POINT WELLS REDEVELOPMENT POINT WELLS, UNINCORPORATED SNOHOMISH COUNTY

COASTAL ENGINEERING ASSESSMENT

Prepared for: BSRE | Point Wells, LP

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Prepared by:

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BSRE | Point Wells, LP

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EXECUTIVE SUMMARY

BSRE | Point Wells, LP intends to enhance the shoreline at Point Wells as part of the Point Wells redevelopment project. The enhancement includes removal of all or portions of the existing seawall, rock revetment, and riprap along the shoreline and restoring the shoreline to a more natural condition.

Moffatt & Nichol (M&N) conducted a coastal engineering assessment to support the proposed shoreline enhancement and provided recommendations for a stable shoreline configuration at a conceptual level of design, and investigated historical trends of shoreline change. This technical report presents the results of this assessment.

M&N coastal engineers conducted a site visit to characterize existing shoreline conditions on March 9, 2018. The site assessment defined three distinct reaches of shoreline with different characteristics in terms of sediment characteristics and slopes of foreshore (the part of a shoreline between high- and low-water marks). Reaches 1, 2, and 3 are stretches of shoreline on the north, west, and south side of Point Wells, respectively.

Reach 1 has a sandy lower foreshore backed by a rock revetment and a seawall. The slope of sandy lower foreshore is 8H:1V (8 units of horizontal run for 1 unit of vertical rise). Reach 2 has a mixed sand and gravel foreshore with a 10H:1V to 12H:1V slope backed by a concrete seawall. Sediment size ranges from coarse gravel at lower foreshore to fine to medium gravel at middle foreshore and sand at the upper foreshore. Reach 3 is a mixed sand and gravel shoreline with a mild slope of 15H:1V with a wide sandy berm. Sediment sizes are smaller than that of Reach 2. This classification was found to be consistent with difference in wave exposure as well.

Shoreline change trends at Point Wells were investigated by delineation of shoreline for historical (dating back to 1954) and recent aerial images. In addition, available LiDAR data sets dating back to 2005 were compared. This investigation showed an accretion pattern along the area between Reaches 1 and 2 (northwest corner of Point Wells). This trend was confirmed by comparison of historical and recent aerial images. Based on analysis of LiDAR data, this accretionary trend was found to change to an erosional pattern approximately 350 feet further south (starting immediately south of the dock office) for the period between 2005 to 2016. However, this recent erosional trend was not observed in aerial images. Our investigation determined that this erosional pattern is either due to seasonal cross-shore evolution of shoreline or due to inaccuracies of LiDAR data. The rest of Point Wells shoreline seems to be generally stable with negligible change in shoreline position for the period of analysis.

The existing rate of relative sea level rise for Seattle is estimated by National Oceanic and Atmospheric Administration (NOAA) to be 2.05 ± 0.15 mm/yr (or approximately 0.67 ft in 100 years) based on long-term measurements of water level. Prediction of future rates of sea level change contain a level of uncertainty. National Research Council (NRC) in 2012 published a study that showed projected future sea-level rise by 2100 ranges from approximately +14 inches to +54 inches, with a medium estimate of +28 inches for

Washington State, which is significantly higher than historical trend (6.6 inches by 2100). The NRC 2012 values are widely considered to be the best available science on sea level rise for Washington State. Incorporating freeboard as well as implementing adaptive measures in design of shoreline enhancement/protection measures can mitigate for rising sea levels.

Locally-generated wind waves were identified as the main driver for possible shoreline evolution. Analysis indicated that swell, passing vessel wakes, and tidal currents at Point Wells would not be the primary drivers of shoreline evolution.

The wind-wave numerical modeling results showed that southerly storms generate the largest wave heights in project vicinity. Waves from southerly storms approach Reach 3 head-on (with an approach angle perpendicular to shoreline) with deep water incident significant wave height (Hs) approximately equal to 4.3 feet and peak wave period (Tp) approximately equal to 4.9 sec. The next strongest storm direction is northerly and northwesterly. These storms approach Reach 1 head-on with deep water incident waves of Hs = 3.9 feet and Tp = 5.3 sec. Westerly storms are not as strong as other directions. These storms can approach Reach 2 head-on with deep water incident waves of Hs = 1.3 feet and Tp = 2.4 sec.

Maximum wave runup for existing conditions at Reaches 1, 2, and 3 was estimated to be 14.5, 14.7, and 13.5 feet referenced to National American Vertical Datum 1988 (NAVD88), respectively, for 50-year storm events occurring at the same time as a Mean Higher High Water (MHHW) tide at Elevation 8.84 feet, NAVD88. Estimated maximum runup value for Reach 2 is a conservative estimate because it does not account for angle of waves approaching the shoreline.

Proposed shoreline enhancements (removal of revetment and seawall and re-grading the slope to a flatter foreshore) would reduce the maximum wave runup at Reaches 1 and 2. Based on estimates of maximum runup for proposed conditions at Reaches 1, 2, and 3, elevation of top of proposed esplanade was recommended to be set to +16.0[1] feet, NAVD88 to prevent overtopping for a 50-year return period storm event occurring at the same time as a MHHW tide. This elevation would provide a minimum freeboard of 1.3 feet and 1.5 feet for existing and proposed conditions, respectively. The freeboard will accommodate future relative sea level rise (based on historical trends and low estimates for future predictions), and more intense storms. It should also be noted that use of maximum runup for determination of esplanade elevation is a conservative approach that precludes all contact between runup and upland structure.

It should be noted that Federal Emergency Management Administration (FEMA) has determined the 1-percent annual chance base flood elevation (BFE) at +14.0 feet, NAVD88 seaward of the existing seawall and +12.0 feet, NAVD88 landward of the seawall.

[1] Elevation for top of promenade for Elliott Bay Seawall was selected to be at +16.0 ft, NAVD88 (City of Seattle 2013).

Selecting the elevation of top of esplanade at +16.0 feet, NAVD88 places the esplanade out of special flood hazard area (area at high risk of flooding).

Removal of the seawall and revetment as well as construction of the enhanced shoreline was investigated and shoreline protection measures, as necessary, were developed at a conceptual level. Reach 3 has a mild foreshore slope of 15H:1V and a sandy berm (20-ft wide on average) along most of the shoreline. Historical trend of shore change rate (SCR) indicated that this reach has been stable. Given wave exposure and estimated runup values lower than berm elevation for this reach, removal of the seawall is feasible and should not alter the shoreline dynamics or require wave protection.

For Reaches 1 and 2, recommended measures for shoreline enhancement/protection required for removal of revetment and seawall were provided at a conceptual level of design. These recommendations include excavation and placement of an enhanced shoreline composed of two dynamically stable layers to accommodate variations in life cycle storm events. Layer 1 (top layer) and Layer 2 (underlying layer) were designed to be dynamically stable for up to a 10-year and 50-year return period storm event occurring at the same time as a MHHW tide, respectively. Size and thickness of material for both layers are provided.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1.0 INTRODUCTION

1.1 Study Purpose

BSRE | Point Wells, LP (Client) intends to enhance the shoreline at Point Wells as part of the Point Wells redevelopment project. The intended enhancement includes removal of all or portions of the existing seawall, rock revetment, and riprap along the shoreline and restoring the shoreline to a more natural condition.

Moffatt & Nichol (M&N) was retained by Client to conduct a coastal engineering assessment to support the proposed shoreline enhancement by providing recommendations for a stable shoreline configuration at a conceptual level of design. This technical report presents the results of this investigation.

1.2 Project Setting

Point Wells is in the unincorporated Snohomish County, WA on the east shoreline of Central Puget Sound, 1.8 miles south of Port of Edmonds Marina and 1.3 miles north of Richmond Beach Saltwater Park. The project site is to the west of Town of Woodway, bordered to the east by a railroad and Richmond Beach Drive and to the north and south by stretches of armored shoreline. The site location is shown in Figure 1-1 on a Google Earth aerial image.

Several waterfront structures are present along the project shoreline. Toward the north end, there are derelict timber piles and remnants of a dock structure that extend approximately 110 feet offshore next to a concrete access ramp. A pile-supported pier is connected to shore with three timber trestles at the central portion of the project shoreline. In addition, three outfalls discharge storm water directly onto the shoreline.

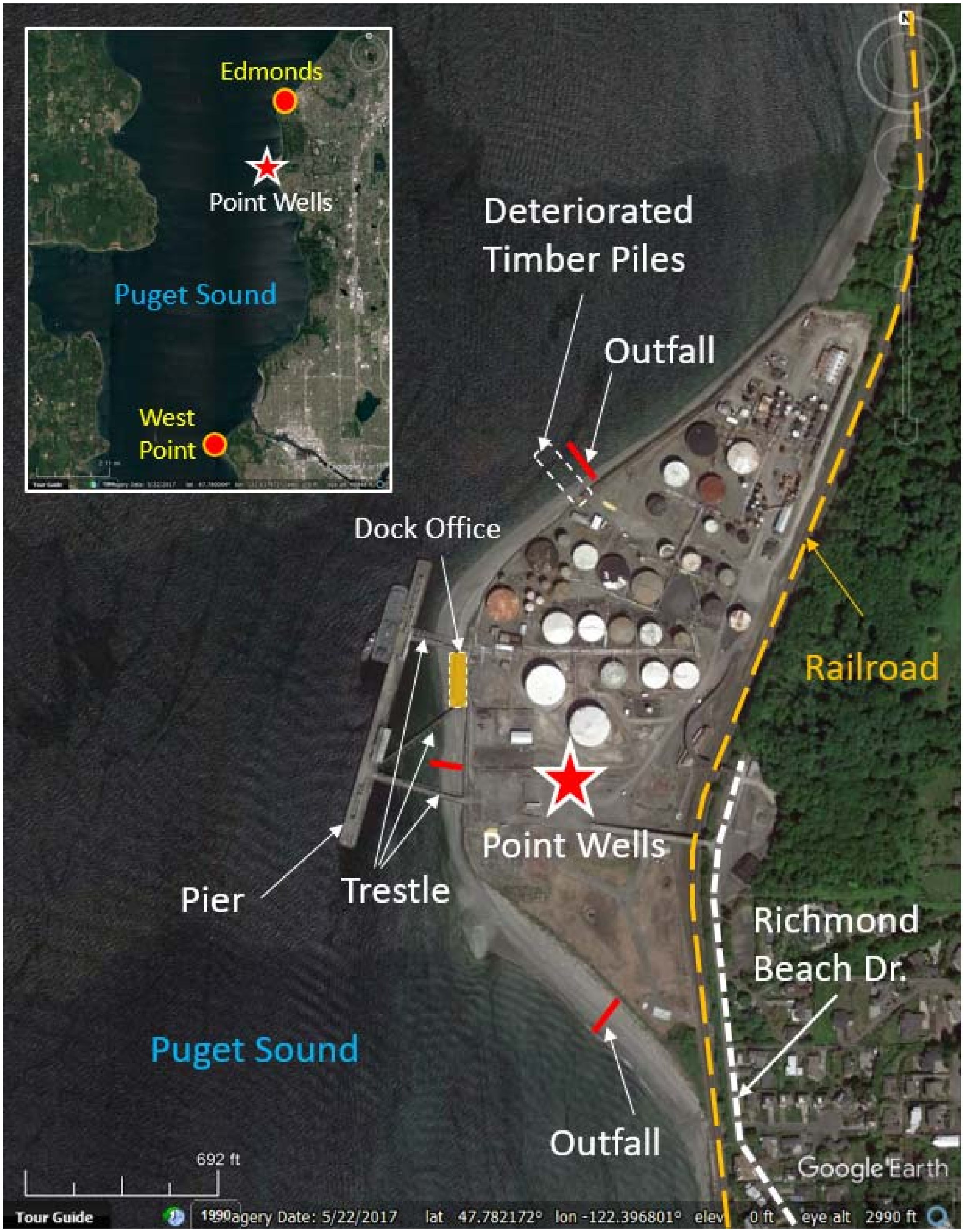

Figure 1-1: Vicinity map of Point Wells shown on a Google Earth aerial image. The inset shows the location of Point Wells with respect to Edmonds and West Point in Washington.

2.0 GEOMORPHIC SETTING

In Puget Sound, the major source of coastal zone sediment is from the erosion and reworking of coastal bluff exposures of till, outwash sediments, and glacial marine deposits (Finlayson 2006). These deposits often exhibit a variety of sediment types simultaneously including clay, silt, sand, and gravel. Consequently, the beach sediments derived from these sources are similarly complex with heterogeneous mixtures of pebble gravels and coarse-grained sands being the most prevalent.

Washington State Department of Ecology (Ecology) identified Geology of Puget Sound shorelines (1978) shown in Figure 2-1. Point Wells geology is identified as artificial fill (af) backed by bluffs comprised of Vashon till (Qvt), landslide deposits (Qls), and Pre-Fraser nonglacial sediments, undifferentiated (Qns). It is observed that gravel deposits in nearshore areas exist to the south and north of Point Wells.

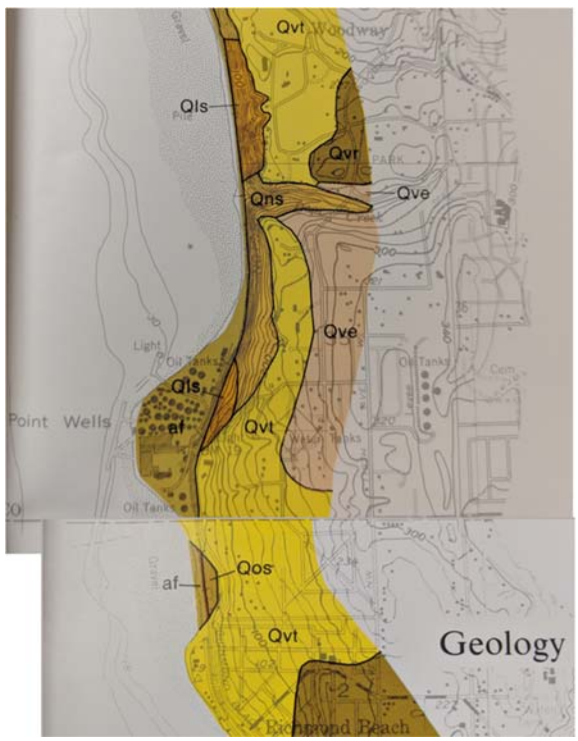

Figure 2-1: Geology of Point Wells vicinity provided by Ecology (1978), a composite of KI1 (King County) and SN11 (Snohomish County) sectors.

2.1.1 Sediment Sources

Historically, bluff erosion provided sediment to the coastal zone in the project vicinity. However, construction of the railroad and armoring the slopes to protect the bluff from erosion along the sound in the late 1890s disconnected this sediment source from the sound. Occasional landslides have occurred in the project vicinity and deposited sediment into the coastal zone.

Two significant landslides have occurred north of Point Wells since the 1970s. A large landslide, named Woodway landslide, occurred in 1997. This landslide was over 100 thousand square feet in area. Aerial images indicate another landslide occurred in the early 1970s approximately 4,000 feet north of the property. Approximate location of these two landslides is delineated in Figure 2-2.

Other sources of sediments include Deer Creek and a few other small streams that bring sand and gravel to the shoreline in the project vicinity, as shown in Figure 2-2. In addition, two outfalls discharge directly onto the shoreline on the south and north ends of project site.

