townsend. Recorded data at this gage shows a net sea level rise of 1.98 mm/year (Figure 2.3), which is equivalent to 0.065 feet every 10 years. Sea level rise for locations in Puget Sound is included in Table 2.2. Note that parts of the Washington Pacific coast are known to experience relative sea level fall, possibly related to glacial rebound and/or tectonic uplift. However, for a project in north Puget Sound the measured sea level trend over the past 100 years in Seattle is appropriate for project design. For an assumed project design life of 50 years it may be appropriate to design for a potential increase in sea level of 0.35 feet.

El Niño events can lead to substantial rise in sea levels. During the relatively severe El Niño of 1996 sea levels in Washington State were approximately 1 foot higher than normal for a number of months. Other factors such as wind set-up can lead to a significant rise in water levels for project sites located at the end of a long inlet. However, the Sinclair Island dock site is open to both the east and west. Therefore set-up is likely not significant. A summary of the factors that can affect water levels is included in Table 2.3.

The recommended design high water elevation at the Sinclair Island dock is +9.8 feet, MLLW based on data given in Table 2.1 and taking into account sea level rise and El Niño effects. The dock should be designed to be operational at water elevations of at least +10 feet, MLLW. The recommended extreme high water elevation is +11.5 feet, MLLW. The dock should be designed to survive without significant damage during a water elevation of at least +11.5 feet, MLLW. The recommended design low water is –4.0 feet, MLLW. These elevations should be evaluated further during final design.

Table 2.1. Water Levels – Sinclair Island (All elevations in feet, MLLW)

Water Levels	Eagle Harbor	Tide Point	Anacortes	Armitage Island [1]	Friday Harbor [2]	Cherry Point
Highest Observed Water Level				+10.5	+11.3	
Highest Predicted water Level	+9.0	+9.4				
Mean Higher High Water (MHHW)	8.2	8.1	8.2	7.8	7.8	9.2
Mean High Water (MHW)	7.4	7.3	7.4	7.2	7.1	8.3
Mean Low Water (MLW)	2.4	2.4	2.6	2.3	2.3	2.6
Mean Lower Low Water (MLLW)	0.0	0.0	0.0	0.0	0.0	0.0
Lowest Observed Water Level				-3.7	-4.0	
Lowest Predicted Water Level	-3.6	-3.7				

[1] Water levels for Armitage Island based on measured data from 1998-2000
[2] Water levels for Friday Harbor based on measured data from 1960-1978

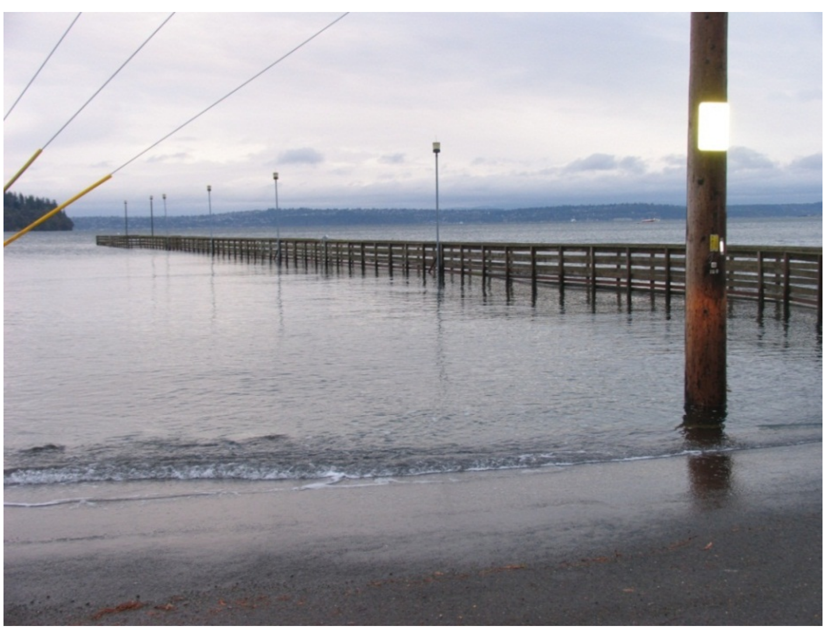

Figure 2.1. Harper Pier, near Bremerton – December 17, 2012 "King Tide"

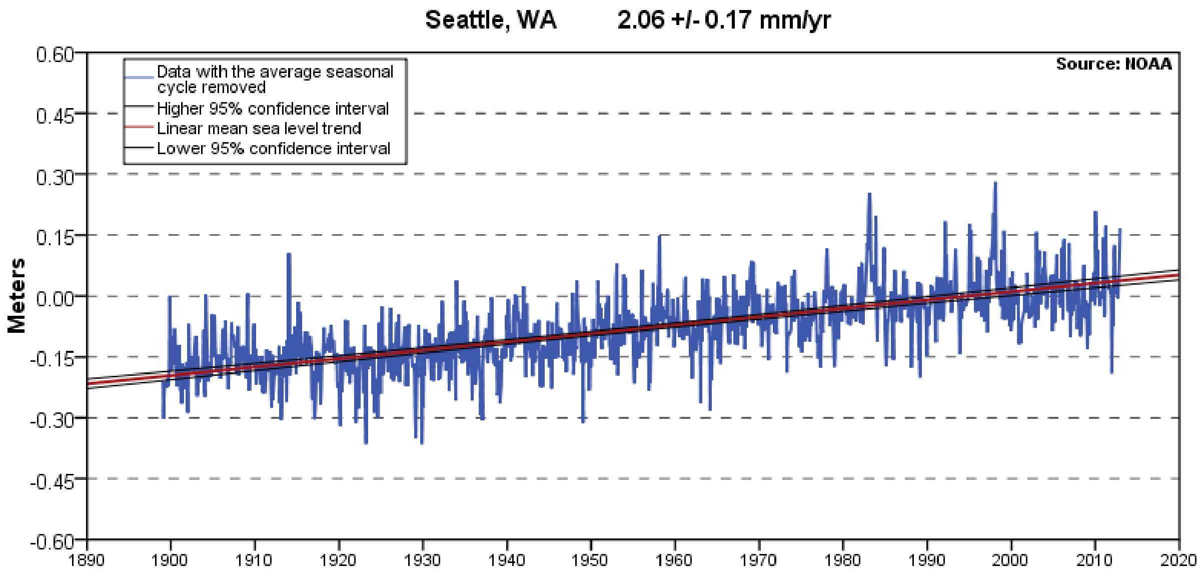

Figure 2.2. Sea Level Rise – Seattle

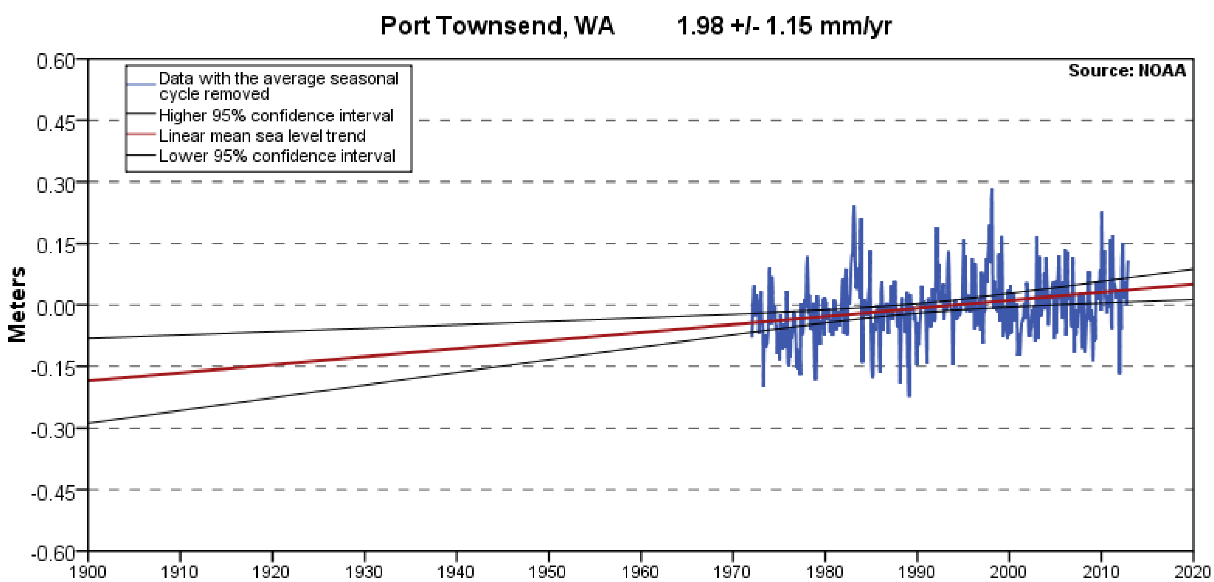

Figure 2.3. Sea Level Rise – Port Townsend

Table 2.2. Sea Level Rise Summary

Location	Data Available (years)	Rate of Sea Level Rise (feet) per 100 years
Seattle	1898-2012	0.70 ±0.05
Port Townsend	1971-2012	0.65 ±0.34
Friday Harbor	1934-2006	0.37 ±0.11
Cherry Point	1973-2006	0.27 ±0.40

Table 2.3. Summary of Factors Affecting Water Levels

	Effect	Description
1	Sea Level Rise (Fall)	Long term changes in relative sea level at a site can be caused by global climate and oceanographic changes (global warming and changes in polar regions ice caps), ground subsidence associated with extraction of groundwater or hydrocarbons, uplift of the earth's crust caused by glacial rebound and/or plate tectonics and changes in the sediment supply from rivers in the region.
2	El Nino/La Nina	During the strong El Nino during the winter of 1996-97 sea levels were elevated by approximately 1 foot in Puget Sound for a few months.
3	Storm surge - set-up/setdown	Storm surge is related to the dynamics of wind driven currents meeting the continental shelf and nearshore bathymetry during a storm. Wind and waves move water onshore or offshore, resulting in sea level set-down or set-up.
4	Astronomic tide	Astronomic tides are the predicted tides, caused principally by the gravitational attraction of the sun and moon.
5	Inverted barometer	The fluctuation in air pressure alone associated with an extreme low pressure weather system can raise the ocean surface about 0.15 m
6	Wave and wind set-up and Seiche	Waves approaching shore contain momentum. As the waves break and decrease in size the wave's momentum remains, pushing the water towards the shore and increasing the water level. Wind stress also occurs. As a rule-of-thumb, set-up is often assumed to be 15 percent of the offshore significant wave height, but with substantial variability depending on local conditions. The concept of a single set-up value is being replaced for some projects and regions by analysis of infra-gravity wave motions. A surge with oscillations can occur in lakes and semi-enclosed bodies of water and is sometimes referred to as a Seiche.
7	Tsunami/Long Waves	The risk of large open ocean tsunamis generally is believed minimal in Central Puget sound, and is not normally a criterion for design of pedestrian piers and marina floats. Long waves associated with submarine slope failure (underwater landslides) may be more relevant.
8	Infra-gravity waves, also termed surf beat (typically filtered out of a tide gage record).	Infra-gravity (long period) waves, with 30 second to 2 minute period, sometimes exist with shorter period waves, and can increase water levels in shallow water the same order of magnitude as the shorter period wave height. Infra-gravity waves are a significant factor on high energy, wide dissipative beaches with a flat slope, and are likely not important for design of a dock at Sinclair Island.
9	Short period waves	Regular ocean waves (2 to 30 second period) are typically superimposed on the longer period fluctuations in the water surface.

3 WIND

Wind data is available from nearby weather stations maintained by the National Climatic Data Center (NCDC). Table 3.1 summarizes the data available from nearby stations. The station locations and the corresponding wind roses are shown in Figure 3.1. The wind data are two minute average wind speeds. Wind direction is defined as the direction winds are travelling from.