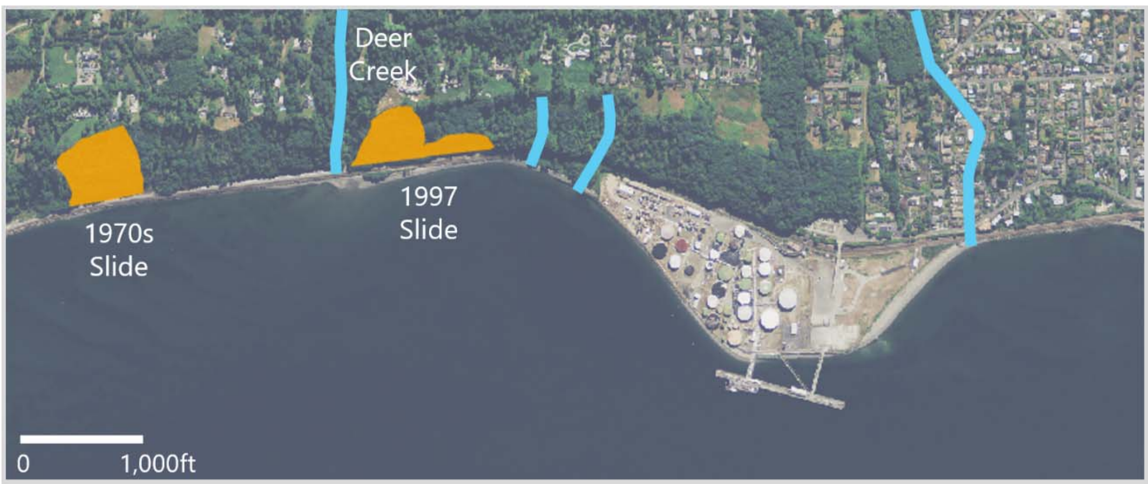

Figure 2-2: Location of two landslides in project vicinity. Deer Creek and other small streams provide sediments to the shoreline.

2.1.2 Net-Shore Drift

The net-shore drift in Puget Sound is typically aligned with the direction of longest fetch (horizontal distance over which a wind generates waves) and dominant wave energy sector. The Ecology has published two data sources documenting shoreline drift (Ecology 1978, 2018) shown in Figure 2-3. Ecology 1978 indicates a convergence of sediment transport paths at Point Wells for both summer and winter net-drift directions, see Figure 2-3(a). On the contrary, Ecology 2018 indicates a continuous sediment transport path from south to north, as shown in Figure 2-3(b). Use of different size cells might have led to this discrepancy. It appears that Ecology 2018 used larger drift cells than Ecology 1978.

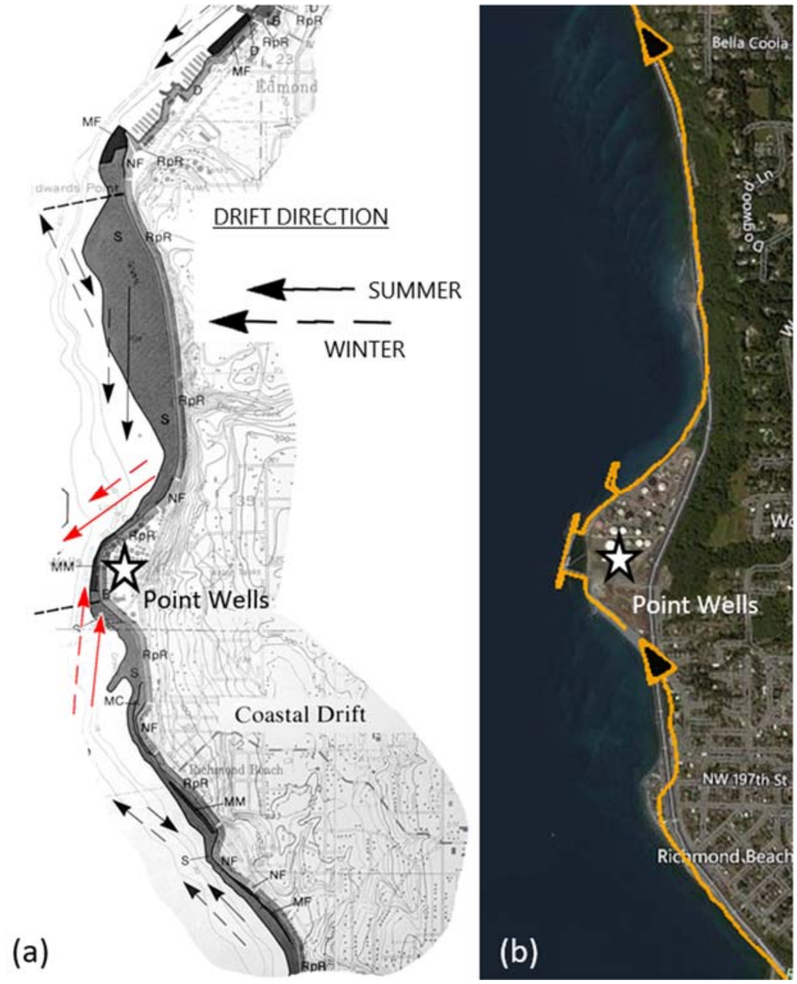

Figure 2-3: Net-Drift direction provided by Ecology: (a) 1978 and (b) 2018.

Investigation of available aerial images showed a consistent sediment lobe feature on the southwest corner of Point Wells identified in aerial images from 1977 and 2014, shown in Figure 2-4 as well as an oblique aerial from 2006, shown in Figure 2-5. Existence of this feature, dating back to at least 1977, indicates that this feature is permanent. The surficial material on the sediment lobe is covered with medium to coarse gravel, as shown in the inset of Figure 2-5. Existence of this feature is potential confirmation of convergence of two drift cells at this location, identified by Ecology 1978.

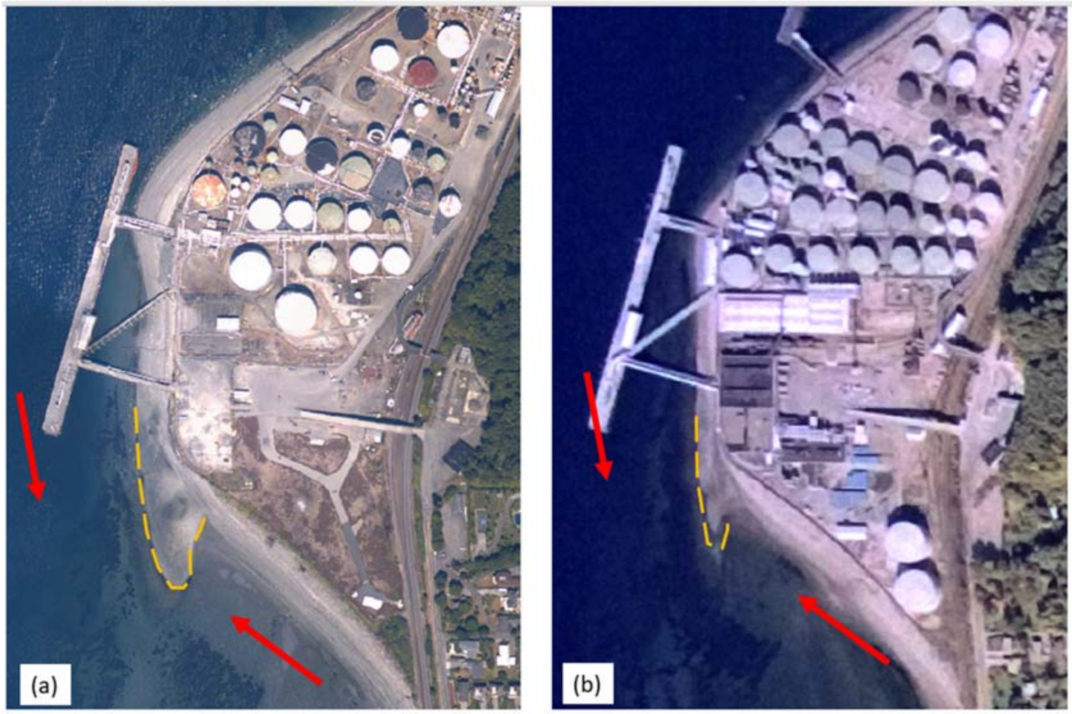

Figure 2-4: Sediment lobe feature outlined with a dashed line in aerial images from (a) 2014 and (b) 1977. Arrows represent assumed net-drift directions.

Figure 2-5: Oblique aerial view (2006) of sediment lobe feature identified with a dashed line. The inset shows a ground photo (M&N 2018) of surficial material.

2.2 Topography and Bathymetry

Numerous topographic data sets with coverage of the Point Wells site were collected to examine the geomorphic conditions in the nearshore zone. The elevation sources and survey dates are listed in Table 2-1. The topographic data covers from 2003 to 2016 with a few surveys capturing elevations as low as +3 feet, NAVD88.

Table 2-1: Elevation data sources and dates with coverage of Point Wells.

Elevation Source and Data set	Survey Date
Western Washington 3DEP QL1 LiDAR Survey	March 2016
Puget Sound LiDAR Consortium 2016-2017 LiDAR Survey	March 2016
WSDOT Rail Slide Hazard LiDAR (WSDOT) Survey	April 2013
NOAA Digitation Elevation Model of Puget Sound, WA	June 2014
Snohomish County LiDAR	2005
Puget Sound LiDAR Consortium 2003 LiDAR Survey	2003
Point Wells LiDAR Survey	March 2003
NOAA H11190 Bathymetry Survey	2002

A digital elevation surface, composite of a 2003 LIDAR data set and a nearshore bathymetry survey, for Point Wells was provided to M&N by the Project Team. All information developed herein with reference to existing grades and elevations is based on this surface and would have to be verified with a combined topography/nearshore bathymetry survey at later phases of design.

2.3 Existing Shoreline Conditions

M&N coastal engineers conducted a site visit to characterize existing shoreline conditions on March 9, 2018. The site assessment showed that there are three distinct reaches of shoreline with different characteristics in terms of shoreline sediment and slopes. These three reaches are named Reach 1, 2, and 3 and are shown in Figure 2-6. This classification is consistent with difference in wave exposure, as observed in Section 3.5.1. The following sections describe characteristics of each reach of shoreline.

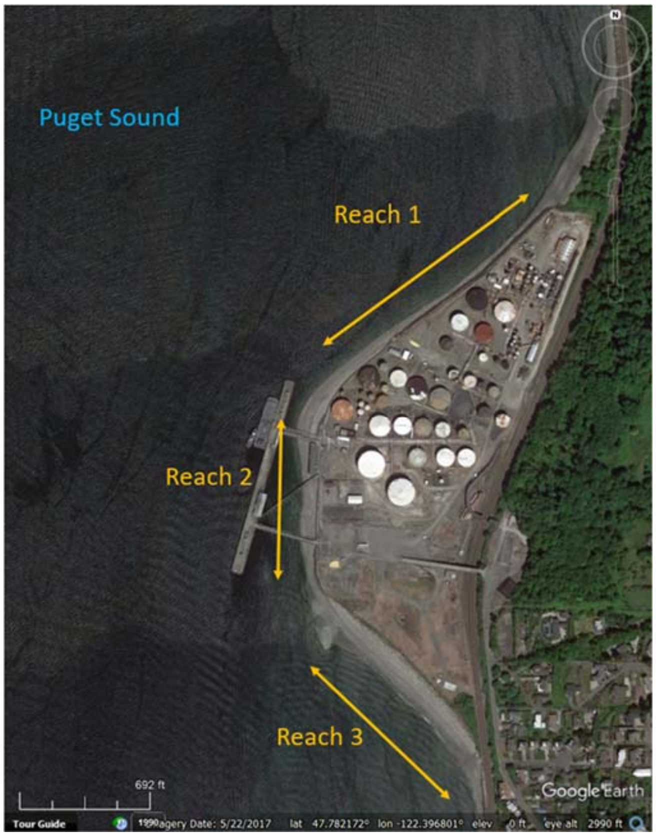

Figure 2-6: Three distinct reaches (Reach 1, 2, and 3) of Point Wells shoreline.

2.3.1 Reach 1

Reach 1 has a sandy lower foreshore backed by a revetment and a seawall (steel sheet pile wall) for most of its length. As-built drawings of the revetment and seawall were not available. Part of Reach 1 is shown on an oblique aerial in Figure 2-7. Piles from a former pier are located within Reach 1 as well as a concrete access ramp, as shown in Figure 2-7. Reach 1 is bordered to the north by a natural looking sandy shoreline.

It was observed that the sandy foreshore of Reach 1 steepens and widens moving from the northeast to northwest corner, while the visible rock revetment width at the toe of the wall decreases. Eventually, there is no visible revetment or riprap seaward of the seawall. This change is clear in comparison of Figure 2-8 with Figure 2-9. It is possible that the revetment has been buried by natural accreting sand over time. As-built drawings of the revetment were not available to confirm this hypothesis.

Figure 2-7: Reach 1 comprised of a sandy lower foreshore backed by a revetment and a seawall, shown on an oblique aerial (Ecology 2016). Reach 1 is bordered to the north by a natural shoreline.

Figure 2-8: Ground photo of Reach 1 looking northeast shows a sandy foreshore backed by a revetment and seawall. A 1.5-feet by 1.5-feet scale is placed on the shoreline for reference.

Figure 2-9: Ground photo of Reach 1 looking southwest shows a wide sandy foreshore backed by scattered rocks and a steel seawall.

Elevation profile for a typical section of Reach 1 is shown in Figure 2-10. It can be observed that a low tide/sub-tidal terrace with a 55H:1V (55 units of horizontal run for every 1 unit of vertical rise) slope leads to the sandy foreshore. The sandy foreshore has a 8H:1V slope and extends from Elevation +0.0 to +6.0 feet, NAVD88. The toe of the rock revetment is at Elevation +6.0 feet and top of the seawall is approximately at Elevation +16.0 feet, NAVD88. It should be noted that elevations shown for Reaches 1, 2, and 3 are approximate and mainly based on the project digital elevation surface provided by the Project Team. Some interpolation between surfaces has been made as well. It is expected that a nearshore topography/bathymetry survey is conducted for future phases of design.

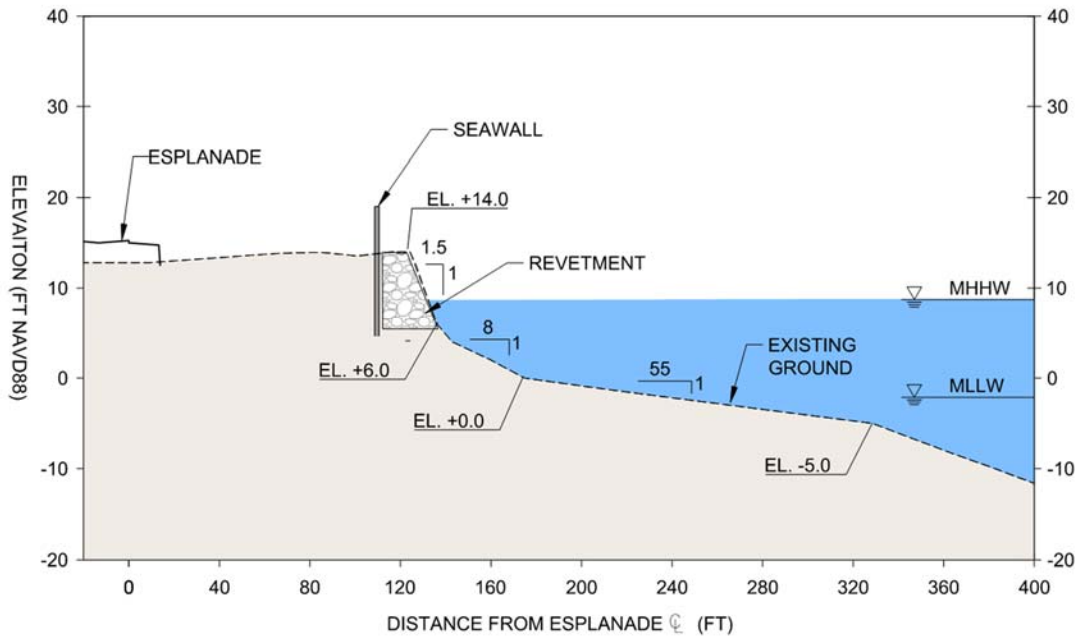

Figure 2-10: Elevation profile for a typical section of Reach 1. Elevations are referenced to NAVD88 in feet, based on digital elevation surface provided by the Project Team. Location and details of seawall and revetment are approximate.