Table 3.1. Wind Data Summary

No.	Site	Start-End Years	No. of Years*	Max Wind Spd (knots)
1	Orcas Island	2004-2013	7	27
2	Whidbey Island	1945-2009	64	45
3	Skagit Regional Airport	1985-2013	26	45
4	Bellingham Airport	1948-2013	59	58

*Number of years of data with gaps removed.

The wind roses show that the winds are influenced by the topography. Winds from the south are prevailing at most stations, except for Whidbey Island naval air station where the winds are more east and west, likely due to its location at the eastern end of the Straights of Juan de Fuca. The highest recorded wind speed at the four stations listed in Table 3.1 was 58 knots at Bellingham Airport.

The wind data extremes (directional) were analyzed to determine the wind speed associated with a given return period. Table 3.2 and Table 3.3 show the ranked wind speed for the different stations. Table 3.4, Table 3.5 and Table 3.6 show the results of the extremal analysis. The 50-year and the 2-year return period wind speeds for the different stations are summarized in Table 3.7. Given the length of record, return period estimates are reasonable for the Bellingham Airport, Whidbey Island, and Sinclair Regional Airport station data. The data from the Orca Islands station is not sufficient for estimating 50-year return period estimates with accuracy. However, due to lack of other sources of data, the 50-year return period wind speed from the Orca Islands station has been used to estimate the hindcast waves from the southwest direction. The stations were chosen for analysis because they are upwind from the project site for the respective fetch direction. The return period analysis was done with all data points. 90% confidence limits on the predictions are included.

Table 3.2. Largest Recorded Annual Wind Speeds – All Directions

Rank	Orcas Island			Whidbey Island			Skagit Regional Airport		
	Date	Wind Speed (knots)	Dir (deg)	Date	Wind Speed (knots)	Dir (deg)	Date	Wind Speed (knots)	Dir (deg)
1	1/25/2012	27	210	12/5/1945	45	180	1/3/1990	45	20
2	11/11/2011	25	340	1/15/1951	45	248	2/27/1998	44	60
3	2/5/2006	24	200	1/1/1959	45	270	1/21/1988	43	150
4	7/12/2007	22	190	7/29/1998	45	180	6/12/1997	40	150
5	12/13/2008	22	250	2/6/1949	44	135	3/3/1999	33	140
6	7/31/2009	22	190	2/25/1977	44	150	4/3/1991	30	130
7	5/29/2005	21	190	8/10/1978	44	130	2/21/1992	30	130
8	8/18/2010	20	190	12/21/1961	42	270	1/20/1993	30	150
9	11/1/2004	19	180	12/15/2000	42	250	12/5/1998	29	120
10	8/19/2012	19	190	11/12/2007	42	160	11/15/2006	26	170

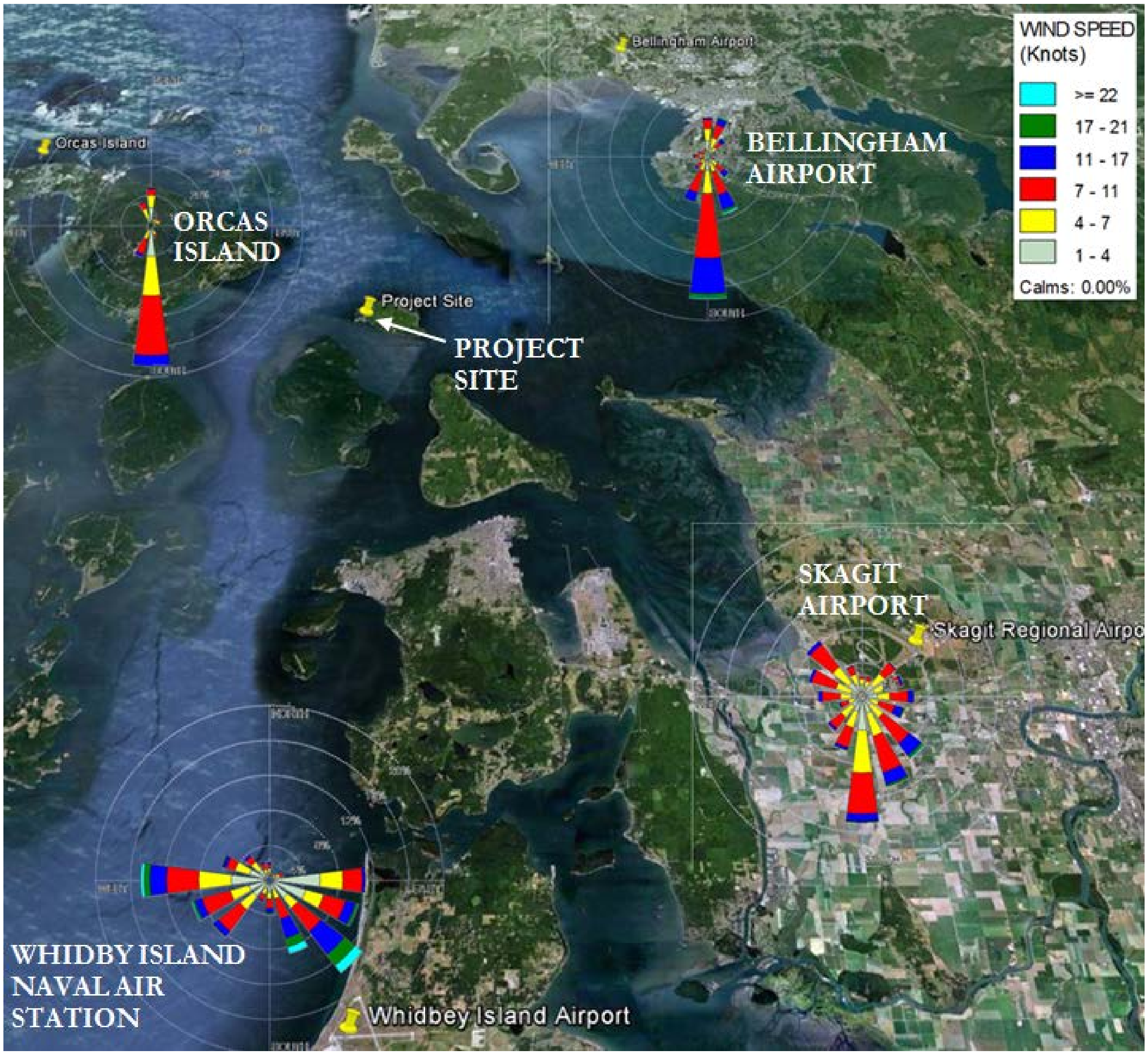

Figure 3.1. Sinclair Island – Wind Data Sources

Table 3.3. Largest Recorded Wind Speeds – Filtered by fetch direction

Rank	Orcas Island Southwest (240°-270°)			Whidbey Island South (150°-180°)			Skagit Regional Airport Southeast (100°-130°)		
	Date	Wind Speed (knots)	Dir (deg)	Date	Wind Speed (knots)	Dir (deg)	Date	Wind Speed (knots)	Dir (deg)
1	11/12/2007	12	240	12/5/1945	45	180	4/3/1991	30	130
2	5/7/2006	11	250	7/29/1998	45	180	2/21/1992	30	130
3	6/13/2011	11	260	11/12/2007	42	160	12/5/1998	29	120
4	6/18/2012	11	240	2/13/1979	40	170	1/27/1999	29	130
5	4/1/2005	10	260	10/22/1982	40	160	1/13/1989	25	130
6	9/11/2004	9	240	1/17/1986	38	160	1/28/1990	25	130
7	4/24/2008	9	240	3/31/1997	38	160	2/13/1994	25	130
8	3/5/2009	9	240	11/14/1981	35	170	3/9/1995	25	110
9	4/30/2010	9	260	2/3/1990	35	160	2/22/1996	25	120
10	3/31/2011	9	240	12/13/1995	35	160	3/31/1997	25	120

Table 3.4. Return Period – Orcas Island Station – Wind Speed (knots) – Direction: 240°-270°

N = 10; Nu = 1.00 NT = 10; K = 10	FT-1	Weibull		
Lambda = 1.00		K = 0.75	K = 1.40	K = 2.00
Correlation Coefficient	0.9650	0.9006	0.9516	0.9667
Return Period (years)				
2	9.5	9.2	9.4	9.6
5	10.7	10.3	10.6	10.8
10	11.4	11.2	11.5	11.5
25	12.4	12.6	12.5	12.2
50	13.1	13.8	13.2	12.7
100	13.8	15.0	13.9	13.2
90% Confidence Interval: Return Period Years				
5	9.5-11.9	8.1-12.5	9.2-12.1	9.6-12.0
10	9.8-13.1	7.8-14.7	9.4-13.5	10.0-12.9
25	10.2-14.6	7.3-18.0	9.8-15.2	10.4-14.0
50	10.5-15.8	6.9-20.7	10.0-16.5	10.7-14.8
100	10.8-16.9	6.4-23.6	10.2-17.7	11.0-15.4

Table 3.5. Return Period – Whidbey Island – Wind Speed (knots) – Direction: 150°-180°

N = 65; Nu = 1.00 NT = 65; K = 65	FT-1	Weibull		
Lambda = 1.00		K = 0.75	K = 1.40	K = 2.00
Correlation Coefficient	0.9903	0.9228	0.9827	0.9887
Return Period (years)				
2	28.9	27.9	28.5	29.2
5	33.8	32.1	33.7	34.3
10	37.1	35.9	37.3	37.3
25	41.2	41.5	41.6	40.1
50	44.2	46.1	44.8	42.7
100	47.2	51.0	47.8	44.7
90% Confidence Interval: Return Period Years				
5	32.0-35.6	29.1-35.1	31.6-35.8	32.6-36.1
10	34.7-39.4	31.2-40.5	34.5-40.0	35.2-39.4
25	38.0-44.3	34.4-48.6	38.0-45.3	38.1-43.0
50	40.4-47.9	36.9-55.3	40.4-49.1	40.0-45.5
100	42.8-51.5	39.7-62.4	42.8-52.8	41.7-47.8

Table 3.6. Return Period – Skagit Regional – Wind Speed (knots) – Direction: 100°-130°

N = 25; Nu = 1.00 NT = 25; K = 65	FT-1	Weibull		
Lambda = 1.00		K = 0.75	K = 1.25	K = 2.00
Correlation Coefficient	0.9649	0.8586	0.9506	0.9794
Return Period (years)				
2	21.4	20.6	21.0	21.6
5	25.5	24.0	25.3	25.9
10	28.1	27.0	28.2	28.3
25	31.5	34.5	31.8	31.1
50	34.0	35.2	34.4	32.9
100	36.5	39.2	36.8	34.5
90% Confidence Interval: Return Period Years				
5	23.0-27.9	19.7-28.2	22.4-28.2	23.5-28.3
10	24.9-31.4	20.5-33.5	24.3-32.1	25.4-31.2
25	27.1-35.8	21.5-41.5	26.6-37.0	27.6-34.5
50	28.8-39.2	22.2-48.2	28.2-40.5	29.0-36.8
100	30.4-42.5	23.1-55.2	29.8-43.9	30.2-38.8

Table 3.7. Return Period Wind Speed Analysis Summary

Station - Direction	2-yr Return Period Wind Speed (knots)	50-yr Return Period Wind Speed (knots)
Orcas Island – (240-270°)	10	13
Whidbey Island – (160-180°)	29	44
Skagit Regional – (100-130°)	22	33

4 WAVE

The design wave height at the project site was estimated using hindcast analysis and wave numerical models. The wind data from the different wind stations was applied to the corresponding fetch direction listed in Table 4.1. The results of the hindcast wind and wave analysis was used as input to the numerical model for waves from the south for some runs. The wave calculations and numerical model are described below.

4.1 Wave Hindcast Calculations

Fetch limited wave calculation methods were applied to determine the wave height and period associated with the wind speeds and fetch lengths shown in Figure 1.4. The hindcast significant wave height (H_s), peak period (T_p), and maximum wave height (Hmax) were calculated using standard wave prediction formulae in the US Army Corps of Engineers Coastal Engineering Manual. The results are listed in Table 4.1. The wave heights estimated are "deepwater" meaning in a depth offshore before they can feel the bottom and shoal or refract. The significant wave height (Hs) is the average wave height of one-third largest waves.