Representative photos of material on the lower and middle foreshore of Reaches 1, 2, and 3 are shown in Figure 2-11. for reference. Surficial sediment samples collected at Reach 1 were analyzed for size gradation by Hart Crowser (2018). The median grain size of the shoreline sediment (d_{50}) for Reach 1 was found to be 0.5 mm, where 99.5% of material was sand and only 0.5% fines (silt and clay). Sediment samples from this shoreline were categorized as poorly graded sand. Some areas of the shoreline had scattered gravel as well as debris, such as brick.

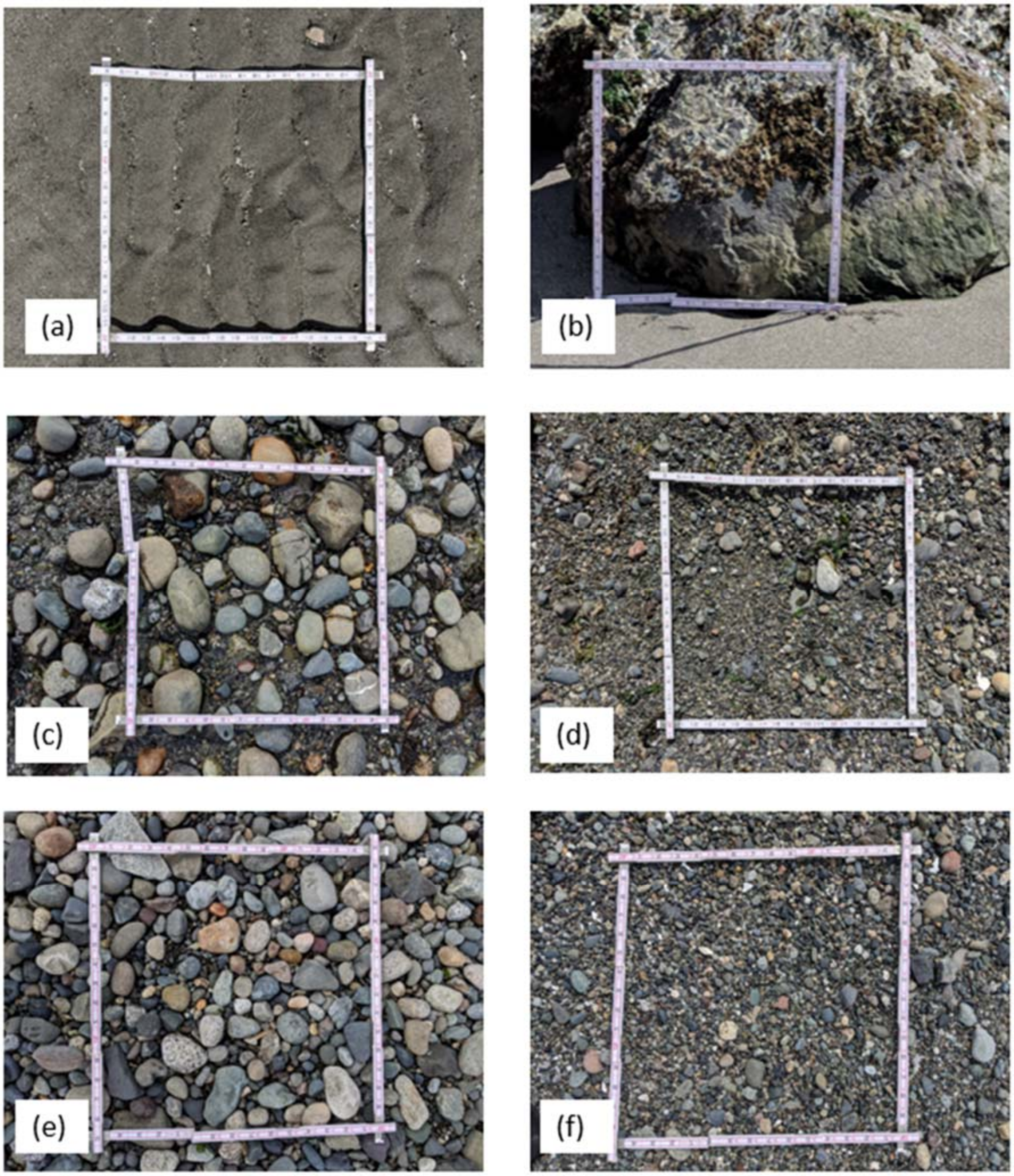

Figure 2-11: Sediment size against a 1.5-feet by 1.5-feet scale for (a) Reach 1, lower foreshore; (b) representative armor stone for Reach 1; (c) Reach 2, lower foreshore; (d) Reach 2, middle foreshore; (e) Reach 3, lower foreshore; and (f) Reach 3, middle foreshore.

2.3.2 Reach 2

This stretch of shoreline is backed by a concrete seawall. Three shore-perpendicular pile-supported trestles lead out to the marine terminal pier. The dock office is a pile-supported administrative building located on Reach 2 between the trestles, see Figure 1-1. A ground photo of Reach 2 is shown in Figure 2-12. The trestles and pier provide minimal sheltering from wave exposure reaching the shoreline based on user observations. The foreshore is composed of mixed sand and gravel with a sandy berm. The gravel sizes range from coarse gravel at lower foreshore to medium to fine gravel at higher elevations, see Figure 2-11(c) and (d).

Reach 2 foreshore is steeper than Reach 1, at approximately 10H to 13H:1V extending landward from Elevation +5.0 to +12.0 feet, NAVD88, as shown in Figure 2-13. Based on available survey information, in the offshore direction, beyond Elevation +5.0 feet NAVD88, the elevation drops off more quickly at a slope of approximately 3H:1V. Unlike Reaches 1 and 3, Reach 2 appears to lack a low tide terrace (wide, shallow offshore bench). The lack of this feature allows more wave energy to reach the shoreline.

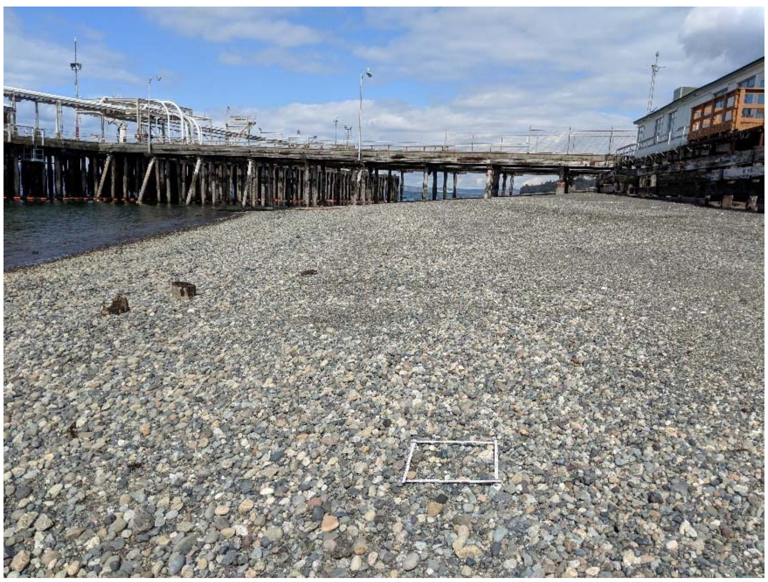

Figure 2-12: Ground photo of Reach 2 taken between the two southern trestles looking north. The mixed sand and fine to coarse gravel shoreline is backed by a concrete seawall.

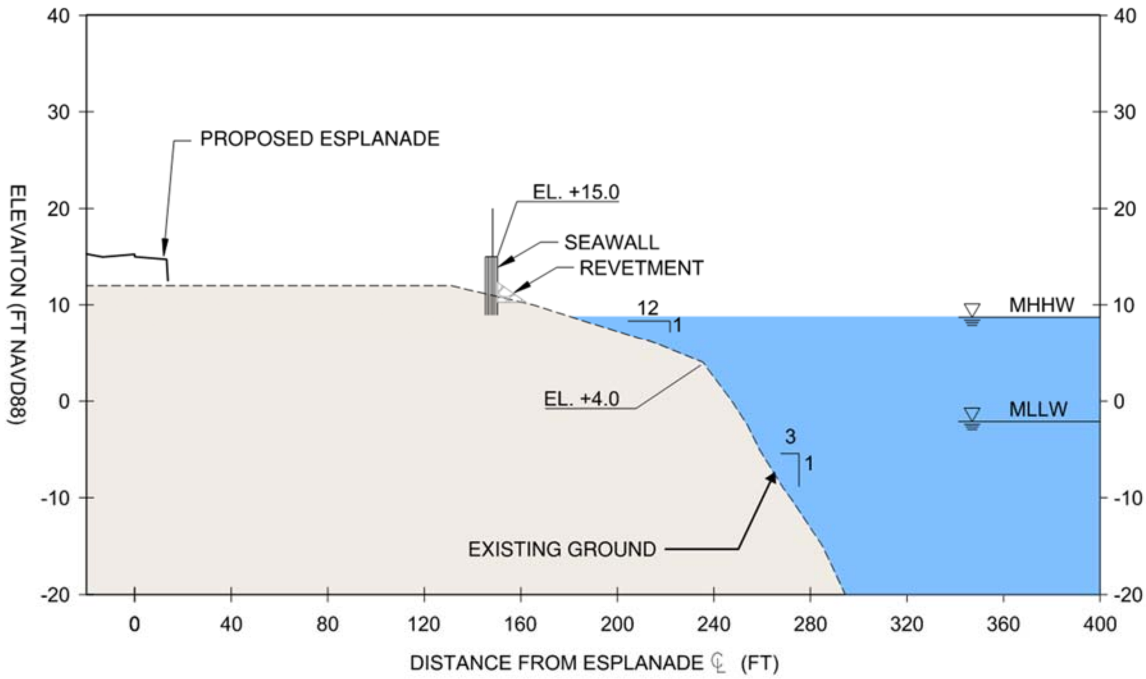

Figure 2-13: Elevation profile for a typical section of Reach 2. Elevations are referenced to NAVD88 in feet. Location and details of seawall and revetment are approximate.

2.3.3 Reach 3

The transition area between Reach 2 and 3 has a mixed sand and gravel foreshore backed by a riprap and a deteriorated timber seawall, as shown in Figure 2-14. The riprap appears to be non-engineered and the sediment gradation and slopes are similar to that of Reach 2. The non-protected width of foreshore is narrower compared to Reach 2 and 3, as shown in Figure 2-14.

Figure 2-14: Oblique aerial view of Reach 2 and 3 (Ecology 2016).

The foreshore of Reach 3 is wider and flatter than that of Reaches 1 and 2, as shown in Figure 2-15. The foreshore is mixed sand and gravel with bands of fine to medium gravel that show seasonal deposition/transport of material. Representative examples of foreshore material at the lower foreshore and middle foreshore are shown in Figure 2-11(e) and (f), respectively. Elevation profile for a typical section of Reach 3 shows that the foreshore extends from Elevation +0.0 to +14.0 feet, NAVD88 at a slope of 15H:1V. A sandy berm (min. 20-ft width) is present and can dissipate wave energy.

Figure 2-15: Ground photo of Reach 3 looking southeast. The foreshore is mixed sand and gravel with bands of fine to medium gravel that show seasonal deposition/transport of material. An outfall discharges directly to the shoreline at an Elevation of approximately +2.0 feet, NAVD88.

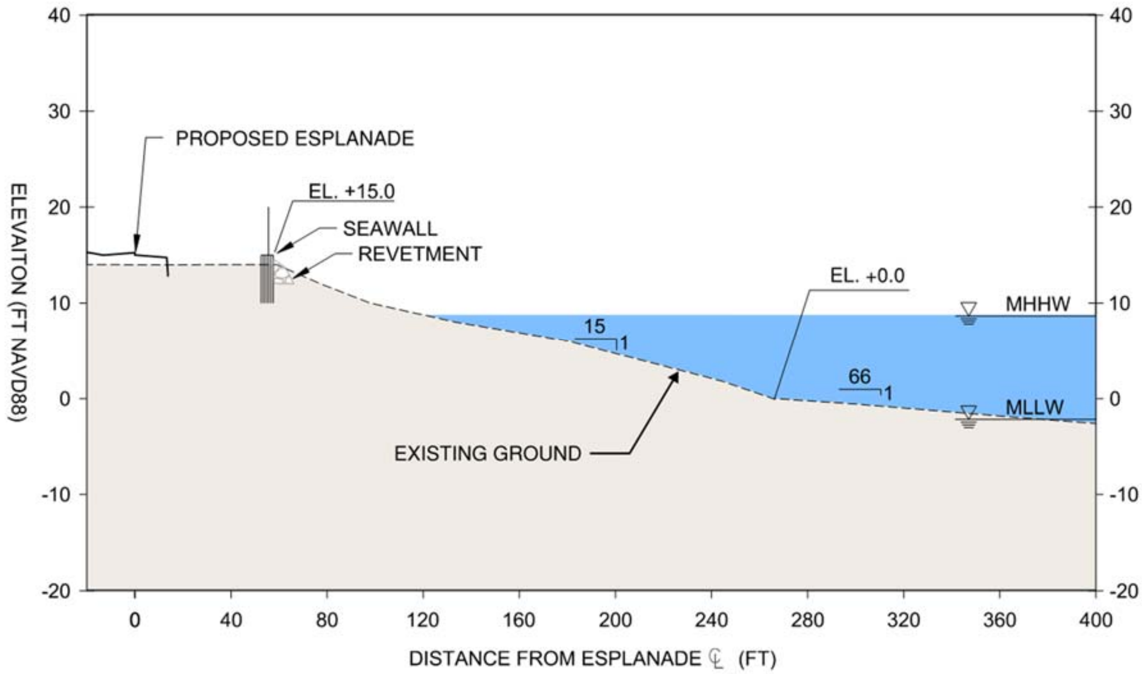

Figure 2-16: Elevation profile for a typical section of Reach 3. Elevations are referenced to NAVD88 in feet. Location and details of seawall and revetment are approximate.

2.4 Shoreline Evolution & Trends

Long-term rates of shoreline change in Puget Sound are typically low, except where there are aggravating circumstances such as historic fill or the toe of a recent or active landslide. Fetch (horizontal distance over which a wind generates seas) and wave energy is typically the dominant driver of shoreline change combined with other factors such as the geology of the material at shoreline level and local variations in sediment supply and abundance.

Historical and recent changes in shoreline position were assessed by comparing historical and recent aerial images, as well as comparing LiDAR data sets. Available aerial imagery of the site provided by various sources was compiled and is listed in Table 2-2.

Table 2-2: List of aerial imagery covering Point Wells provided by various sources.

Year	Month	Day	Time	Resolution (m)	Geo-rectified?	Oblique?	Source
1941	6	11	*	~0.9	Y	N	USGS[2]
1952	7	2	*	~1.8	Y	N	USGS
1968	8	30	14:30	~2.2	Y	N	USGS
1974	7	13	12:35	~2.3	Y	N	USGS

[2] United States Geological Survey

Year	Month	Day	Time	Resolution (m)	Geo-rectified?	Oblique?	Source
1977	10	11	12:05	~3.4	Y	N	USGS
1977	6	17	15:10	N/A	N/A	Y	Ecology
1980	7	29	10:20	~1.6	Y	N	USGS
1990	7	10	*	1	N	N	USGS NAPP[3]
1998	6 - 8	*	*	1	N	N	WADNR[4]
2001	*	*	*	*	N	N	WADNR
2002	6	43151	17:00	0.3	N	N	Snohomish County
2005	7	*	*	0.3	N	N	King County
2006	4	*	*	0.5	N	N	USGS NAPP
2006	6	27	14:44	N/A	N/A	Y	Ecology
2006	7	21		1	N	N	USDA NAIP[5]
2007	6	1	10:15	0.3	N	N	Snohomish County
2009	5 - 6	*	*	0.3	N	N	King County
2009	5	28-30	*	0.3	N	N	King County
2011	6 - 9	*	*	0.3	N	N	Snohomish County
2011	8	26	13:00	1	N	N	USDA NAIP
2012	4	7	11:52	0.08	N	N	King County
2012	4 - 8	*	*	0.23	N	N	Snohomish County
2013	7	15	10:00	1	N	N	USDA NAIP
2014	7	26-27	*	0.5	N	N	NOAA ICOM
2015	8	7	15:40	1	N	N	USDA NAIP
2015	3	8	18:30	0.15	N	N	King County
2015	4	17	11:35	0.08	N	N	WWRO[6]
2016	6	27	2:44	N/A	N	Y	Ecology
2017	8	21	14:18	1	N	N	USDA NAIP

Comparison of oblique aerial imagery for the stretch of shoreline between Reach 1 and 2 from 1977 and 2016 at approximately same tide level shows wider foreshore in 2016 and indicates accretion of shoreline since 1977. It is unclear whether the revetment along the seawall has been removed or buried underneath the migrating sand. This accretionary pattern could be due to long-shore transport and deposit of material from the 1997 Woodway landslide.

[3] National Aerial Photography Program
[4] Washington State Department of Natural Resources
[5] U.S. Department of Agriculture, National Agriculture Imagery Program
[6] Western Washington Regional Orthophotography

Figure 2-17: Comparison of oblique aerials for transition between Reach 1 and 2 from (a) 1977 and (b) 2016 at approximately same tide level show wider foreshore in 2016 and indicate accretion of shoreline. It is unclear whether the rock revetment along the seawall has been removed or buried underneath the migrating sand.

SCR for Point Wells was estimated for two periods of 2005-2016 and 1974-2016 to represent recent and historical trends, respectively. For the 1974-2016 period, first the USGS 1974 aerial image was geo-rectified. Next, the time of day when the image was taken was estimated based on average shadow size for the oil tanks and buildings using NOAA Solar Calculator tool. Then, based on the date and time of the image, tide level was obtained as 4.4 feet, NAVD88 from water level records measured at NOAA Seattle tide station. The position of shoreline was delineated for the geo-rectified image. This delineated shoreline corresponds to contour line with elevation of 4.4 feet, NAVD88 and was compared to position of contour line with the same elevation from 2016 LiDAR data. The results are shown in Figure 2-18.

For the 2005-2016 period, change in position of elevation 4.4 feet, NAVD88 contour line from two LiDAR data sets of 2005 and 2016 was obtained. Estimated rates for this 13-year period is shown in Figure 2-18.

It can be observed that the stretch of shoreline between Reach 1 and 2 shows an accretionary pattern for both historical (1974-2016) and recent (2005-2016) periods. Estimated rates of shoreline change for this stretch are higher (maximum of 3 ft/yr) for recent period of analysis compared to the historical period (maximum of 1.5 ft/yr). The stretch of Reach 2 immediately south of the dock office is demonstrating an erosional trend in the 2005-2016 period. This erosional trend is neither captured in the analysis for 1974-2016 period nor in comparison of recent or historical aerial images. This erosional pattern south of the dock office is likely due to seasonal cross-shore changes in shoreline or inaccuracies of one LiDAR data.

Rates of shoreline change for the rest of the Point Wells shoreline (east end of Reach 1, stretch of shoreline between Reach 2 and 3, and Reach 3) are not significant for both periods of analysis. This is an indication that most of the shoreline has been relatively stable.

It should be noted that another study identified the entire Point Wells shoreline as accretionary (CGS 2005). CGS (2005) conducted field mapping of feeder bluff and accretion shoreforms. However, detail of determination of Point Wells shoreline as accretionary were not provided.

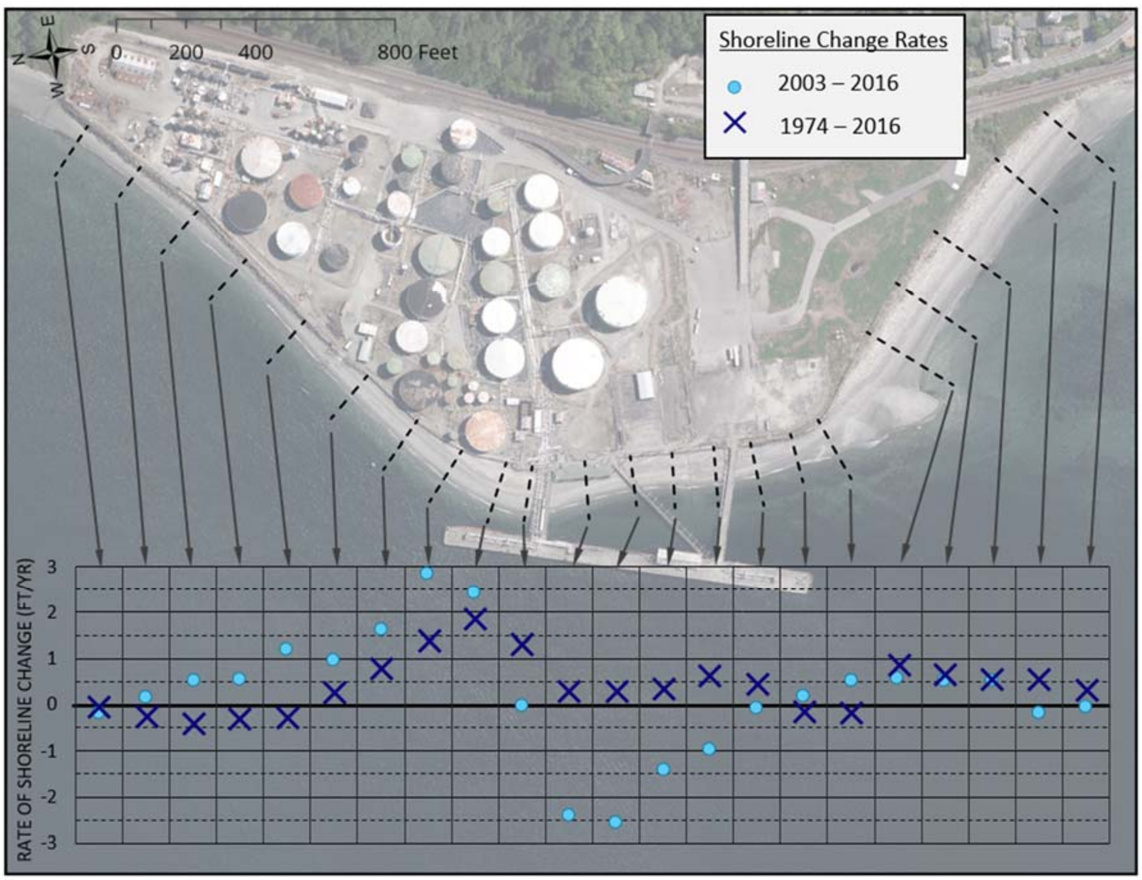

Figure 2-18: Estimates of shoreline change rate for Point Wells in feet/year based on comparison of LiDAR data sets of 2005 and 2016 as well as comparison of 1974 aerial image with 2016 LiDAR data.

3.0 COASTAL ENVIRONMENT

3.1 Tides and Water Levels

Tides in Puget Sound have a mixed (semidiurnal) pattern characterized by two highs of approximately equal heights and two lows of unequal heights during each lunar day. Diurnal tidal range (equal to the difference between Mean Higher High Water and Mean Lower Low Water) in Puget Sound increases from 6.2 feet at the southern end of Vancouver Island to 14.4 feet in Olympia.

Hourly measurements of water level from 1899 to present are available at National Oceanic and Atmospheric Administration (NOAA) Station ID# 9447130, Seattle, WA (NOAA 2018b). In addition, tidal datums are provided by NOAA for Seattle, WA (NOAA Station ID# 9447130) and Edmonds, WA (NOAA Station ID# 9447427), tidal epoch 1983-2001 (NOAA 2018c), and are listed in Table 3-1. The datums and water levels listed in Table 3-1 are referenced to NAVD88 in feet. Location of Seattle and Edmonds tidal stations with respect to Point Wells is shown in Figure 3-1.

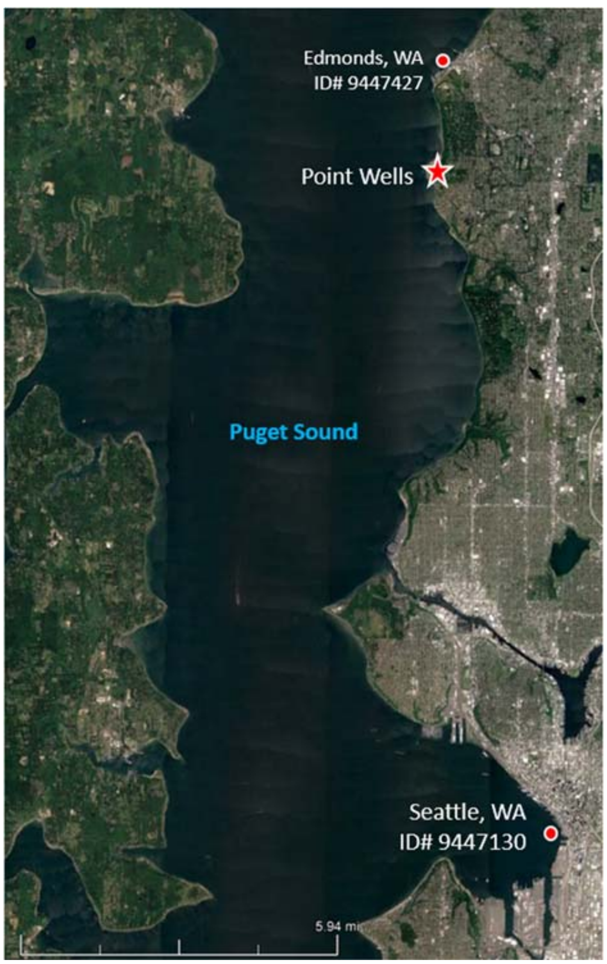

Figure 3-1: Location of NOAA tides and currents stations adjacent to Point Wells, WA.

Tidal datums at the project site were obtained using VDatum ver. 3.8, provided by NOAA (2018d), and are listed in Table 3-1. Mean tidal range (MHHW – MLLW) at Point Wells is equal to 10.96 feet. It is observed that tidal datums at Point Wells are approximately equal to datums at Edmonds, WA station because of their proximity.

Table 3-1: Tidal datums and water levels - Point Wells (obtained using VDatum) and two nearby NOAA stations (Seattle, WA and Edmonds, WA) provided by NOAA referenced to NAVD88 in feet.

Datum & Water Level Description	Abbreviation	Seattle, WA	Edmonds, WA	Point Wells, WA
Highest Observed Water Level	HOWL	12.14	N/A	N/A
Mean Higher High Water	MHHW	9.02	8.85	8.84
Mean High Water	MHW	8.15	7.98	7.98
Mean Tide Level	MTL	4.32	4.35	4.33
Mean Sea Level	MSL	4.3	4.34	4.32
National Geodetic Vertical Datum 1929	NGVD29	3.58	3.58	3.58
Mean Low Water	MLW	0.49	0.72	0.68
North American Vertical Datum 1988	NAVD88	0	0	0
Mean Lower Low Water	MLLW	-2.34	-2.09	-2.12
Lowest Observed Water Level	LOWL	-7.38	N/A	N/A

3.1.1 Extreme Water Levels

High and low annual exceedance probability levels relative to the geodetic NAVD88 are listed in Table 3-2, provided by NOAA (2018d). The extreme levels measured by the tide gauges during storms are called storm tides, which are a combination of the astronomical tide, the storm surge, and limited wave setup caused by breaking waves. These water levels do not include wave runup, the movement of water up a slope. Therefore, the 1% annual exceedance probability levels listed in Table 3-2 do not necessarily correspond to the Base Flood Elevations (BFE) discussed in Section 3.8. On average, the 1% level will be exceeded in only one year per century, the 10% level will be exceeded in ten years per century, and the 50% level will be exceeded in fifty years per century. The 99% level will be exceeded in all but one year per century, although it could be exceeded more than once in other years.

Table 3-2: Annual exceedance probability levels relative to NAVD88 in feet for NOAA Station ID# 9447130 Seattle, WA (NOAA 2018d) for the National Tidal Datum Epoch (1983-2001)

Annual Exceedance Probability Level	High Water Level	Low Water Level
1%	12.20	-7.09
10%	11.78	-6.79
50%	11.29	-6.27
99%	10.50	-5.18

3.2 Sea Level Change

3.2.1 Historical Trend

Sea level change varies locally and regionally based on oceanic and atmospheric circulation patterns and geologic factors such as land subsidence or uplift, compaction of sediment, crustal rebound in formerly glaciated areas, and withdrawal of subsurface fluids. The existing rate of relative sea level rise at the Seattle Station (NOAA Station ID# 9447130) is estimated by NOAA to be 2.05 ± 0.15 mm/yr, which is equal to approximately 0.67 feet in 100 years, see Figure 3-2. This rate is obtained based on monthly mean sea level data from 1899 to 2017.

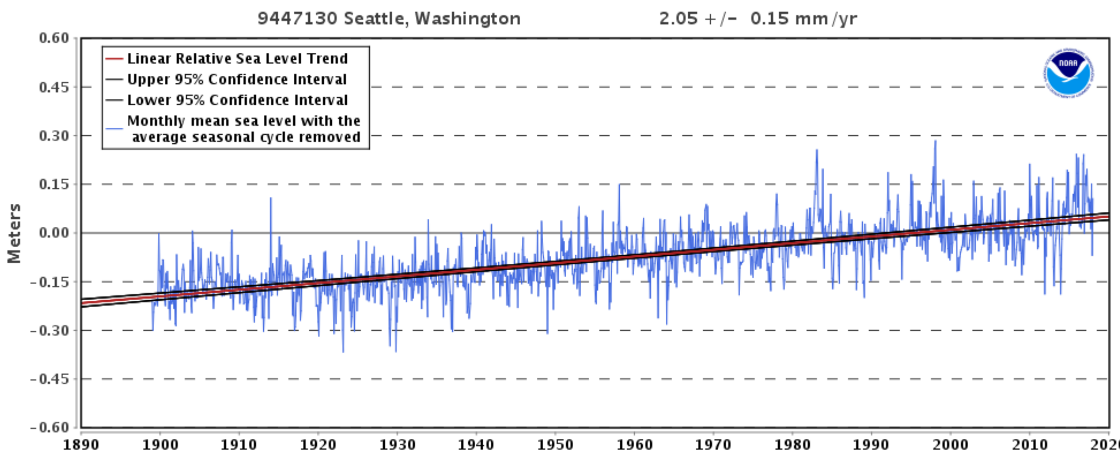

Figure 3-2: Relative sea level trend for Seattle, WA NOAA Station ID# 9447130, (NOAA 2018b).

3.2.2 Future Predictions

Prediction of future rates of sea level change contain a level of uncertainty. National Research Council (NRC 2012) studied available global and regional predictions and developed a guideline for coasts of California, Oregon, and Washington. NRC found that projected future sea-level rise by 2100 ranges from approximately +14 inches to +54 inches with a medium estimate of +28 inches for Washington State, see Table 3-3. The NRC 2012 values are widely considered to be the best available science on sea level rise for Washington State.