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 50-year return period significant wave height at the project is approximately 4.3 feet for winds blowing from the southeast along an assumed fetch of 10 nautical miles. The estimated wave height is approximately 4.0 feet for winds blowing from the south and 1.1 feet for winds blowing from the southwest. The results of the wave hindcast analysis were used as inputs to the Delft3D-Wave numerical model for some of the test runs.

Table 4.1. Wave Hindcast Analysis – Sinclair Island Dock

No.	Direction - Fetch	Wind Speed (knots)	H_s (feet)	H_{max} (feet)	T_p (s)
2-Year Return Period					
1	Southwest – 4.8 NM	10.0	0.7	1.2	1.6
2	South – 4.2 NM	29.0	2.2	3.7	2.3
3	Southeast – 10.0 NM	22.0	2.3	3.9	2.7
50-Year Return Period					
4	Southwest – 4.8 NM	13.0	1.1	1.7	1.8
5	South – 4.2 NM	44.0	4.0	6.8	2.9
6	Southeast – 10.0 NM	33.0	4.3	7.3	3.4

4.2 Delft3D-Wave Numerical Model

The Delft3D-Wave numerical model was applied to simulate the generation and transformation of wind generated waves. The model computes the non-steady propagation of short crested waves over an uneven bottom, considering wind action, energy dissipation due to bottom friction, wave breaking, refraction (due to bottom topography, water levels and flow fields), shoaling and directional spreading. The program is widely used and is based on the spectral model SWAN, developed at Delft University of Technology.

Bathymetry data obtained from the NOAA National Geophysical Data Center (NGDC), shown in Figure 4.1, was used to develop the model grids for the project site. The model domain (Figure 4.2) covers part of Rosario Strait, Bellingham Channel and Padilla Bay. Two smaller grids are nested inside the larger grid. The nested grids are more refined, with closing spacing of the grid nodes. The two nested grid limits are shown in Figure 4.3. The location of the observation stations for the model simulations are shown in Figure 4.4.

The land boundary was defined at points that are above the expected maximum water elevation. Sea boundary was defined at three different locations based on the wind input conditions. For example, a sea boundary was defined at Rosario Strait to propagate winds from the southwest. Similarly, a sea boundary was defined at Bellingham Channel to propagate waves from the South and at Padilla Bay to propagate waves from the southeast.

The wind input used at the sea boundary was based on the results of the return period analysis. A no wave input was assumed to analyze wind and wave conditions from the southeast and southwest as the sea boundaries are very close to the shore. A wave input was added at the boundary to analyze conditions from the south. The input conditions for the model simulations are included in Table 4.2. The model was not calibrated due to the lack of measured wave data at the project site, but the results are consistent with the desktop calculations and appear reasonable.

The significant wave height and period were calculated at every grid point. Output at the dock site was analyzed for winds and waves from three directions- southeast, south and southwest. The output includes color map plots. One plot for one run is shown in Figure 4.5. The plots for all simulation runs are included in Appendix B. The plots show the wave height distribution and the peak wave direction. The outputs at the observation locations are included in Table 4.2.

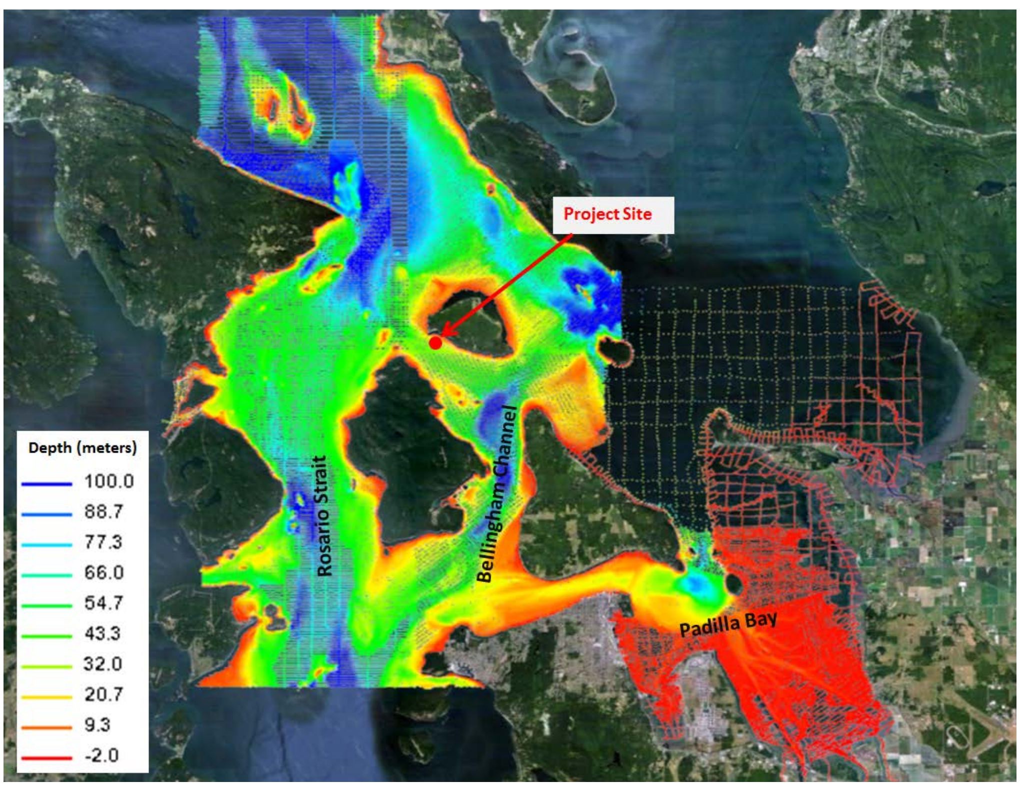

Figure 4.1. Bathymetry data from NGDC

The project site is relatively protected from waves from the southwest. The maximum significant wave height is 0.8 feet for winds blowing from the southwest. The winds blowing from the south lead to the largest significant wave heights at the project site. Note that this direction does not correspond to the longest fetch distance. However, the strongest winds blow from the south. The maximum significant wave height for a wind speed of 46 knots blowing from the south is 4.4 feet at the project site. The waves from the southeast are smaller with a maximum significant wave height of 2.9 feet. The longer fetch along the southeast is narrow and the waves experience diffraction effects before reaching the project site, resulting in smaller wave heights. The simulations also show that the waves diffract around the dock. The area immediately behind the dock is well protected from waves from all directions. The maximum significant wave height was 1 foot at the observation point located behind the dock. However, the Deflt3D model is not able to precisely model the effects of diffraction. A phase resolving model such as CGWAVE is recommended during design to test different breakwater lengths. The model simulations show no unexpected results and are comparable to the wave hindast analysis. Based on the hindcast analysis and the wave numerical model results a significant wave height of 4.4 feet is recommended for design of a dock.

Figure 4.2. Numerical Model Domain Limits – Grid 1

Table 4.2. Delft3D-Wave Model – Input and Output Summary

			Input					Output					
			Wind		Wave			Point 1 (-50 feet contour offshore)			Point 2 (behind breakwater)		
No.	Water Level (feet, MLLW)	Description	Spd (kts)	Dir. (deg)	Hs (ft)	Tp (s)	Dir. (deg)	Hs (ft)	Tp (s)	Dir. (deg)	Hs (ft)	Tp (s)	Dir. (deg)
50 year - return period event													
1	9.8	ESE – wind only	33.0	117	--	--	--	2.5	3.5	144	1.0	2.9	114
2	9.8	SE – wind only	33.0	127	--	--	--	2.9	3.6	140	0.2	1.0	30
3	9.8	S – wind+wave	44.0	180	4.0	2.9	180	4.4	4.1	150	0.3	2.3	90
4	9.8	S– wind only	44.0	180	--	--	--	4.4	4.1	150	0.4	3.4	87
5	9.8	WSW – wind only	13.0	249	--	--	--	0.8	2.0	252	0.1	1.0	282
6	0.0	S – wind+wave	44.0	180	4.0	2.9	180	4.4	4.1	150	0.1	1.0	177
7	0.0	S – wind only	44.0	180	--	--	--	4.4	4.1	150	0.1	2.8	203
2 year - return period event													
8	9.8	ESE – wind only	22.0	117	--	--	--	1.6	2.8	147	0.0	--	--
9	9.8	SE – wind only	22.0	127	--	--	--	1.5	2.8	141	0.2	1.5	28
10	9.8	S – wind+wave	29.0	180	2.2	2.3	180	2.3	3.3	150	0.2	2.1	124
11	9.8	S– wind only	29.0	180	--	--	--	2.3	3.2	152	0.2	2.0	119
12	9.8	WSW – wind only	10.0	249	--	--	--	0.7	1.8	256	0.0	--	--