University of Washington Climate Impacts Group (Mauger et al. 2015) references NRC (2012) study as well as regional study of Mote et al. (2008) for range of estimates of sea level rise, see Table 3-3. It is observed that medium estimates for sea level change in 2050 and 2100 from both studies are significantly higher than estimates obtained by the historical trend (2.6 inches and 6.6 inches, respectively).

Table 3-3: Potential ranges of sea level change (NRC 2012) as well as historical trend for Seattle in inches.

Domain	2030	2050	2100
Washington State (NRC 2012, without uplift)	+4 in. (+1 to +8 in.)	+9 in. (+4 to +18 in.)	+28 in. (+14 to +54 in.)
Puget Sound (Mote et al. 2008)	-----	+6 in. (+4 to +15 in.)	+13 in. (+7 to +37 in.)
Historical Trend	+1 in.	+2.6 in.	+6.6 in.

3.3 Tidal Currents

Tidal currents were measured at the project site for 15 days, from September 23 to October 8, 1992 (CH2M HILL 1995). The measurements were conducted by deploying two current meters in water depths of 5 feet and 20 feet, MLLW where deteriorated timber piles exist, see Figure 1-1. Maximum current speed measured at both locations for this period was equal to 0.3 knots (16.0 cm/s).

Prediction of surface currents in the project vicinity, 2.5 miles West of Edmonds, WA (station ID# PUG1503, water depth: 67 feet) are provided by NOAA (2018a). The predictions indicate a maximum speed of 1.0 and 0.5 knots for ebb and flood currents, respectively. Based on the field measurements of 1999 and predictions of current, it appears that tidal currents are less than 1.0 knot in the nearshore areas and are not likely to affect beach morphology.

3.4 Winds

Predominant (strongest) and prevailing (most frequent) storms over Central Puget Sound are southerly followed by occasional strong northerly storms during winter. Location of nearby weather stations in the project vicinity with hourly measurements of wind speed and direction are shown in Figure 3-3. Station information and the corresponding period of record for each station is listed in Table 3-4.

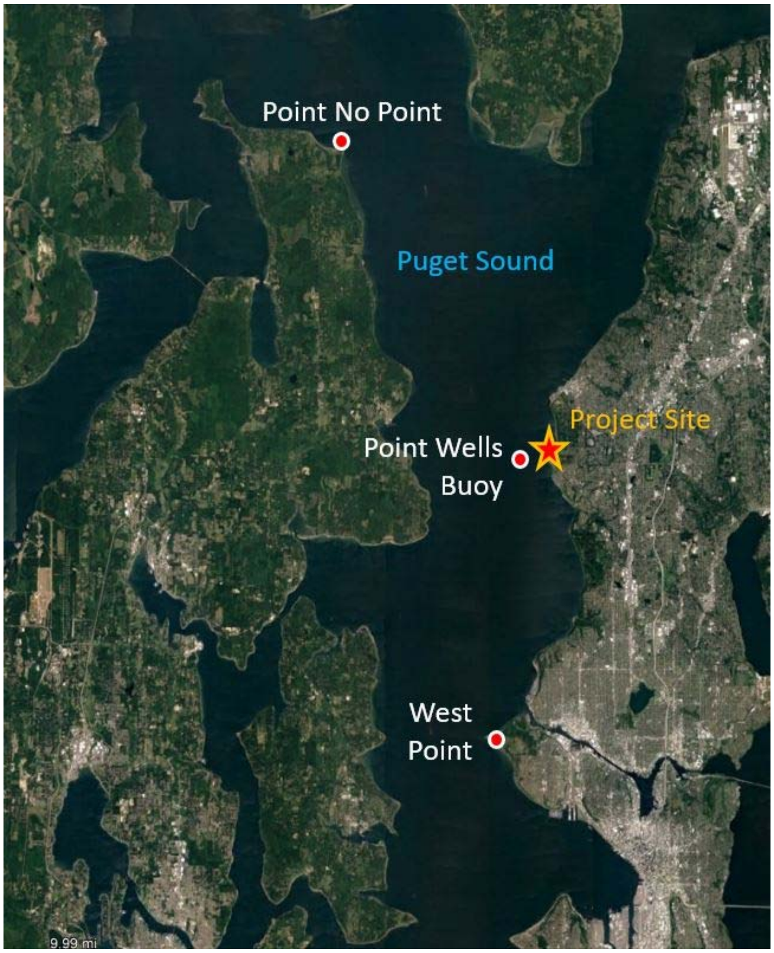

Figure 3-3: Location of weather stations in the project vicinity: Point No Point, Point Wells Buoy, and West Point stations.

Table 3-4: List of weather stations in project vicinity with hourly measurements of wind speed and direction.

Station Name	Station ID	Operated By	Coordinates	Period of Record
West Point, WA	WPOW1	NDBC[7]	47.761°N, 122.397°W	1985 to 2018
West Point CGL[8]	742076	NCDC[9]	47.670°N, 122.430°W	1975 to 1986
Point Wells Buoy	46120	UW[10]/ NDBC	47.662°N, 122.436°W	2016 to 2018
Point No Point	742065	NCDC	47.920°N, 122.530°W	1975 to 1991

Two weather stations have operated in West Point, as listed in Table 3-4. The West Point, WA station (Station ID# WPOW1) has a longer period of record and will be used in this study. Hourly measurements of wind speed and direction were used to develop the wind

[7] National Data Buoy Center
[8] West Point Coast Guard Light Station
[9] National Climate Data Center
[10] University of Washington

roses for Point No Point, WA, Point Wells Buoy, and West Point stations, shown in Figure 3-4. Predominant and prevailing southerly winds are captured by both Point No Point and WPOW1 stations. However, it is not clear why the Point Wells Buoy wind rose does not capture strong southerly winds.

Wind measurements at WPOW1 appear to be good representatives for wave generation and propagation to Point Wells due to exposure and length of record at this station. However, the wind rose for Point No Point shows a strong bi-directional wind pattern along northwest-southeast direction that may not be captured by WPOW1. This pattern is consistent with the topology of Puget Sound in Point No Point vicinity. Winds blowing from northwest can potentially generate large waves that approach Point Wells. Therefore, return-period northwesterly wind speeds at Point No Point were compared to that from WPOW1 to ensure that winds from this direction are reasonably represented in wind wave numerical simulation. Measurements recorded at Point Wells Buoy were not used in this study because of the discrepancy in capturing southerly storms, short length of record, and high percentage of (approximately 50%) missing data.

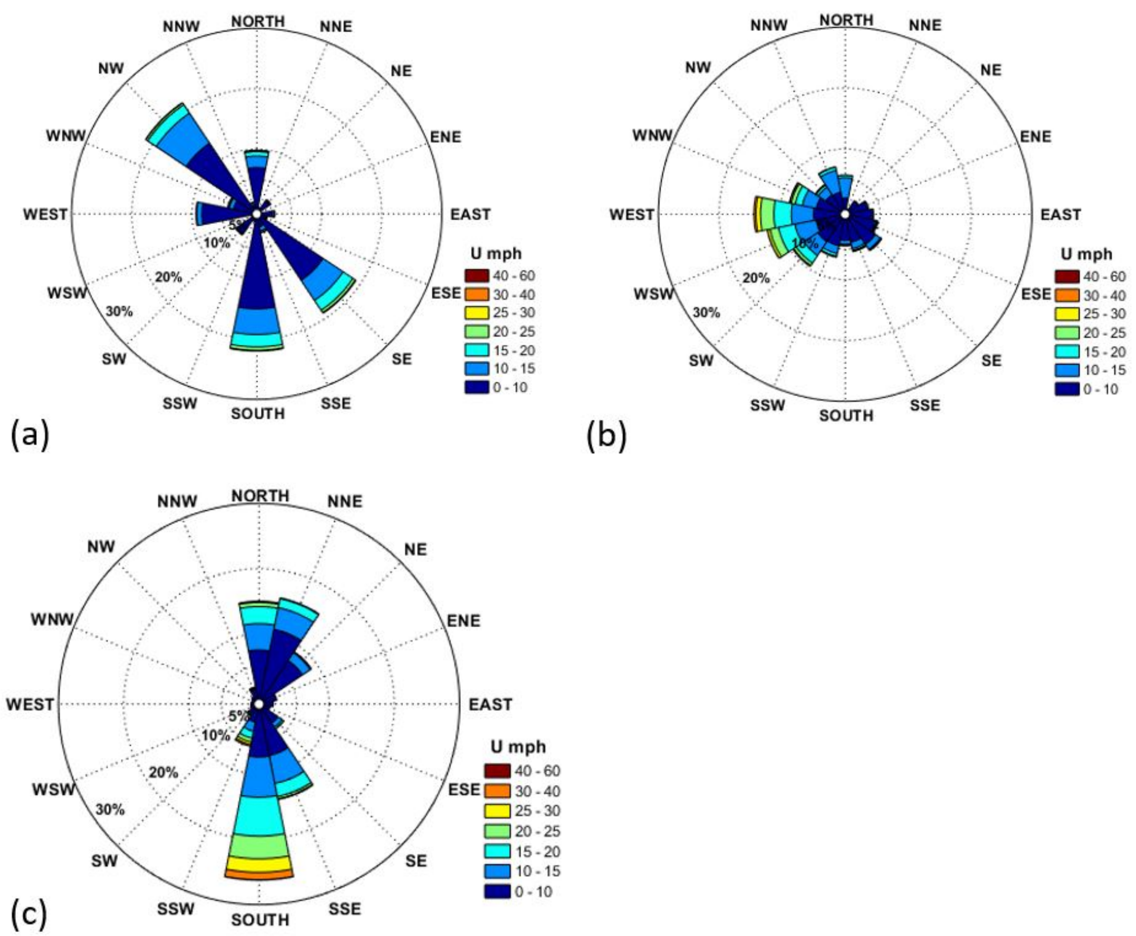

Figure 3-4: Wind rose developed based on hourly measurements of wind speed and direction for stations (a) Point No Point; (b) Point Wells Buoy; and (c) West Point, WA (WPOW1).

Wind measurements representing 2-minute duration were compiled and statistically processed for both Point No Point and WPOW1 stations. Results of the extreme analysis of wind speed for varying directions for 1-, 2-, 5-, 10-, 25-, 50-, and 100-year return period storm events are shown in Figure 3-5. It was observed that estimated return period wind speeds for northwest and southeast directions at WPOW1 station were equal or greater than corresponding wind speeds for Point No Point station. Therefore, return period wind speeds for WPOW1 station were used for numerical simulation of wind waves for directions generating the largest waves at the project site.

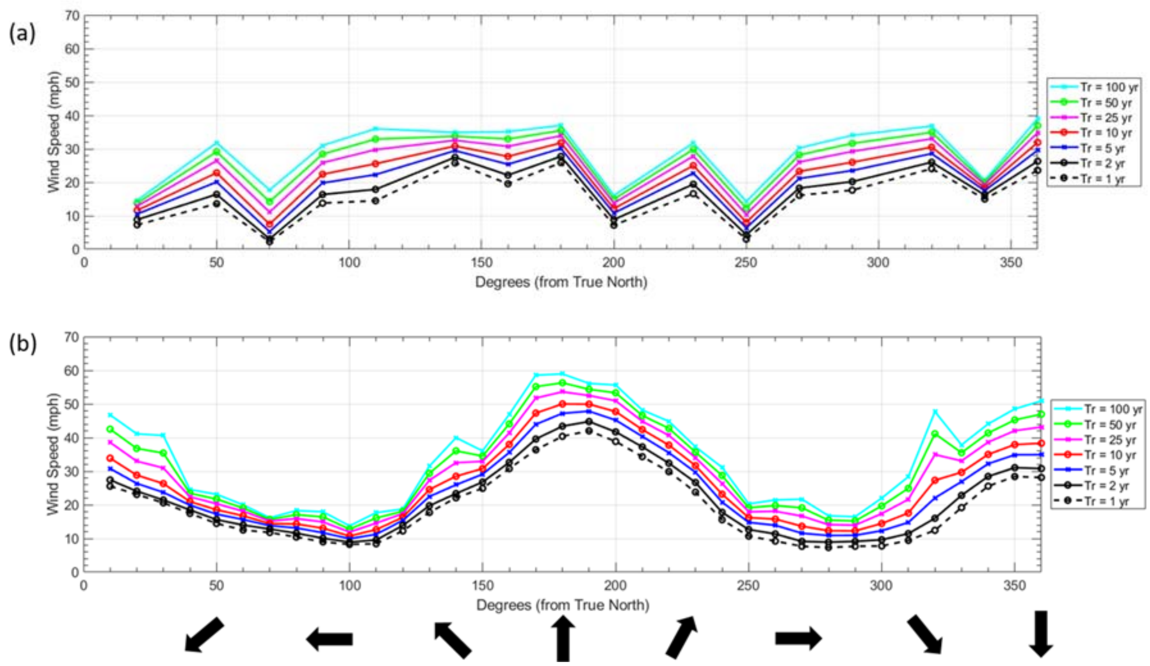

Figure 3-5: Return period wind speeds (2-min averaged) for varying directions for (a) Point No Point; and (b) West Point, WA stations. The arrows demonstrate the direction of wind.

3.5 Waves

Local winds can generate waves over Puget Sound where the largest waves are generated by the predominant southerly storms in winter. Observations by long-time operators at the site indicated that swell waves (wind-generated waves that have travelled out of their generating area) are minimal at the project site. This investigation was limited to locally generated wind waves (wind-waves). Wave measurements are not available at the site. However, wind-wave conditions at the site were developed with numerical simulation of wave growth and propagation over Puget Sound using existing measurements of wind speed and direction in the following sections.

3.5.1 Wind-Wave Numerical Modeling

Wave conditions at the site were developed from numerical modeling of wave generation and propagation to the project site using design wind events. Field wave measurements during extreme storms were not available at the project site.

3.5.2 Methodology

Wave modeling was conducted using the two-dimensional (2-D) Simulating Waves Nearshore Model (SWAN 40.91), Delft Technical University (2012) in steady state mode (assuming sustained wind speeds do not vary significantly over the duration of the storm). SWAN simulates wind wave growth and propagation accounting for shoaling, refraction, diffraction, and bottom damping of waves as they approach the shoreline.

The numerical model SWAN was applied to a regional (large) as well as a local (nested) domain to allow spatially-varying model resolution at the project site. The model resolution for the large and nested domains was selected to be 328 feet × 574 feet (100 m × 175 m) and 33 feet × 33 feet (10 m × 10 m), respectively. The SWAN model elevation was developed using the topography/bathymetry data from NOAA (2014) Digital Elevation Model. Model elevation for the large and nested modeling domains is shown in Figure 3-6.