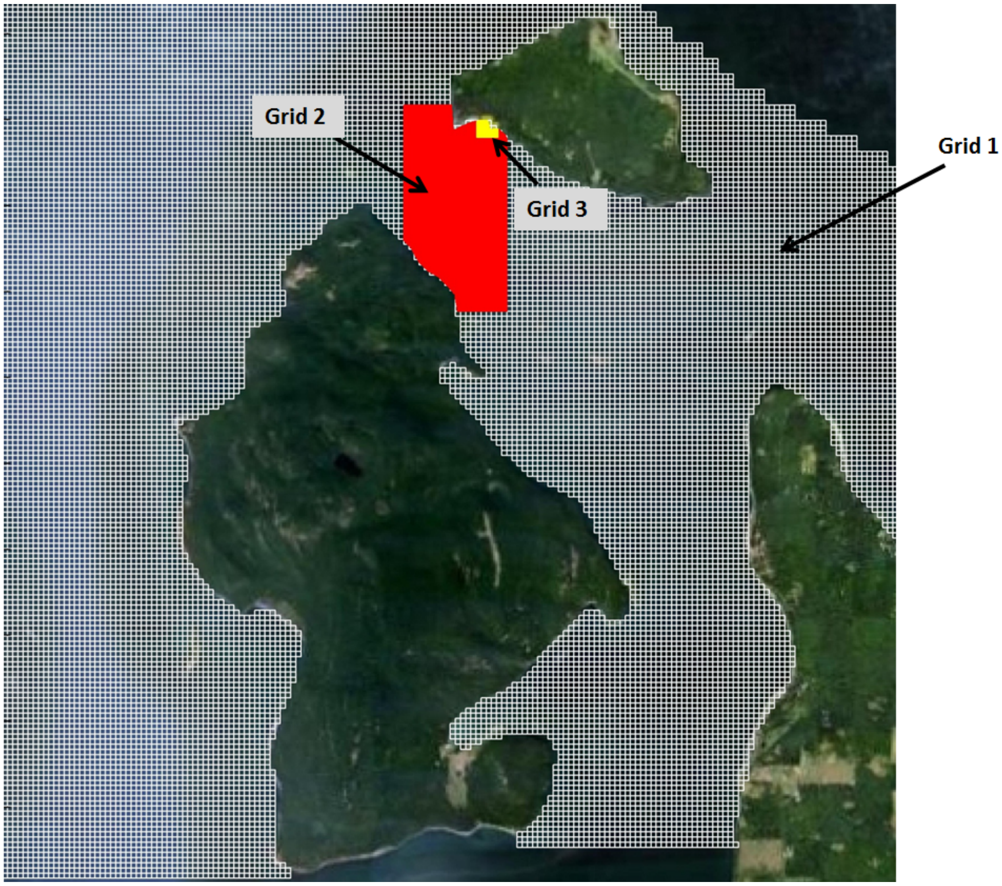

Figure 4.3. Delft3D-Wave Model Grids

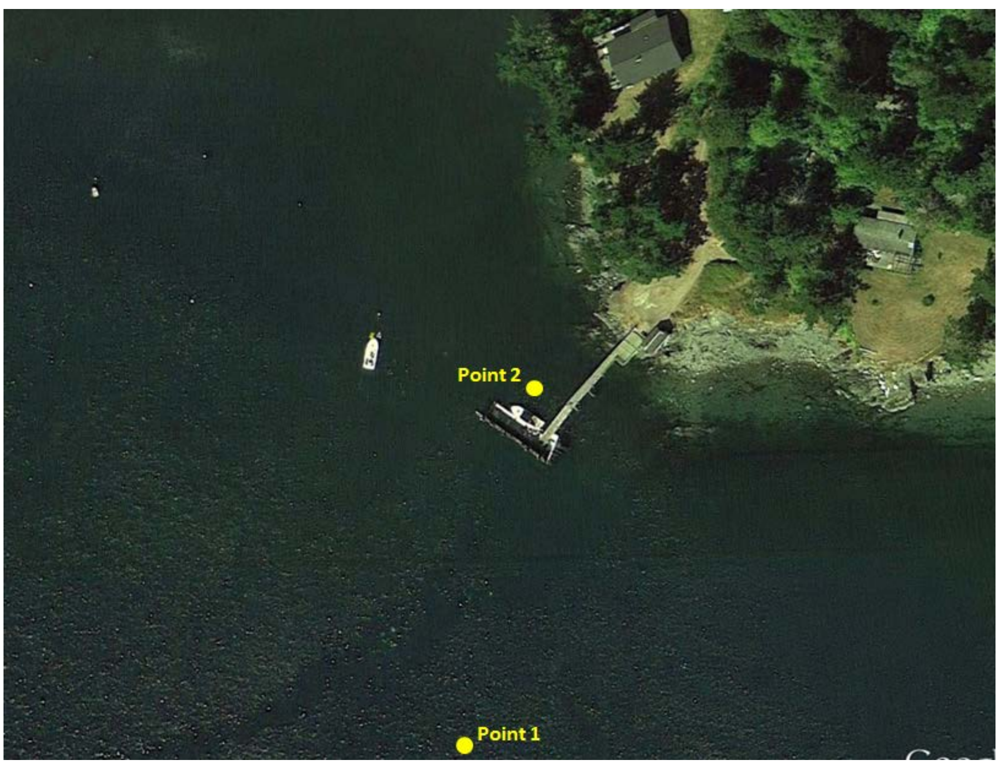

Figure 4.4. Delft3D-Wave Model Observation Locations

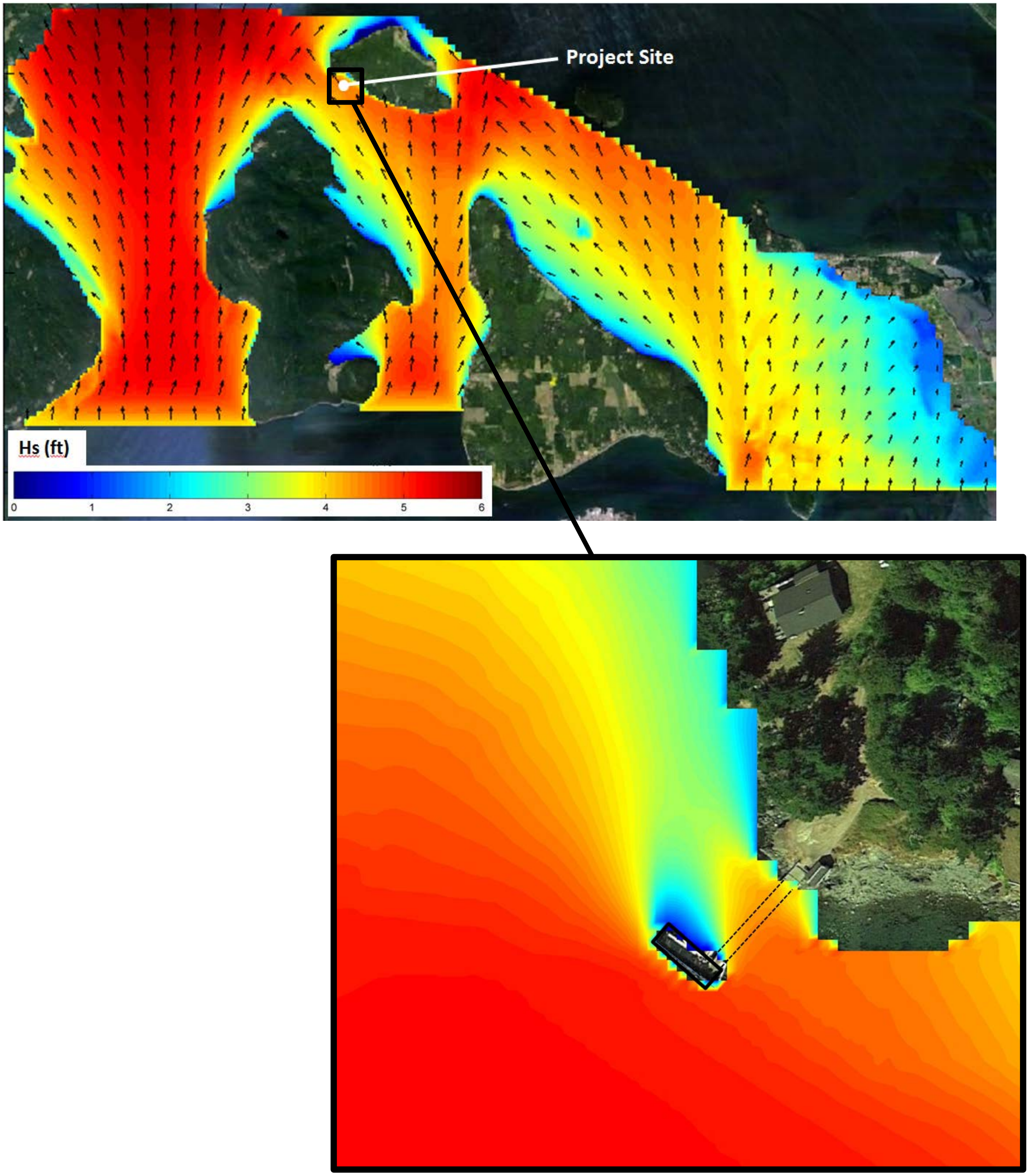

Figure 4.5. Delft3D Wave Model Output – Run 3 (Input: Wind 46 knots, direction 160°; Wave 4.5 feet, 2.9 seconds)

5 CURRENTS

Currents can be large in some areas of Puget Sound due to the relatively large tide range in the region. Measured current data near the project site has not been found. However, NOAA tide predictions are available approximately 2400 feet southwest from the Sinclair Island Dock (48° 36.73' N, 122°42.13' W). The point is shown in Figure 1.3. The average flood current speed and direction is 0.8 knots, 315°. The average ebb current speed and direction is 0.4 knots, 125°. The maximum predicted flood and ebb speed during 2013 is 1.9 knots and 0.7 knots respectively.

Note winds can move water in the upper part of the water column locally; typically at a speed of 1-3% of the windspeed. A 50 knot wind can result in a 0.5 to 1.5 knot surface current.

Measuring currents by throwing an orange in the water from the pier and measuring how long it takes to move during different tide stage will provide useful information on the currents at the project site. Discussions with local residents may also provide useful information.

Currents associated with tsunami and longs waves are not normally a design criterion for pedestrian piers and floats, but should be considered during final design. Long waves due to submarine landslides have occurred in Puget Sound but are not typically considered for design of small boat piers and floats.

6 CONCLUSIONS

The recommended Design Environmental Conditions (DEC) for the Sinclair Island project are summarized in Table 6.1. The DEC are the extreme conditions with a specific combination of tide, wind, waves and currents for which the system is to be designed.

Table 6.1. Sinclair Island – Design Environmental Conditions – 50-year Return Period Events

No.	Description	Water Level (ft, MLLW)	Wind		Wave			Current	
			Spd (kts)	Dir. (deg)	Hs (ft)	Tp (s)	Dir. (deg)	Spd (kts)	Dir. (deg)
1	Southwest Wave		13	249	0.8	2.0	252		
2	South Wave	+10.0	44	180	4.4	4.1	150	2.0	315
3	Southeast Wave		33	117	2.9	2.9	140		

A conventional float is likely not appropriate at the project site without a breakwater. A year-round float would need extra-strong mooring piles and robust connections to survive the expected wind and wave conditions. Maintenance and wear would be significant even with a robust design. A seasonal float that is hauled out of the water at the end of each summer would cost less and may be the only feasible alternative without a breakwater to provide a protected harbor.

Prevailing winds are from the south and southeast. The wind distribution is highly influenced by the regional topography. The 50-year return period wind speed is 44.0 knots for winds from the south and 33.0 knots for winds from the southeast. The 50 year return period significant wave height is approximately 4.4 feet, from the direction of prevailing winds to the south.

El Nino events and sea level rise should be considered during design. Tsunami and long waves also should be considered but are not normally a design criterion for floats and small boat harbors. An extreme high water elevation of +11.5 feet above Mean Lower Low Water is appropriate for design.
Currents can be large south of the project site. A 2.0 knot current speed is recommended for design.

A field study is recommended prior to final design to measure waves and currents at the project site. The data will be useful for verifying assumptions, calibrating numerical models and providing a more refined design with less risk. Appendix A shows examples of field measurement instruments owned by PND that have been used on recent projects in Alaska.

6.1 Study Limitations

The information presented in this report is based on professional opinions derived from our analysis and interpretation of available documents and information. This report was prepared by PND for the sole use of Skagit County Public Works. Our conclusions and recommendations are intended for this project and limitations of scope, schedule and budget apply. The scope of services performed for this investigation may not be appropriate to satisfy the needs of other users. If there is a substantial lapse of time between the submission of this report and the start of construction, or if conditions have changed due to project design, or appear to be different from those described in this report, PND should be notified so that we can review our report to determine the applicability of the conclusions and recommendations considering the possible changed conditions.

7 REFERENCES

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APPENDIX A

FIELD MEASUREMENTS

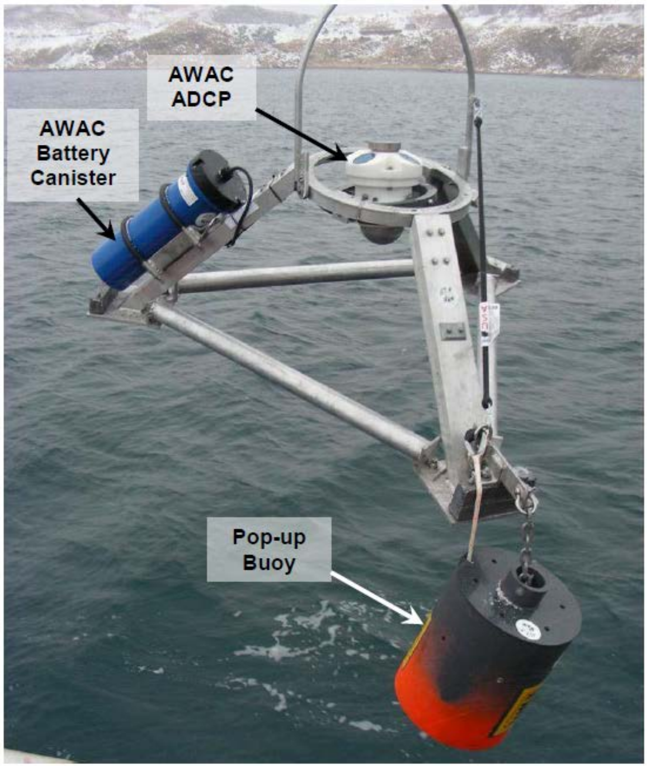

Figure A1. AWAC Instrument setup on tripod for wave, current and water level field measurements.

Figure A2. Aquadopp Instrument attached to dock pile for wave and current field measurements

APPENDIX B

Delft3D-Wave MODEL OUTPUT

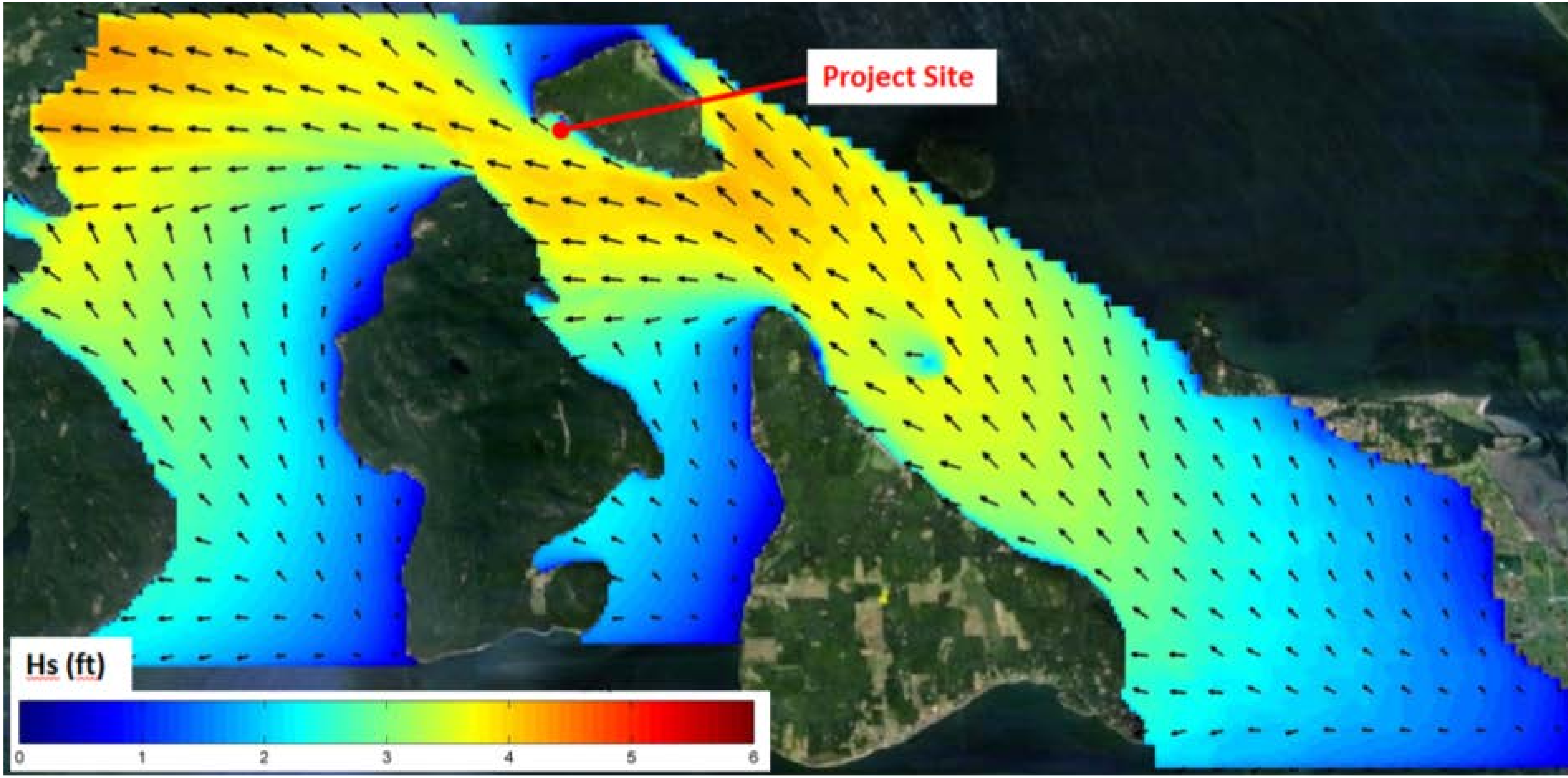

Figure B1. Delft3D-Wave Model Output – Run 1. Wind Input: 33.0 knots; Direction: 117°; Water Level: +9.8 feet MLLW

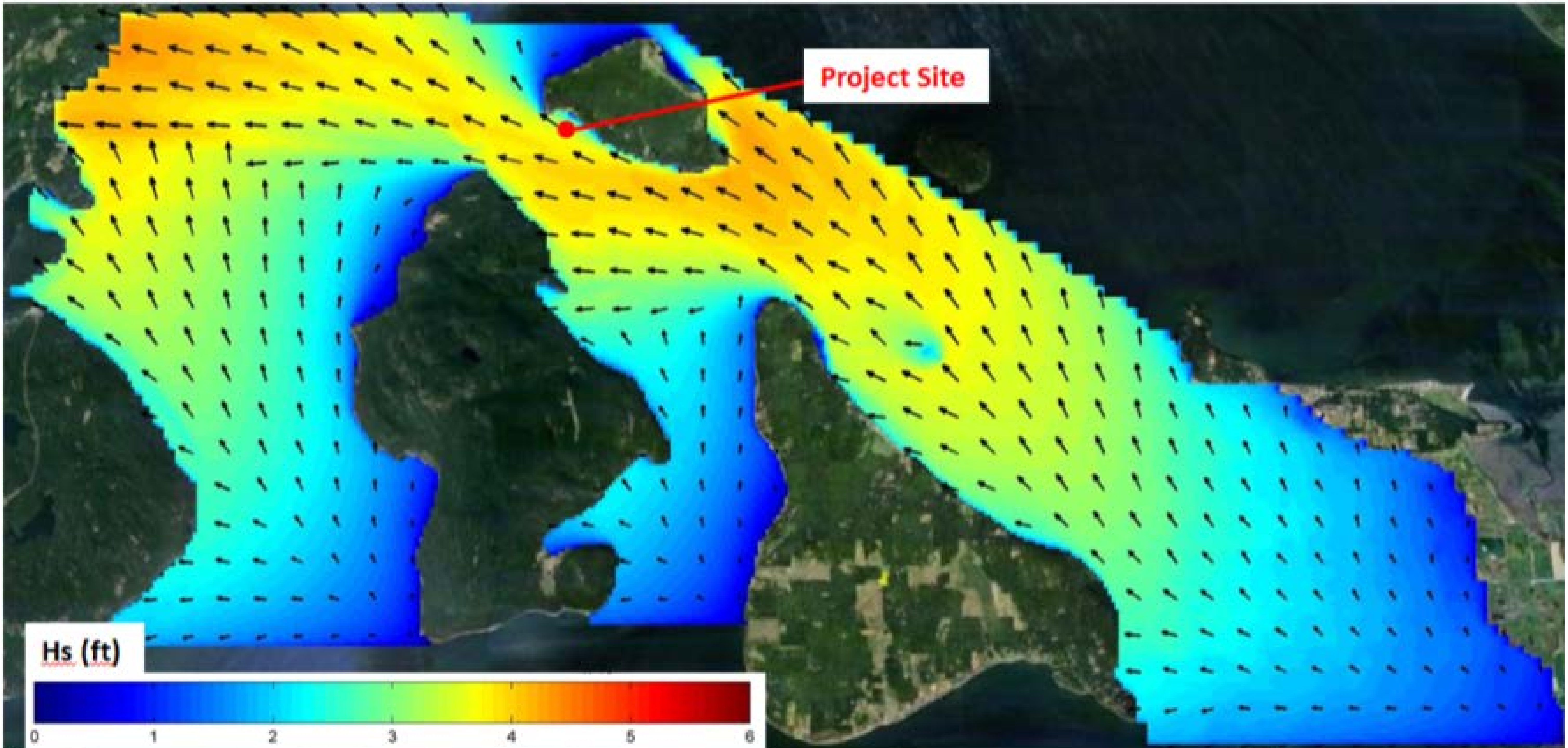

Figure B2. Wave Model Output – Run 2. Wind Input: 33.0 knots; Direction: 127°; Water Level: +9.8 feet MLLW

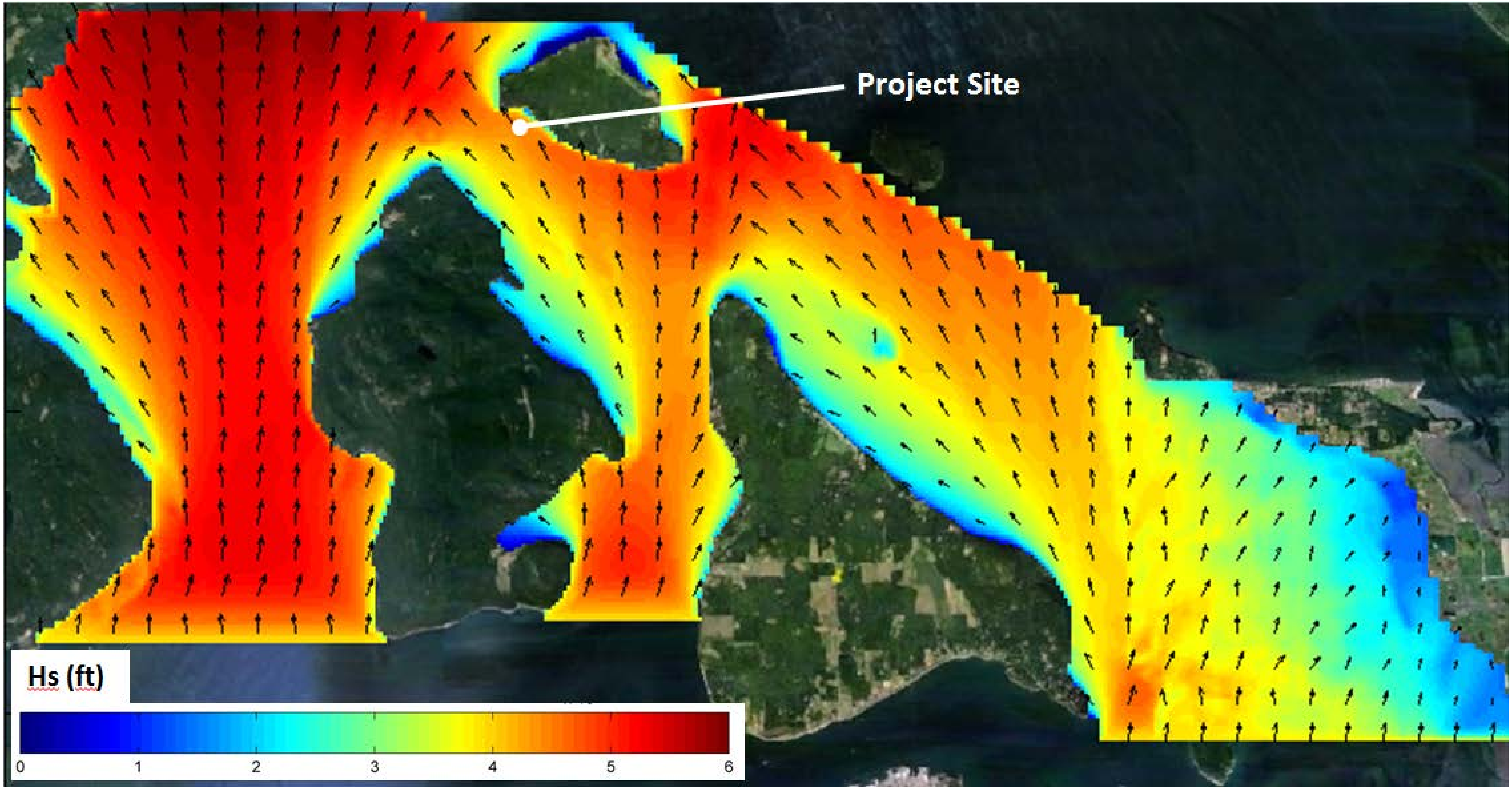

Figure B3. Delft3D Wave Model Output – Run 3 (Input: Wind 44.0 knots, direction 180°; Wave 4.5 feet, 2.9 seconds)