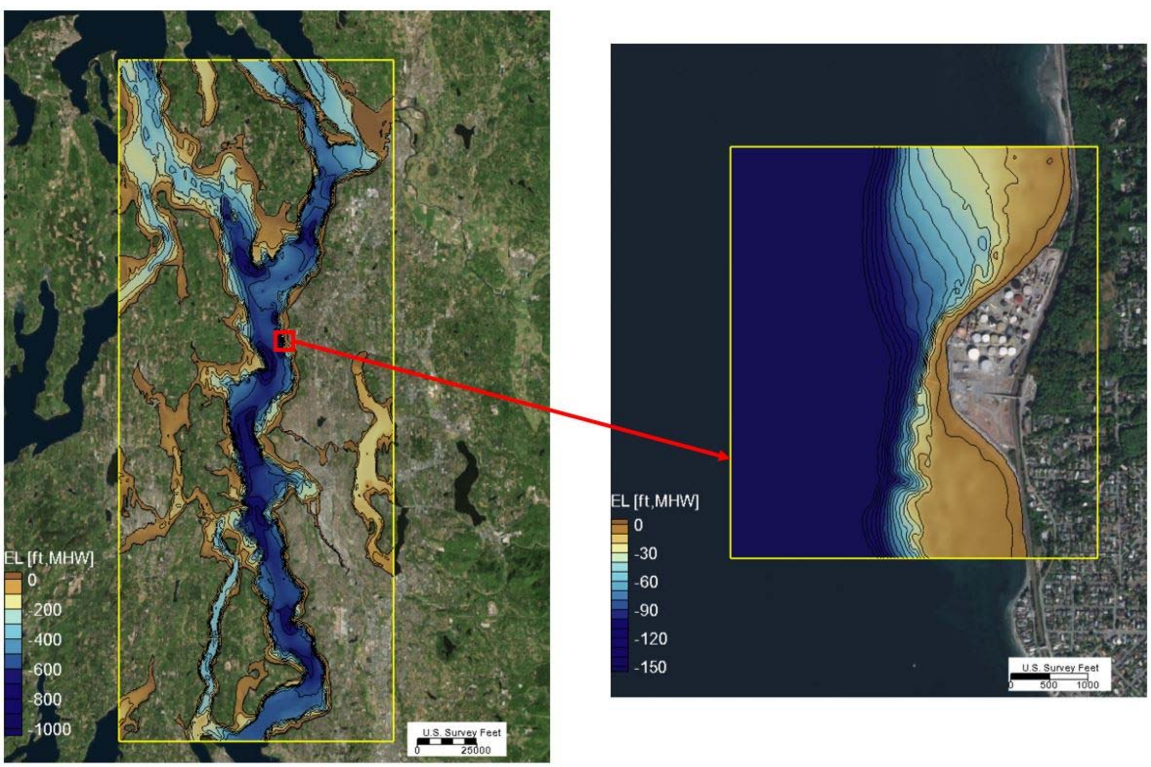

Figure 3-6: Model elevation for large and nested model domains referenced to MHW in feet.

Simulation of wind-wave growth and propagation was conducted for the 50-year and 10-year return period storm events for the predominant wind directions, developed in Section 3.4. Wind speed used in the wave numerical modeling was adjusted to a 1-hour averaged speed to be representative of time duration for storms to generate fully developed waves. Return period wind speeds used in numerical simulation for varying directions of south (S), southwest (SW), west (W), northwest (NW), north-northwest (NNW), and north (N) are listed in Table 3-5. Numerical simulation of waves was conducted assuming storms occurring at the same time as MHHW tide.

Table 3-5: 10-yr and 50-yr return period wind speeds (1-hr averaged) in mph for varying directions (based on records from WPOW1 station) used in numerical simulation of wind-wave growth and propagation.

Direction (° TN)	180 (S)	225 (SW)	270 (W)	315 (NW)	320 (NNW)	360 (N)
10-yr	43.5	30.2	11.9	19.5	23.8	33.3
50-yr	49.0	34.1	16.6	28.7	35.8	40.8

3.5.3 Results

An example modeling result for large and nested domain is shown in Figure 3-7. Spatial distribution of significant wave height is shown in color format during the 50-year return period storm with winds blowing at 56.3 mph (2-min averaged) from South (180 ° True North or TN) over the modeling domain. Large modeling domain shows that significant wave height (Hs) increases in northward direction and exceeds Hs = 6 feet in Central Puget Sound. It is also observed that the largest wave heights occur in the center of the Sound and they decrease with distance away from the center.

The nested modeling domain shows that wave height further decreases as the waves approach the shoreline. It is also observed that wave direction changes from southerly to perpendicular to shoreline. This indicates that potential longshore transport for Reach 3 is small.

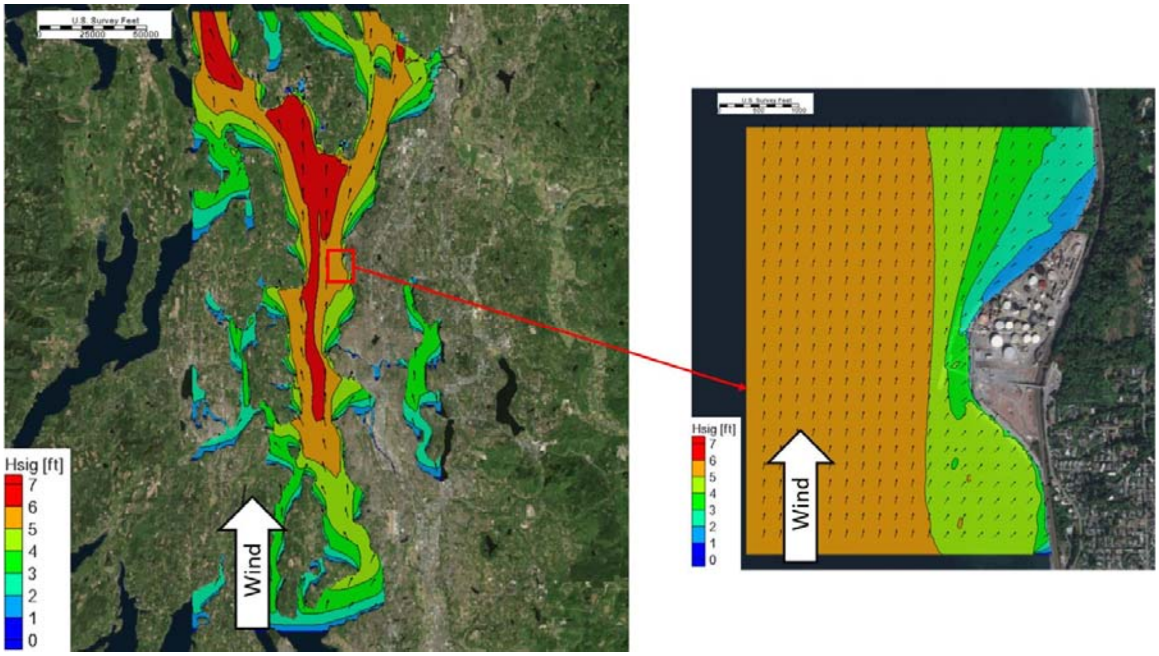

Figure 3-7: Example of wind-wave numerical simulation results in terms of significant wave height for large and nested domains.

Waves at the project site for 50-year return period storm events from predominant directions (southwest, southwest, west, northwest, and north) in terms of significant wave height and peak period are shown in Figure 3-8 and Figure 3-9, respectively.

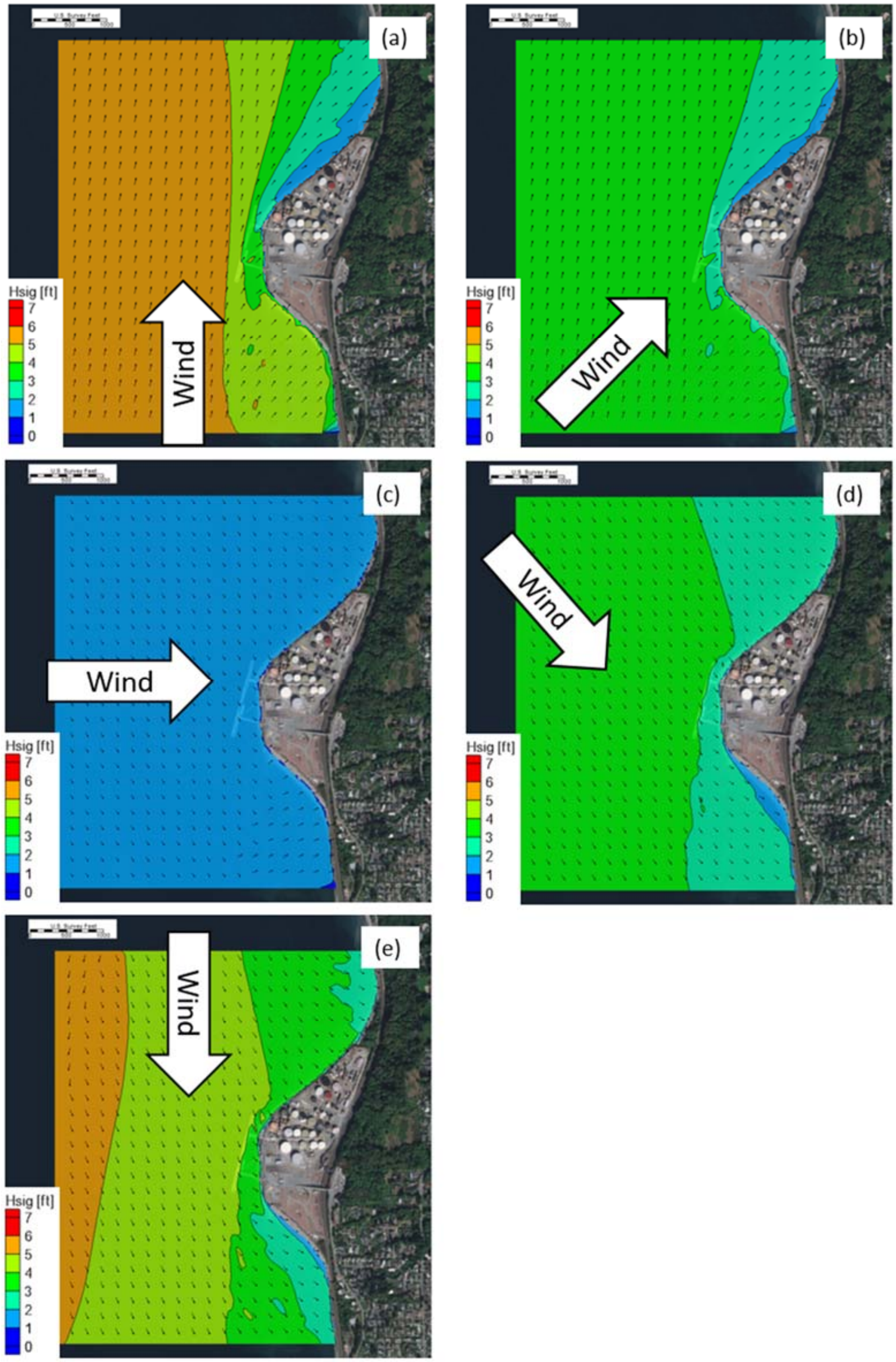

Figure 3-8: Results of wind wave numerical modeling in terms of significant wave height (Hs) in feet for the nested domain for varying wind directions: (a) south; (b) southwest; (c) west; (d) northwest; and (e) north.

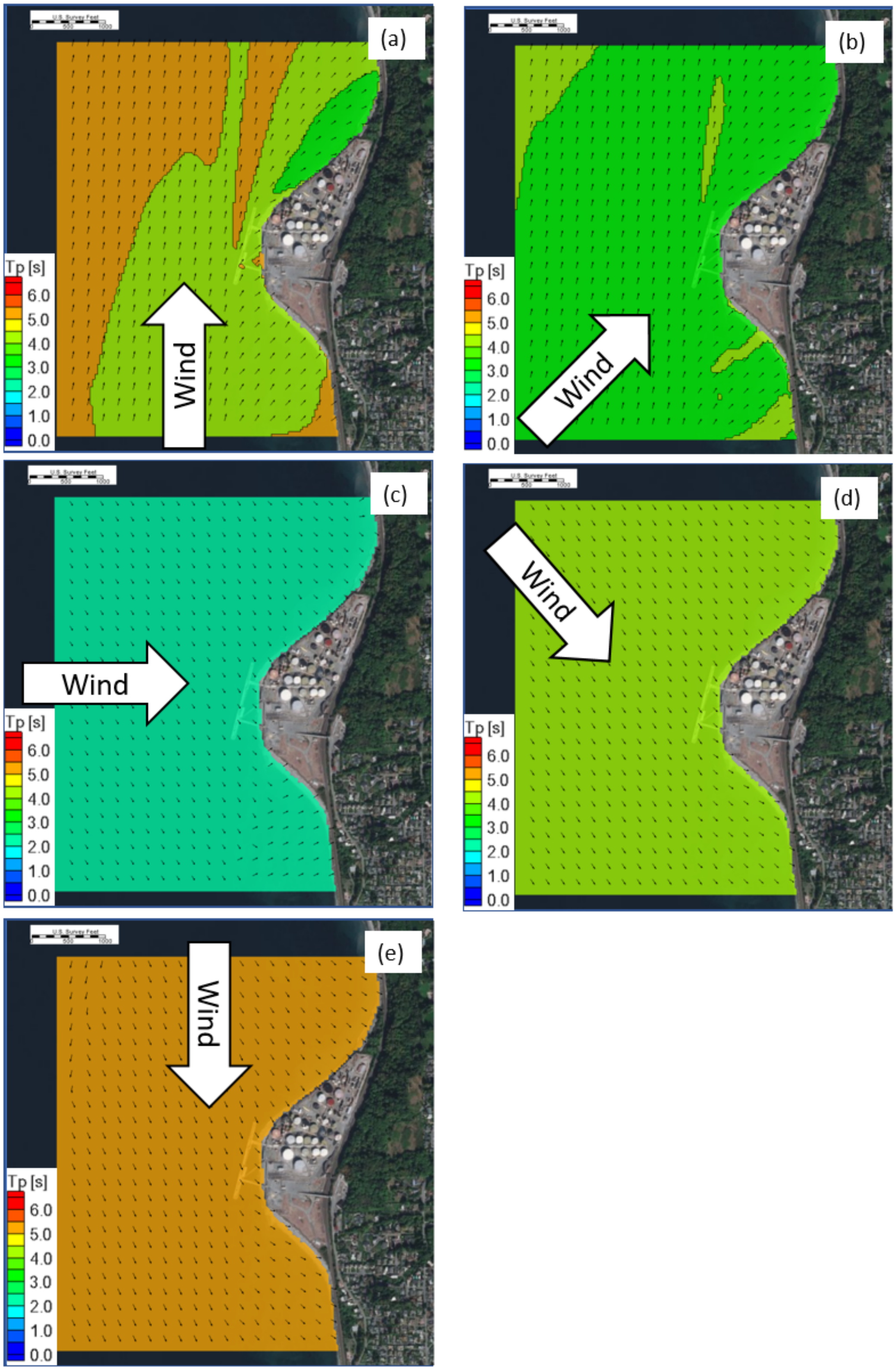

Figure 3-9: Results of wind wave numerical modeling in terms of peak period (Tp) in seconds for the nested domain for varying wind directions: (a) south; (b) southwest; (c) west; (d) northwest; and (e) north

The numerical modeling results show that for 50-year return period storms occurring at the same time as MHHW, southerly storms generate largest wave heights (Hs approximately equal to 4.3 feet) and wave periods (Tp approximately equal to 4.9 sec) that directly approach Reach 3. Reach 1 receives largest wave heights (Hs = 3.9 feet, Tp = 5.3 s). Reach 2 is closer to deep water depths but westerly storms are not as strong as other directions to generate similar wave heights. Model results shows that Hs = 1.3 feet and Tp = 2.4 s for Reach 2.

Four observation points were selected to extract modeling results, shown in Figure 3-10. Wave climate information extracted from the model results for 50-year and 10-year return period storms occurring at the same time as MHHW at these observation points are listed in Table 3-6 and Table 3-7, respectively.