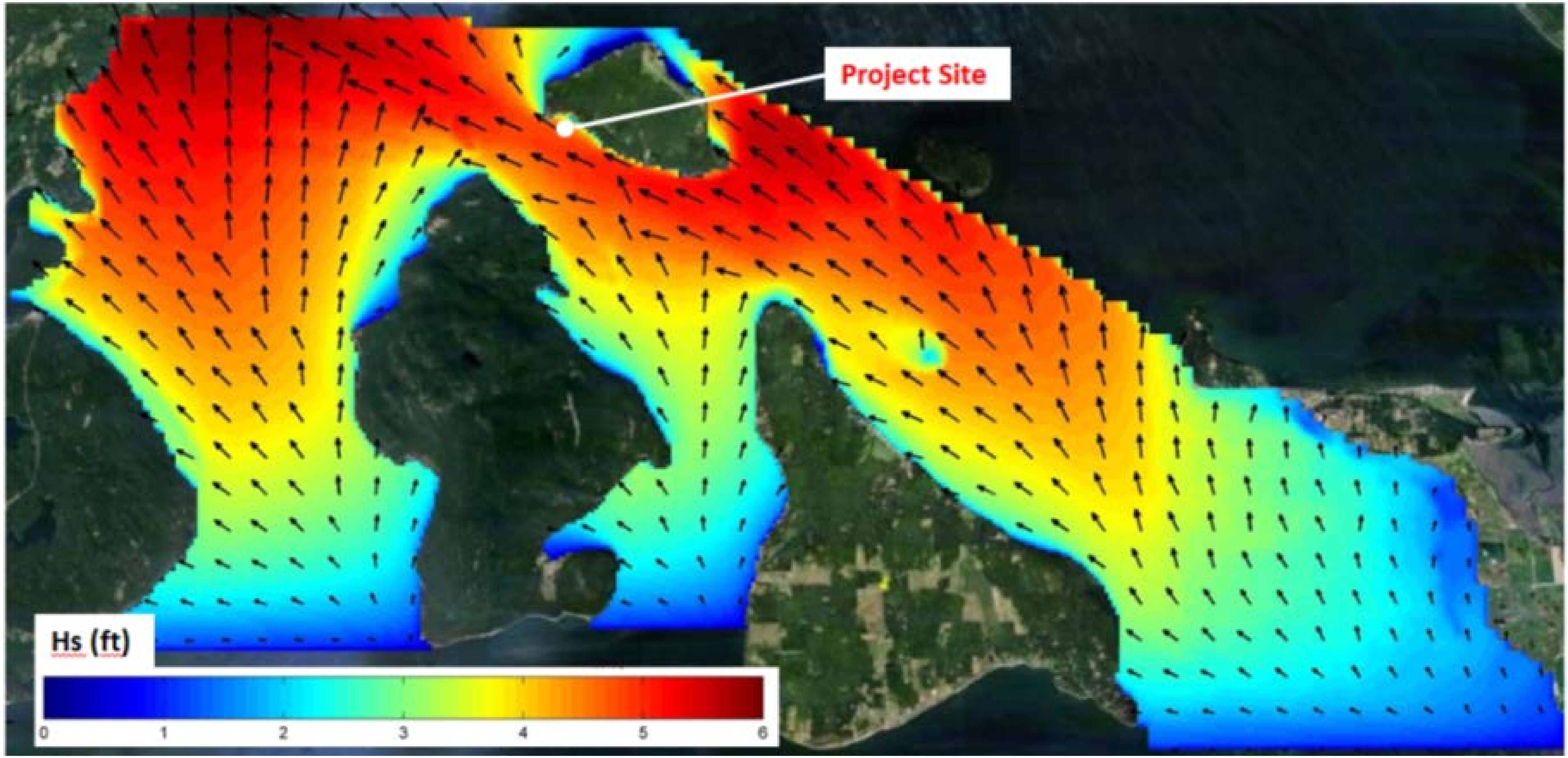

Figure B4. Delft3D-Wave Model Output – Run 4. Wind Input: 44.0 knots; Direction: 180°; Water Level: +9.8 feet MLLW

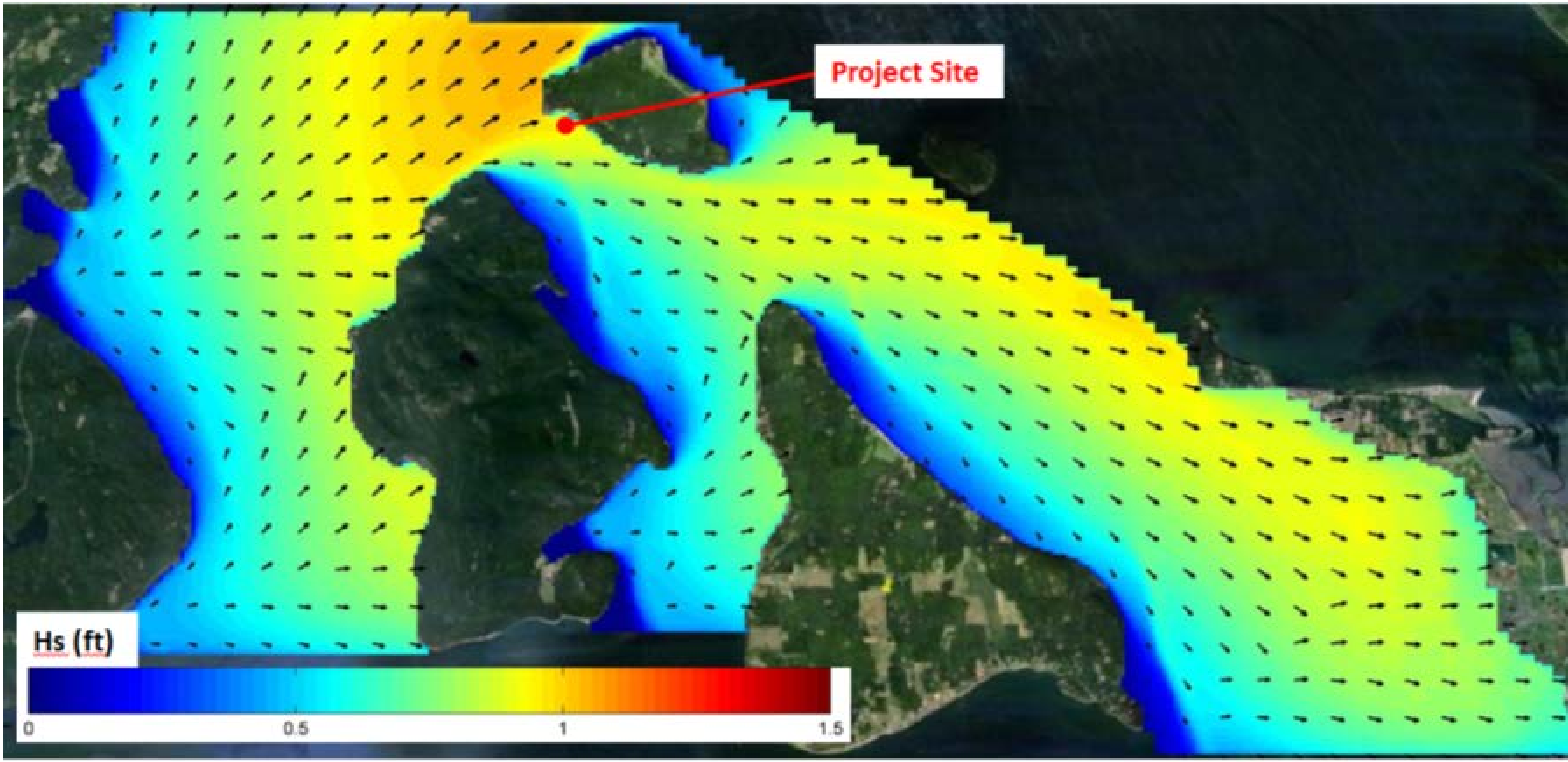

Figure B5. Delft3D-Wave Model Output – Run 5. Wind Input: 13.0 knots; Direction: 249°; Water Level: +9.8 feet MLLW

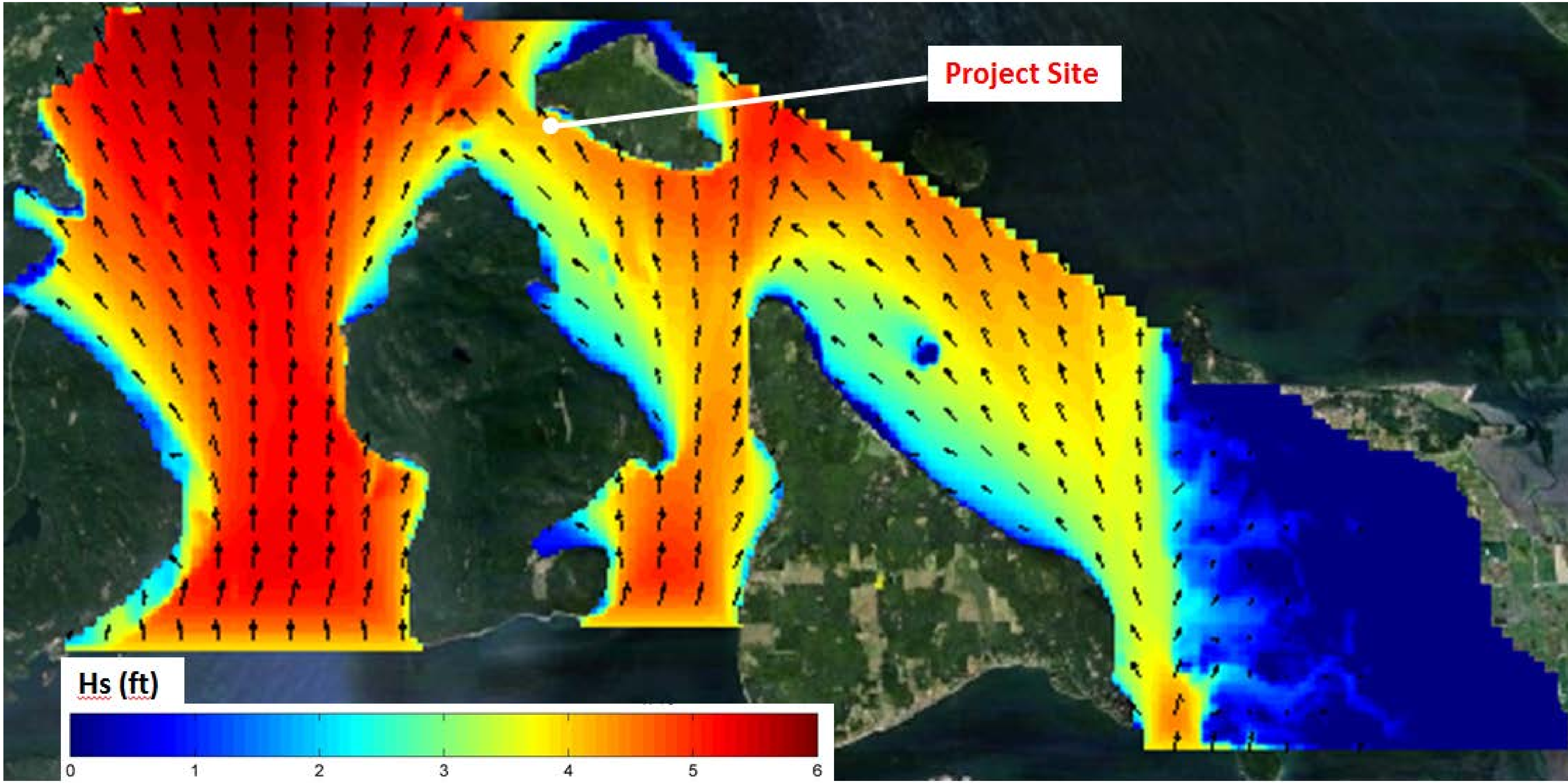

Figure B6. Delft3D-Wave Model Output – Run 6. Wind Input: 44.0 knots; Wave Input: 4.0 feet, 2.9s; Direction: 160°; Water Level: 0.0 feet MLLW