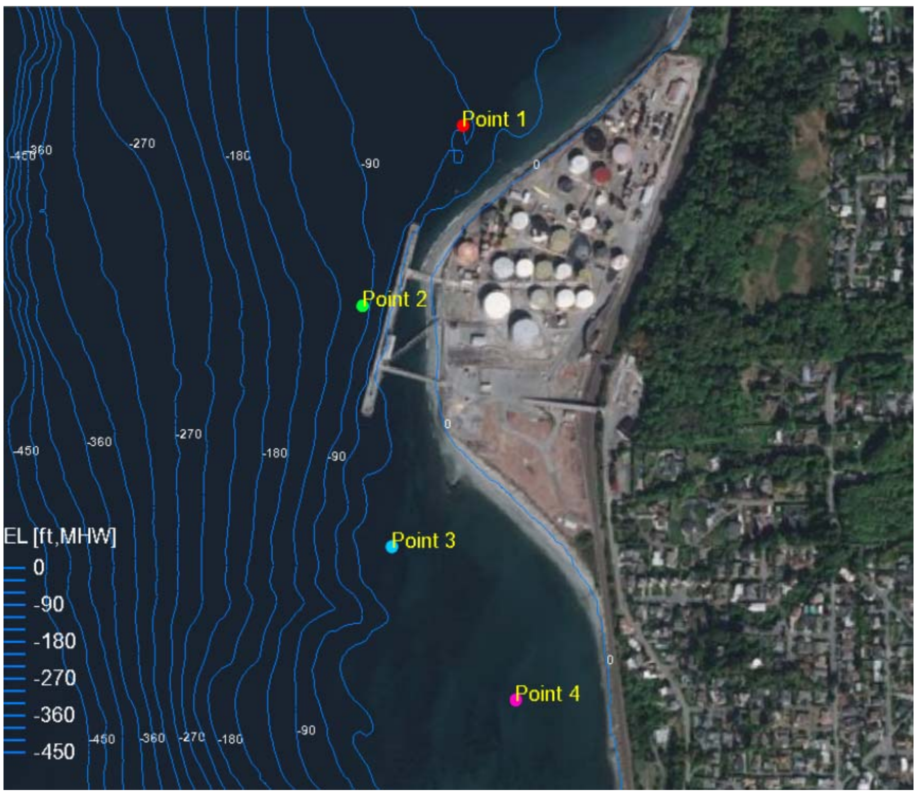

Figure 3-10: Observation points 1 to 4 in project vicinity for extraction of modeling results. Contour lines are labeled with elevation referenced to MHW in feet.

Table 3-6: Results of wind wave numerical modeling for 50-yr return period storm extracted at observation points in terms of significant wave height (Hs) in feet, peak period (Tp) in seconds, and wave direction (Dir) in degrees from True

North (TN) for storms from south (S), southwest (SW), west (W), northwest (NW), north-northwest (NNW), and north (N) directions.

	S			SW			W			NW			NNW			N		
Pt#	Hs	Tp	Dir	Hs	Tp	Dir	Hs	Tp	Dir	Hs	Tp	Dir	Hs	Tp	Dir	Hs	Tp	Dir
1	3.1	4.6	215	2.8	3.9	215	1.3	2.4	-35	3.0	4.2	-35	4.0	4.6	-35	3.9	5.3	-35
2	3.9	4.9	225	3.1	3.9	225	1.3	2.4	-35	2.9	4.2	-35	3.9	4.9	-35	3.9	5.3	-35
3	4.3	4.9	215	3.2	3.9	215	1.3	2.4	-35	2.8	4.2	-35	3.7	5.3	-35	3.7	5.3	-35
4	4.4	4.9	225	3.2	3.9	225	1.3	2.4	245	2.5	4.6	-45	3.4	5.3	-45	3.2	5.3	-45

Table 3-7: Results of wind wave numerical modeling for 10-yr return period storm extracted at observation points in terms of significant wave height (Hs) in feet, peak period (Tp) in seconds, and wave direction (Dir) in degrees, True North (TN) for storms from south (S), southwest (SW), west (W), northwest (NW), north-northwest (NNW), and north (N) directions.

	S			SW			W			NW			NNW			N		
Pt#	Hs	Tp	Dir	Hs	Tp	Dir	Hs	Tp	Dir	Hs	Tp	Dir	Hs	Tp	Dir	Hs	Tp	Dir
1	2.7	4.2	215	2.4	3.6	215	0.8	2.1	-35	1.9	3.3	-35	2.4	3.9	-35	3.1	4.6	-35
2	3.4	4.6	225	2.7	3.6	225	0.8	1.9	-35	1.8	3.3	-35	2.3	3.9	-35	3.1	4.9	-35
3	3.7	4.6	215	2.8	3.6	215	0.8	1.9	-35	1.8	3.3	-35	2.3	3.9	-35	2.9	4.9	-35
4	3.8	4.6	225	2.7	3.6	225	0.8	2.1	245	1.6	3.6	-45	2.0	4.2	-45	2.5	4.9	-45

3.6 Wave Runup

Wave runup (the vertical height above the still-water level to which water from an incident wave will run up the face of a structure or a slope) determines the required structure height if wave overtopping cannot be permitted.

3.6.1 Methodology

Wave runup for Reaches 1, 2, and 3 was estimated using the guidelines of Shore Protection Manual (USACE 1984) and Coastal Engineering Manual (USACE 2006). Coastal Engineering Manual (CEM) provides formulations for estimation of runup for smooth (impervious) surfaces without any structures as well as runup for an armored shoreline. The estimation of runup for impervious surfaces can be used as an upper bound estimate for pervious surfaces.

3.6.2 Results

Numerical modeling results obtained for 50-year return period storms occurring at the same time as MHHW were used to estimate runup. Maximum wave runup for Reaches 1, 2, and 3 for was estimated to be 14.5, 14.7, and 13.5 feet, NAVD88, respectively. Wave runup is proportional to foreshore slope: the flatter the slope, the lower the wave runup. This is consistent with estimated runup value for Reach 3 being smaller than that of Reach 2 despite exposure to more energetic waves.

Presence of structures intensifies the wave runup as the waves interact with structure. This is consistent with estimated runup value for Reach 1 being higher than that of Reach 3 given less wave exposure at Reach 1.

Proposed shoreline enhancements (removal of revetment and seawall and re-grading the slope to a flatter foreshore) would reduce the maximum wave runup at Reaches 1 and 2. Based on estimates of maximum runup for Reaches 1, 2, and 3, elevation of top of proposed esplanade was recommended to be set to +16.0[11] feet, NAVD88 to prevent overtopping for a 50-year return period storm event occurring at the same time as a MHHW tide. This elevation would provide a minimum freeboard of 1.3 feet and larger for existing and proposed conditions, respectively. The freeboard will accommodate relative sea level rise and more intense storms. It should also be noted that use of maximum runup for determination of esplanade elevation is a conservative approach that precludes all contact between runup and upland structure.

3.7 Vessel Wakes

Passing vessel-generated short-period (Kelvin) wakes may affect the stability of the shoreline. Vessels passing by the project site include fishing vessels, tug boats serving the Port of Seattle, Victoria Clipper (a passenger-only fast ferry), cruise ships, container ships, and recreational boats traveling in Central Puget Sound. Passing vessel wake energy at the shoreline is a function of vessel type, speed, and distance from the shoreline to sailing line. Large passing vessels in Puget Sound typically stay within the federal navigation channel, which is approximately 1.8 miles west of Point Wells. Given the large distance of main navigation channel to shoreline, passing vessels are not anticipated to generate wake heights capable of significant shoreline change at the project site. Anecdotal observations of site operators indicate that passing vessel wakes are significantly smaller than wind waves generated during storms.

3.8 Coastal Flooding

Flood Insurance rate maps (FIRMs) are developed by FEMA to identify riverine or coastal flood hazard. These maps identify the base (1-percent-annual-chance) flood elevation (BFE) to which flood water is anticipated to rise during base flood. Currently, FIRMs developed in 1999 are effective for this project site. However, more recent preliminary maps have been developed and are anticipated to be released in 2018 and replace the 1999 maps.

[11] Elevation for top of promenade for Elliott Bay Seawall was selected to be at +16.0 ft, NAVD88 (City of Seattle 2013).

3.8.1 Effective Maps

FEMA FIRM panels 53061C1292E and 53061C1294 E, effective date of November 8, 1999, have identified a BFE of 10 feet referenced to NGVD29, see Figure 3-11(a). This BFE corresponds to +13.58 feet referenced to NAVD88. The western edge of the property adjacent to Puget Sound is within the AE zone with a BFE of 10 feet NGVD29. AE zones are areas subject to inundation by the 1-percent-annual-chance flood event determined by detailed methods. BFEs are provided by FEMA for these areas. Most of the property is located outside of the Special Flood Hazard Area (SFHA).

3.8.2 Preliminary Maps

Snohomish County received preliminary digital flood insurance rate maps (DFIRMs) in July 2016 and is in the process of reviewing these maps for potential adoption, see Figure 3-11(b). Most of the project site, has a coastal flooding designation of AE with a BFE of +12.0 and +14.0 feet, NAVD88, landward and seaward of seawall, respectively per preliminary DFIRM panels 53061C1292 F and 53061C1294 F, dated July 22, 2016.

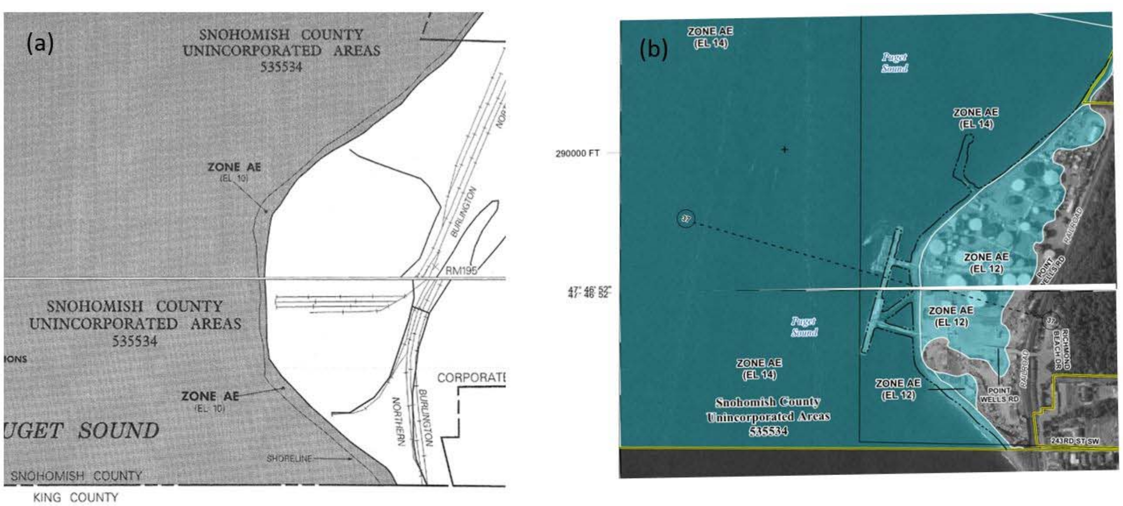

Figure 3-11: Base flood elevation (BFE) at the project site provided by FEMA for (a) effective maps dated 1999, elevations are referenced to NGVD29 in feet; and (b) preliminary maps dated July 2016, elevations are referenced to NAVD88 in feet. To convert NGVD29 elevations to NAVD88, add +3.58 feet.

3.9 Tsunami

Tsunamis are most commonly generated by earthquakes in marine and coastal regions. Major tsunamis are produced by large (greater than magnitude-7 on the Richter scale), shallow focus (< 30km depth in the earth) earthquakes associated with the movement of oceanic and continental plates. Subaerial (underwater) landslides associated with smaller earthquakes are also capable of generating destructive tsunamis.

The following potential sources can generate tsunami waves that could reach Point Wells:

- Cascadia Subduction Zone (CSZ) stretching from northern California to Vancouver Island.
- Local Puget Sound Faults including Seattle Fault, Tacoma Fault and South Whidbey Island Fault.

American Society of Civil Engineers (ASCE) recently developed a Tsunami Design Geodatabase as part of the ASCE 7-16 building code (ASCE 2016). This geodatabase provides maximum tsunami runup elevations for magnitude-9 (on the Richter scale) CSZ earthquake scenarios as well as Seattle and Tacoma local faults in Puget Sound. A snapshot of the geodatabase is shown in Figure 3-12. The maximum runup elevation for Point Wells is +14.94 feet, NAVD88[12].

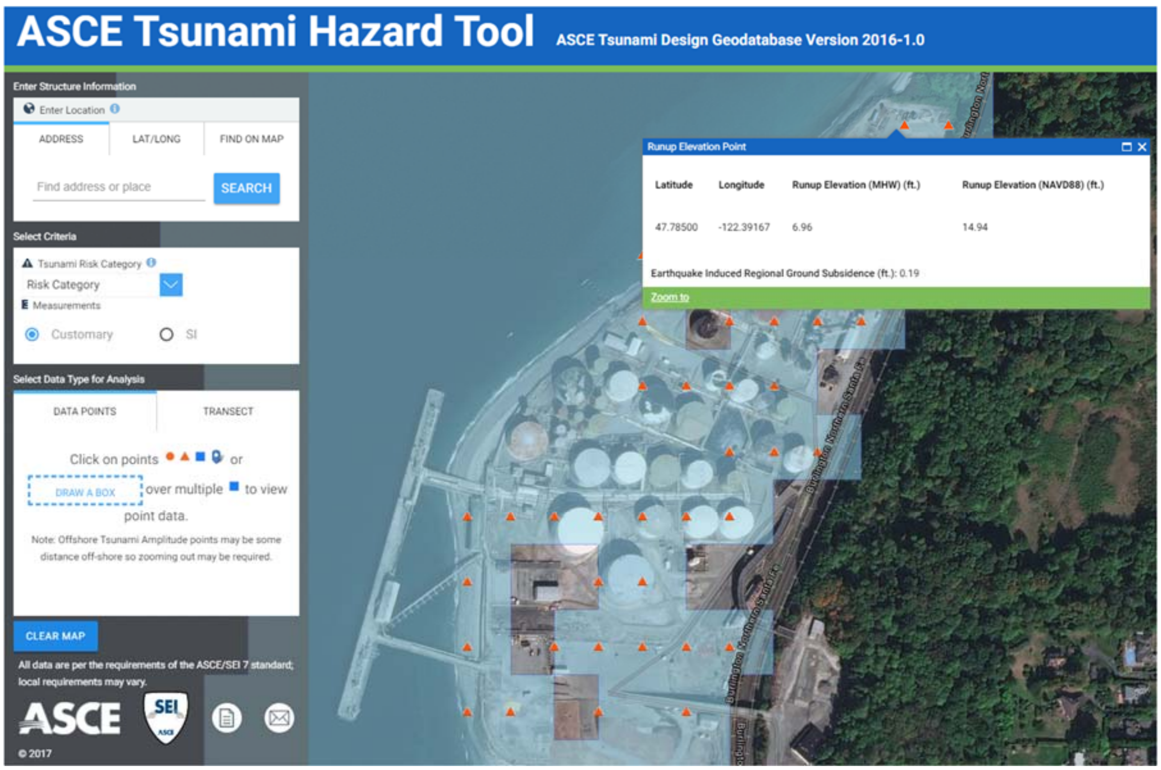

Figure 3-12: Snapshot of American Society of Civil Engineers (ASCE) Tsunami Design Geodatabase Version 2016-1.0 shows tsunami runup elevation of +14.94 feet, NAVD88 at one location on the north end of Point Wells.

[12] Tsunami generation and propagation modeling is initiated with a MHW tide level.

4.0 SHORELINE PROTECTION FOR PROPOSED MODIFICATIONS

4.1 Proposed Modifications & Constraints

Client intends to enhance the shoreline at Point Wells by removing all or portions of the existing seawall and riprap along the shoreline and enhancing the shoreline to a more natural condition.

Function of seawalls and revetments, if properly designed, is to protect the upland infrastructure/slopes from potential erosion due to wave runup and overtopping. Removal of seawall/revetment without increasing likelihood of erosion for the upland infrastructure/slopes requires assessment of wave runup on proposed slopes.