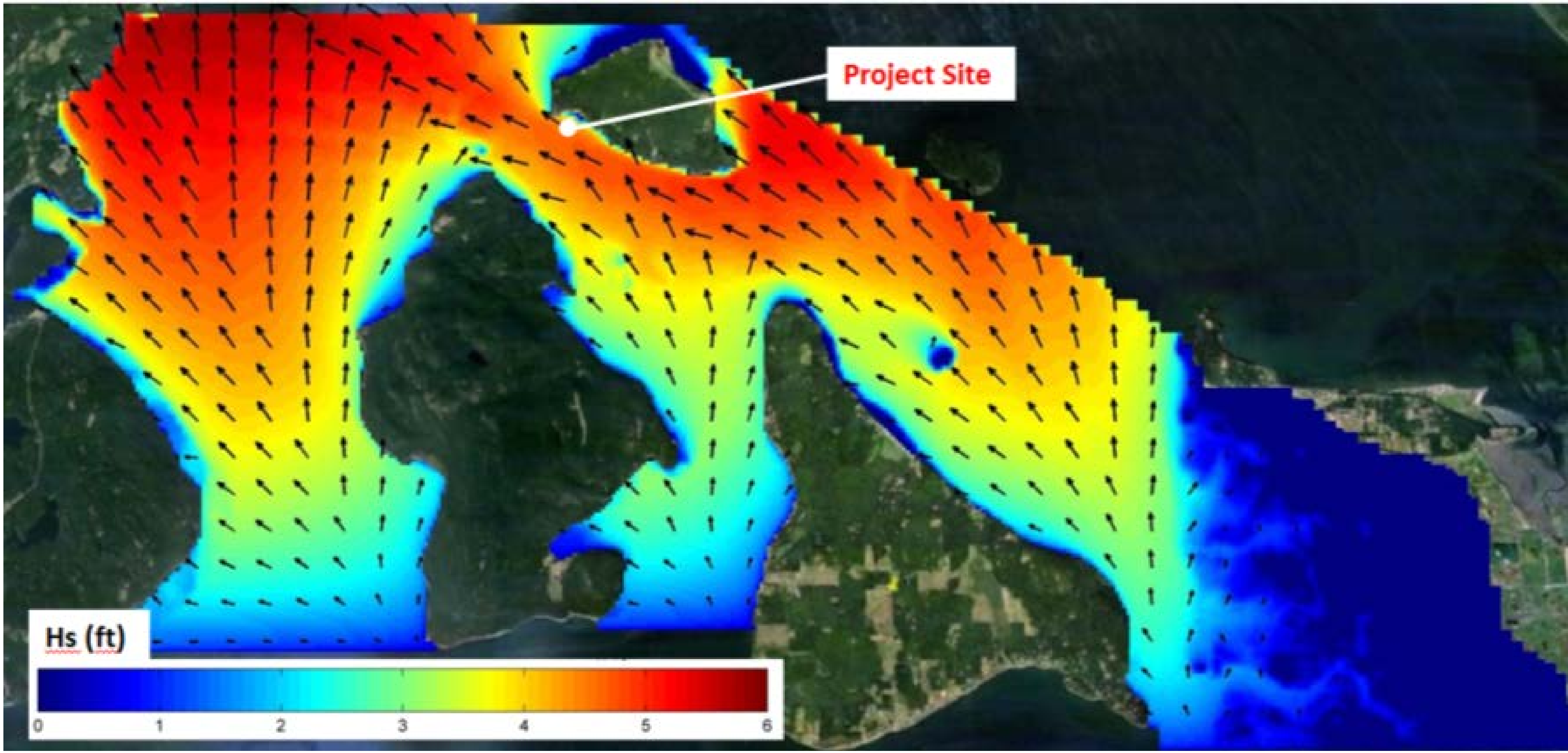

Figure B7. Delft3D-Wave Model Output – Run 7. Wind Input: 44.0 knots; Direction: 160 °; Water Level: +0.0 feet MLLW

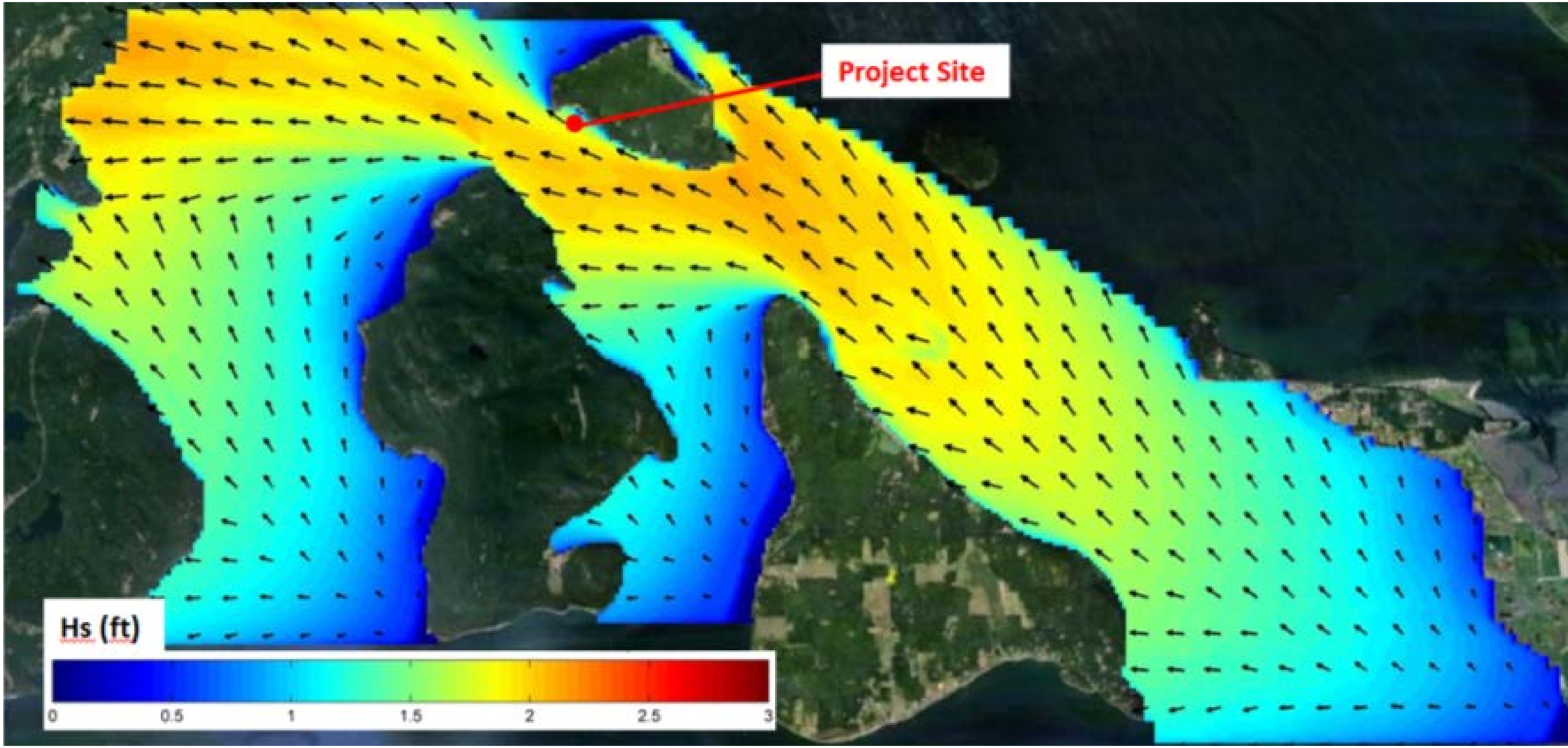

Figure B8. Delft3D-Wave Model Output – Run 8. Wind Input: 22.0 knots; Direction: 127°; Water Level: +9.8 feet MLLW

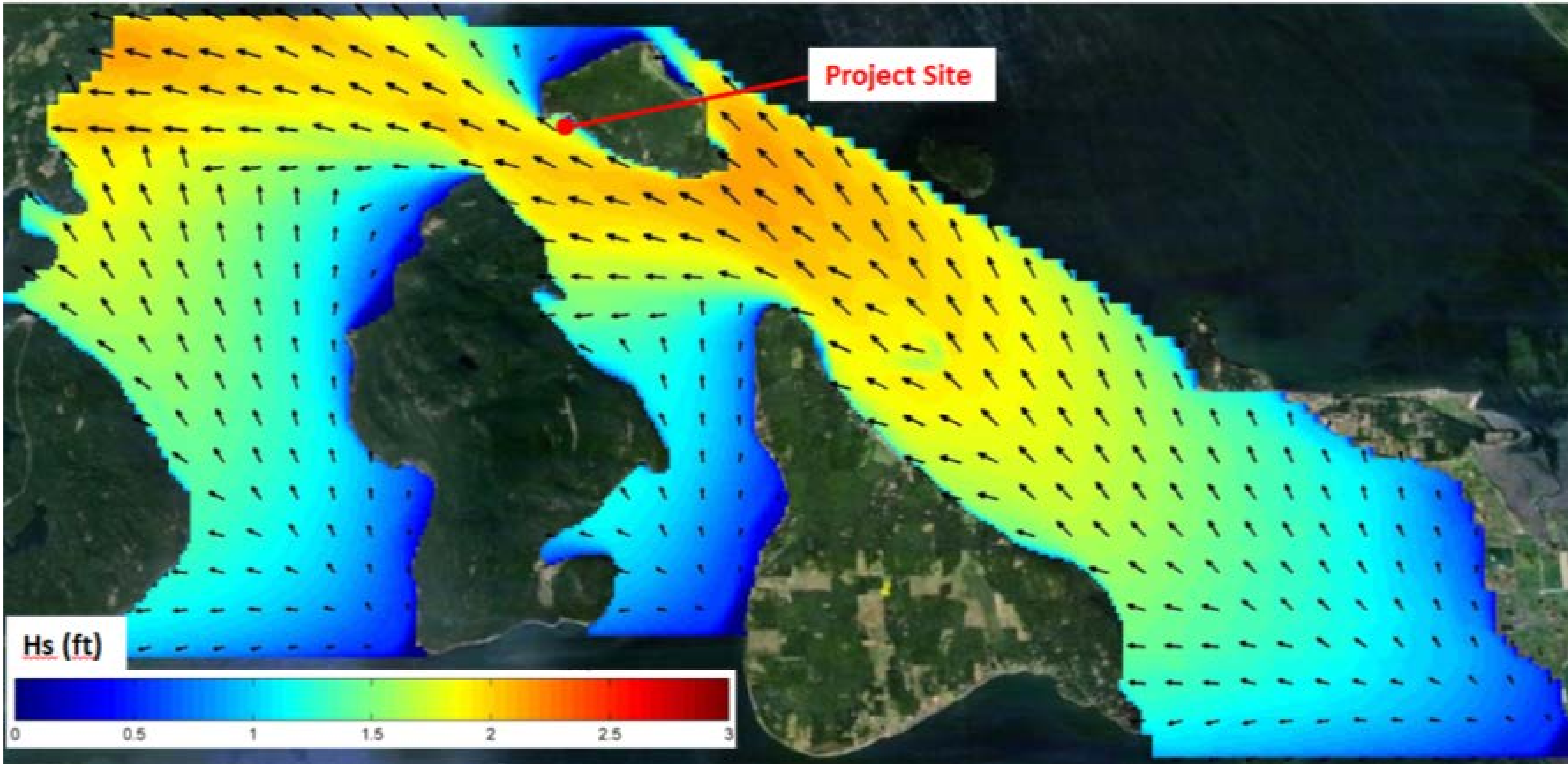

Figure B9. Delft3D-Wave Model Output – Run 9. Wind Input: 22.0 knots; Direction: 127°; Water Level: +9.8 feet MLLW