4.1.1 Assessment Methodology

Using the dynamic equilibrium criteria, recommended median grain sizes were determined using a procedure developed for coarse material beaches. The procedure relates incident waves to particle size and mean equilibrium beach slope using formulas developed by H.R. Wallingford (Powell 1993). Based on results of the wave modeling obtained in Section 3.5.1, size and thickness of material was obtained for Reaches 1 to 3.

4.2 Recommended Shoreline Protection

4.2.1 Reaches 1 and 2

The proposed modifications for Reaches 1 and 2 include removal of seawall and rock revetment and re-grading the slope to connect with a proposed esplanade (top of esplanade is at Elevation +16.0 feet, NAVD88).

Recommended measures for wave protection at Reaches 1 and 2 are shown schematically in Figure 4-1 and Figure 4-2, respectively. These measures include excavation and placement of two layers (Layers 1 and 2) to re-grade the slope of upper foreshore for Reaches 1 and 2 as follows:

- Reach 1: the re-graded slope starts from toe of existing revetment (Elevation of approximately +6.0 feet, NAVD88) with a slope approximately equal to existing lower foreshore slope of 8H:1V and extending it landward to the edge of esplanade (Elevation +16.0 feet, NAVD88).

- Reach 2: the re-graded surface starts from toe of existing revetment (Elevation of approximately +6.0 feet, NAVD88) with a slope not steeper than existing foreshore slope of 10H:1V and extends landward to the edge of esplanade (Elevation +16.0 feet, NAVD88).

Two layers (Layer 1 and 2) of material have been designed to dissipate wave energy without significant erosion. Layer 1 was designed to be dynamically stabile during storms with 10-year return period. Layer 2 was designed to be dynamically stable during storms with 50-year return period following methodology by Powell (1993). Function of Layer 2 is to prevent erosion at the toe of esplanade and underneath Layer 1 during more extreme storms. A filter layer (either a geotextile filter fabric or a bedding layer) may be needed underneath Layer 2 to prevent the sand material from getting washed away. The need and details for the filter layer will be determined at later phases of design.

Sizing and thickness of Layers 1 and 2 were developed following methodology proposed by Powell (1993) and Van der Meer (1988), respectively as follows:

- Reach 1:
  - Layer 1 is recommended to be 2-foot thick with 1.5-inch minus mixed sand and gravel.
  - Layer 2 is recommended to be 1-foot thick with 5.0-inch minus cobble and gravel with interstitial spaces filled with coarse sand.
- Reach 2:
  - Layer 1 is recommended to be 2-foot thick with 2.5-inch minus mixed sand and gravel.
  - Layer 2 is recommended to be 1-foot thick with 5.0-inch minus cobble and gravel with interstitial spaces filled with coarse sand.

Finally, a concrete wall is recommended to be placed below grade at the edge of proposed esplanade extending down at least 1 foot deeper than Layer 2 to prevent undermining of esplanade if erosion occurs over time under repeated extreme storms.

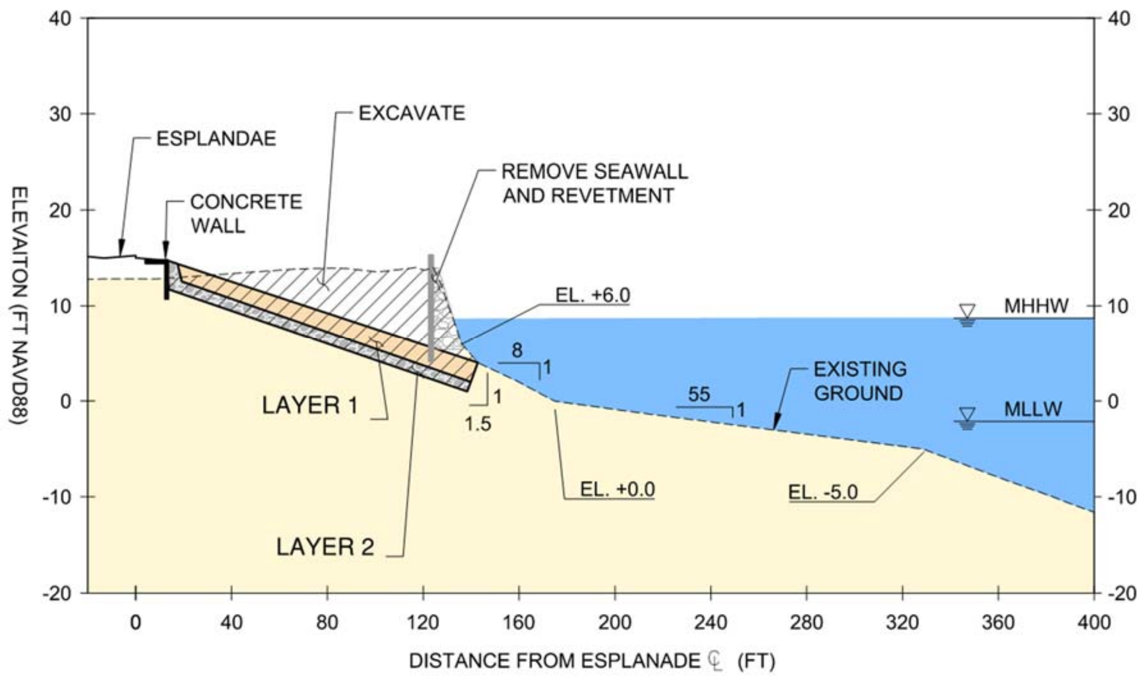

Figure 4-1: Recommended shoreline protection for proposed modifications (removal of seawall and revetment) at Reach 1.

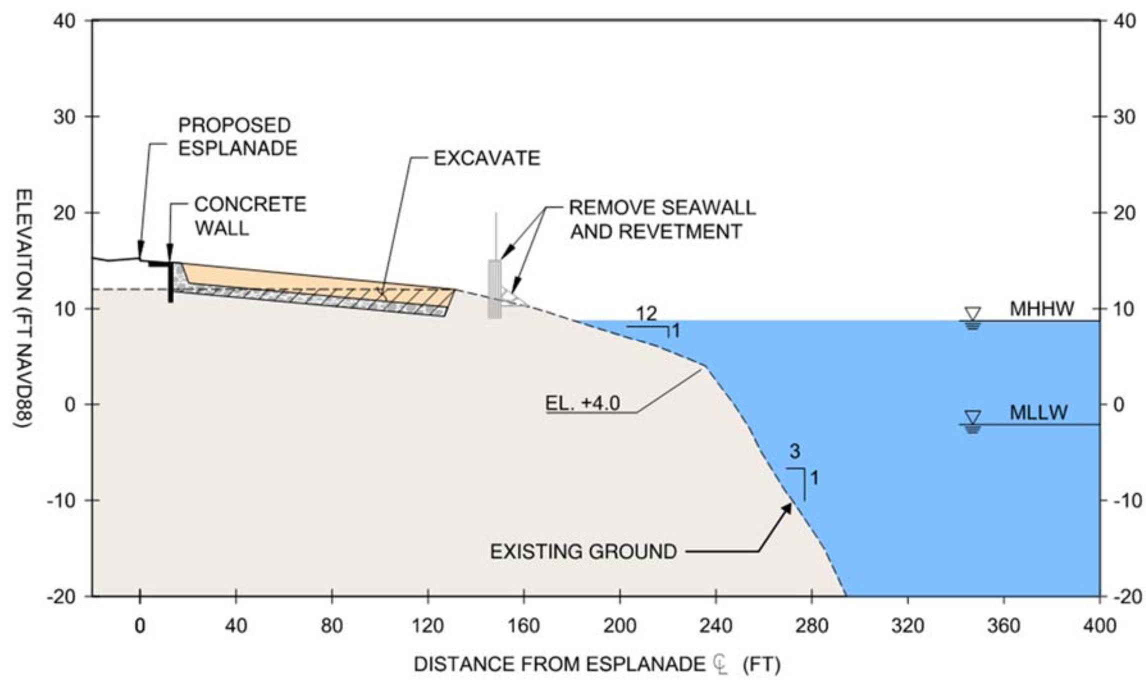

Figure 4-2: Recommended shoreline protection for proposed modifications (removal of seawall and revetment) at Reach 2.

4.2.2 Reach 3

Reach 3 has a mild foreshore slope of 15H:1V and a sandy berm (20-ft wide on average) along most of the shoreline. Analysis and historical trend of SCR indicated that this reach has been stable. Given wave exposure and estimated runup values lower than berm elevation for this reach, removal of seawall is feasible and should not alter the shoreline dynamics to require wave protection.

5.0 CONCLUSIONS

Historical shoreline change rate (SCR) for Point Wells was estimated by comparison of historic photographs dating back to 1954 and LIDAR data sets. It was found that most of Point Wells shoreline appears to be generally stable or accretionary with limited change in shoreline for the analysis period. The historical shoreline change pattern was found to be accretionary for the northwest corner (between Reaches 1 and 2). This pattern was confirmed qualitatively by comparison of oblique aerials as well. The recent shoreline change pattern for Reach 2 immediately south of the dock office was found to be potentially erosional for 2005-2016 period based on comparison of LIDAR data. This pattern was not confirmed by comparison of aerial images and could be due to potential inaccuracies in of LiDAR data sets analyzed or seasonal cross-shore shoreline change.

Locally-generated wind waves were identified as the main driver for shoreline evolution. Swell, passing vessel wakes, and tidal current at Point Wells are very unlikely to induce significant changes in shoreline.

The wind-wave numerical modeling results showed that southerly storms generate the largest wave heights in project vicinity. Waves from southerly storms approach Reach 3 head-on (with an approach angle perpendicular to shoreline) with deep water incident significant wave height (Hs) approximately equal to 4.3 feet and peak wave period (Tp) approximately equal to 4.9 sec. The next strongest storm direction is northerly and northwesterly. These storms approach Reach 1 head-on with deep water incident waves of Hs = 3.9 feet and Tp = 5.3 sec. Westerly storms are not as strong as other directions. These storms can approach Reach 2 head-on with deep water incident waves of Hs = 1.3 feet and Tp = 2.4 sec.

Wave runup under existing conditions for Reach 1, 2, and 3 was estimated to be 14.5, 15.0, and 13.5 feet, NAVD88, respectively. It is expected that removal of revetment and seawall will reduce wave runup along the shoreline, especially along Reach 1. Based on estimates of the runup for Reach 1, 2, and 3, elevation of top of proposed esplanade was recommended to be set to +16.0 feet, NAVD88 to prevent overtopping for 50-year return period storms.

Removal of seawall and revetment along the shoreline was investigated. Shoreline protection measures were designed at a conceptual level. Reach 3 has a mild foreshore slope of 15H:1V and a sandy berm (20-ft wide on average) offshore of the seawall along most of the shoreline. Historical trend of SCR indicated that this reach has been stable. Given wave exposure and estimated runup values lower than the berm elevation for this reach, removal of the seawall is feasible and should not alter the shoreline dynamics to require wave protection.

For Reaches 1 and 2, recommended measures for shoreline protection required for removal of revetment and seawall were provided. These recommendations included excavation and placement of two dynamically stable layers of material. Layer 1 (top layer) and Layer 2 (underlying layer) were designed to be dynamically stable for 10-year and 50-year return period storm events, respectively. Size and thickness of material for both layers were provided.

5.1 Recommendations

It is recommended that layout of esplanade and site features is designed accounting for wave runup and required set-backs to prevent overtopping through an iterative process between landscape and coastal engineering teams.

5.2 Limitations and Guidelines for Use

Elevation profiles shown herein were approximate and were developed based on a composite digital elevation surface provided by the Project Team. Some interpolation between the surfaces was done. It is expected that a combined topography/nearshore bathymetry survey will be conducted at later phases of design to verify this information.

The information provided here is developed at the conceptual level of design and is not intended for final design and/or construction. Nearshore bathymetry is a critical factor in the transformation of waves as they approach the shoreline. It is expected a nearshore topography/bathymetry survey will be conducted for next phases of design and additional analysis will be performed to validate results presented at the conceptual stage. The information presented in this technical memorandum are intended for this project, and limitations of scope and schedule apply.

6.0 CODES, STANDARDS, AND DESIGN GUIDELINES

U.S. Army Corps of Engineers (USACE), Coastal Engineering Research Center. 1984. Shore Protection Manual.

U.S. Army Corps of Engineers (USACE), Coastal Engineering Research Center. 2006. Coastal Engineering Manual. EM 1110-2-1100.

7.0 REFERENCES

American Society of Civil Engineers (ASCE). 2016. ASCE Tsunami Design Geodatabase Version 2016-1.0. https://asce7tsunami.online/

CH2M HILL. 1995. Dilution Ratio Study Report. Point Wells Terminal and Asphalt Plant, NPDES Permit No. WA 000323-9 (1), prepared for Chevron U.S.A. Products Company.

Coastal Geologic Services (CGS). 2005. Inventory and Assessment of Current and Historic Beach Feeding Sources/Erosion and Accretion Areas for the Marine Shorelines of Water Resource Inventory Areas 8 & 9, Prepared by Coastal Geologic Services, Prepared for King County Department of Natural Resources and Parks, Seattle, WA.

Delft University of Technology, Environmental Fluid Mechanics Section (Delft). 2012. SWAN – User Manual, Version 40.91, April 2012.

Finlayson, D. 2006. The geomorphology of Puget Sound beaches. Puget Sound Nearshore Partnership Report No. 2006-02. Published by Washington Sea Grant Program, University of Washington, Seattle, Washington.

Hart Crowser. 2018. Point Wells Beach Sampling, prepared for Moffatt & Nichol. Project No. 17203-54.

Mauger, G.S., J.H. Casola, H.A. Morgan, R.L. Strauch, B. Jones, B. Curry, T.M. Busch Isaksen, L. Whitely Binder, M.B. Krosby, and A.K. Snover. 2015. State of Knowledge: Climate Change in Puget Sound. Report prepared for the Puget Sound Partnership and the National Oceanic and Atmospheric Administration. Climate Impacts Group, University of Washington, Seattle. doi:10.7915/CIG93777D

Mote PW, Peterson A, Reeder S, Shipman H, Whitely Binder L (2008) Sea level rise in the coastal waters of Washington state. Climate Impacts Group, Joint Institute for the Study of the Atmosphere and Ocean, University of Washington, 11 pp.

National Oceanic and Atmospheric Administration (NOAA). 2018a. Current Predictions. https://tidesandcurrents.noaa.gov/noaacurrents/Predictions?id=PUG1503_34, accessed on March 15, 2018.

National Oceanic and Atmospheric Administration (NOAA). 2018b. Tides and Currents. https://tidesandcurrents.noaa.gov/stationhome.html?id=9447130, accessed on March 15, 2018.

National Oceanic and Atmospheric Administration (NOAA). 2018c. Tides and Currents. https://tidesandcurrents.noaa.gov/inventory.html?id=9447427, accessed on March 15, 2018.

National Oceanic and Atmospheric Administration (NOAA). 2018d. Vertical Datum Transformation, VDatum v3.8. https://vdatum.noaa.gov/.

National Oceanic and Atmospheric Administration (NOAA). 2014. Digital Elevation Model of Puget Sound, Washington: Procedures, Data Sources, and Analysis. Prepared for the National Tsunami Hazard Mitigation Program (NTHMP) by the NOAA National Geophysical Data Center (NGDC). June 24, 2014.

National Research Council. 2012. Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future. Washington, DC: The National Academies Press. https://doi.org/10.17226/13389.

Powell, K.A. 1993. Dissimilar Sediments: Model Tests of Replenished Beaches Using Widely Graded Sediments. HR Wallingford Report SR 350, Oxfordshire, OX10 8BA, UK, 29 p.

Washington State Department of Ecology. 1978. Coastal Zone Atlas of Washington. Publication No. DOE 77-21-5.

Van der Meer, J.W. 1988. Rock Slopes and Gravel Beaches under Wave Attack. Delft Hydraulics Communication No. 396, The Netherlands.