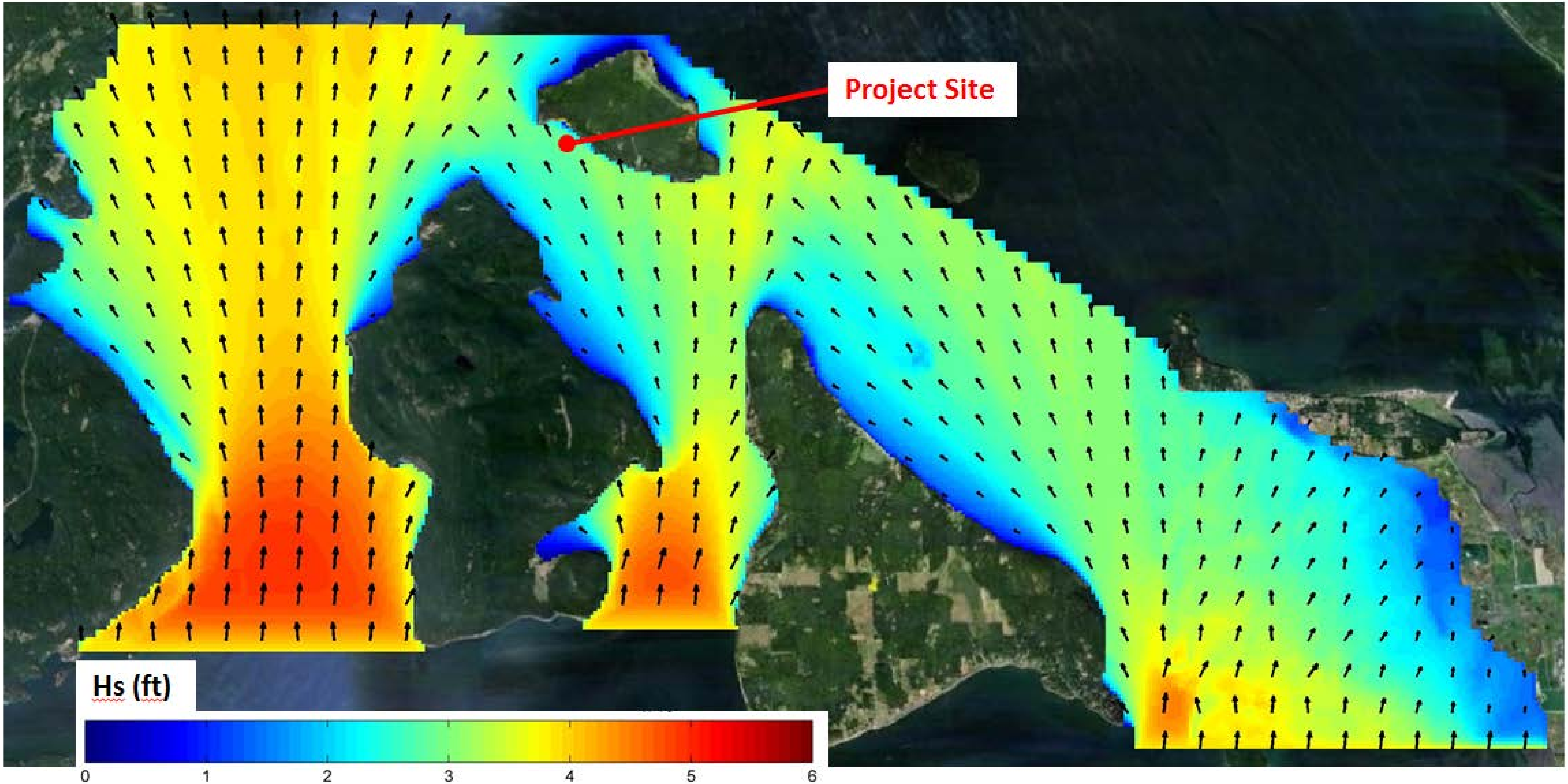

Figure B10. Delft3D-Wave Model Output – Run 10. Wind Input: 29.0 knots; Wave Input: 2.2 feet, 2.3 s; Direction: 180°, Water Level: +9.8 feet MLLW

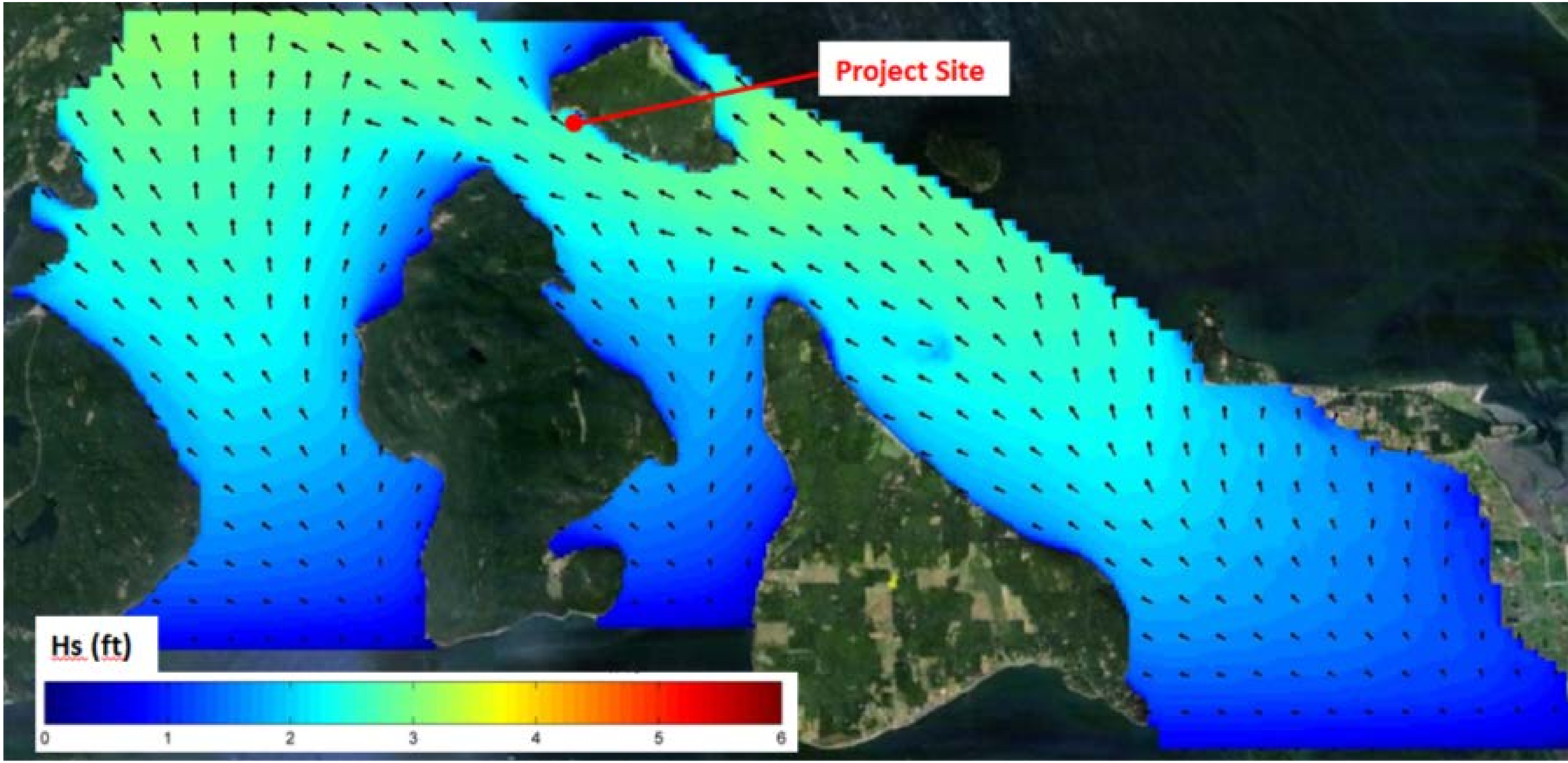

Figure B11. Delft3D-Wave Model Output – Run 11. Wind Input: 29.0 knots; Direction: 180°; Water Level: +9.8 feet MLLW

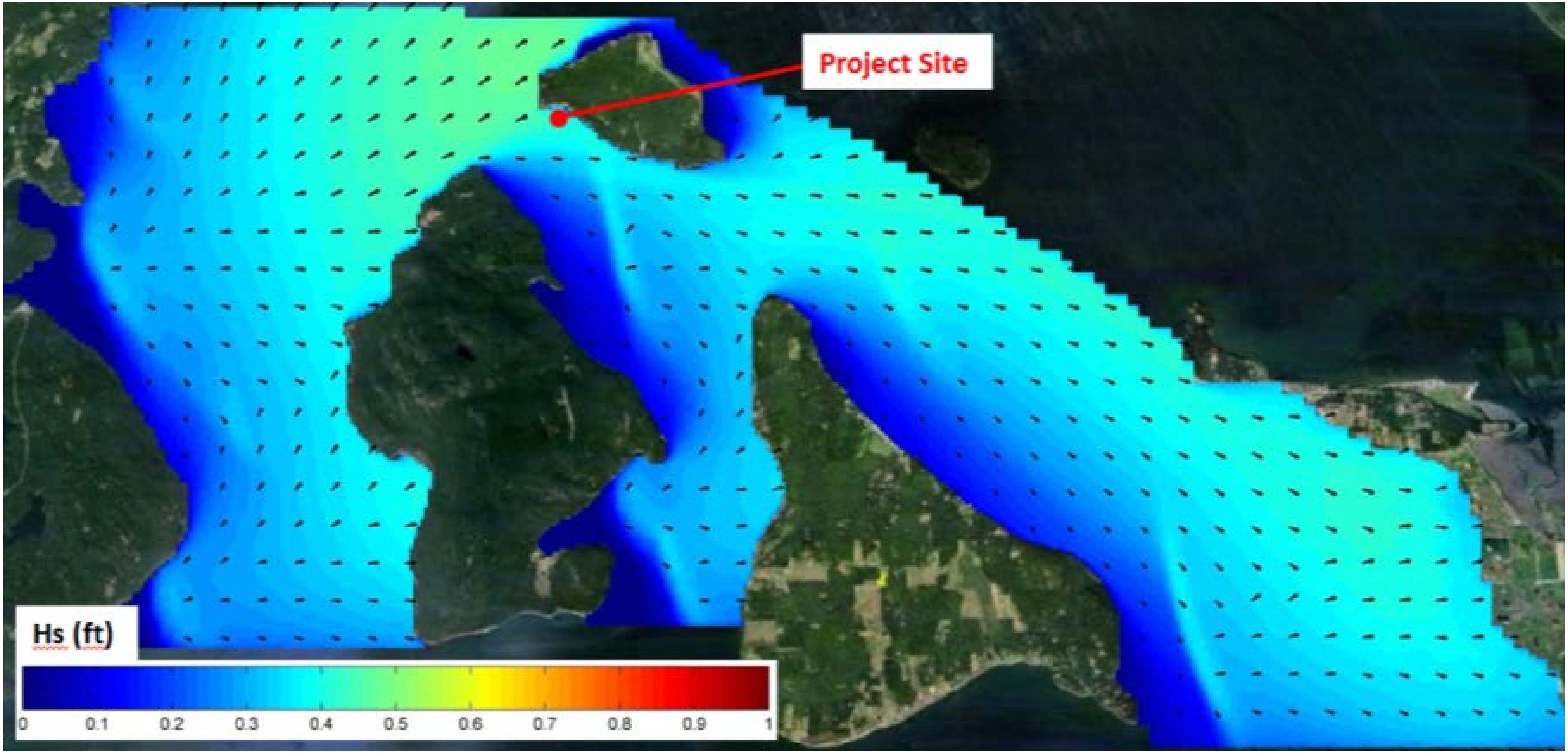

Figure B12. Delft3D-Wave Model Output – Run 12. Wind Input: 10.0 knots; Direction: 249°; Water Level: +9.8 feet MLLW