Coastal Study Report

Coastal Investigation of the Westport Light State Park

Washington State Parks
Westport Light State Park
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Executive Summary

AECOM conducted a coastal study of the Westport Light State Park (Park) for the Washington State Parks and Recreation Commission to examine future shoreline retreat and dune erosion due to sea level rise (SLR) and coastal storms. This study will support a Master Plan currently in preparation for the Park. This study is a high-level study to determine which areas of the Park could be at risk for future coastal retreat, storm erosion, and flooding associated with SLR.

Approach

- AECOM analyzed future long-term shoreline retreat due to SLR and episodic dune erosion due to a 30- and 100-Year coastal storm to evaluate future impacts to the Park and its resources. This analysis included both the open coast shoreline and the sheltered Half Moon Bay shoreline.
- Impacts were assessed under two general future scenarios. The Moderate-Risk Scenario assumes a moderate level of risk for coastal erosion and flooding processes defined by a high greenhouse gas emissions scenario, a 50% exceedance SLR projection, and a moderate (30-Year return period) coastal storm event. The High-Risk Scenario assumes a high level of risk for coastal erosion and flooding processes defined by a high greenhouse gas emissions scenario, a 1% exceedance SLR projection, and a severe coastal storm event (100-Year return period). Including both a moderate- and high-risk scenario gives a range of potential future flood and erosion hazard zones that can be used in planning for future conditions.
- AECOM used recent rates of long-term retreat observed between 2002–2016. During this period, long-term retreat was observed along the entire Park shoreline (both Half Moon Bay and the open coast). Retreat rates were lower immediately south of the jetty, and higher moving south along the Park shoreline. Also during this period, the beach and dunes near the South Jetty were heavily nourished. Sand was annually placed in the nearshore area immediately south of the jetty and in Half Moon Bay, and placed on the beach and dunes to fill two potential dune breaches in 2010 and 2012. The recent nourishments have likely reduced the observed retreat rates near the South Jetty. AECOM's future retreat analysis incorporates this recent level of nourishment, to some degree.

Results

- Our analysis of shoreline retreat due to SLR and dune erosion show that assets at the Park, including the paved path, parking lot, and restroom facilities, could be at risk after 2030 under the Moderate-Risk Scenario and this decade under the High-Risk Scenario.
- The magnitude of long-term retreat varies by location, future decade, and scenario. For the year 2100, the estimated retreat and erosion distances vary from approximately 440 to 1,100 feet under the Moderate-Risk Scenario and 700 to 1,500 feet under the High-Risk Scenario.
- The magnitude of storm-induced erosion varies by location and storm severity. Estimated erosion distances vary from approximately 8 to 65 feet for the 30-Year storm and 11 to 76 feet for the 100-Year storm.

- In general, slower retreat and less erosion are predicted for the Moderate-Risk Scenario than the High-Risk Scenario. Under the Moderate-Risk Scenario, the northern section of the paved dune path could be at risk after 2050, and the southern section could be at risk after 2030. The northern edge of the parking lot along Half Moon Bay and the restroom facilities could be at risk after 2050.

- Under the High-Risk Scenario, the dunes are predicted to retreat and erode more rapidly. The northern section of the paved dune path could be at risk after 2040, and the southern section could be at risk this decade. The northern edge of the parking lot along Half Moon Bay and the restroom facilities could be at risk after 2040.

- AECOM used future dune retreat and erosion modelling to estimate the timing of future flooding. The analysis shows that flooding due to both a 30- and 100-Year coastal storm could expand landward of the current open-coast dunes after 2060 under the Moderate-Risk Scenario and after 2050 under the High-Risk Scenario. This is a conservative estimate as the analysis was conducted at the northwestern edge of the park, where there are developed park facilities, but the nourished dunes are larger and provide more protection for critical facilities. This analysis could yield different results if conducted in area where the dunes are smaller, but there are no developed facilities. This analysis also includes discussion of how the Federal Emergency Management Agency-mapped coastal floodplain might change as this could create development regulations.

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List of Acronyms

DEM	Digital Elevation Model
DOC	Depth of Closure
FEMA	Federal Emergency Management Agency
LiDAR	Light Detection and Ranging
GIS	Geographic Information Systems
MHHW	Mean Higher High Water
MHW	Mean High Water
MLLW	Mean Lower Low Water
MLW	Mean Low Water
MSL	Mean Sea Level
NAVD88	North American Vertical Datum of 1988 (NAVD88)
NGVD29	National Geodetic Vertical Datum of 1929
NOAA	National Oceanographic and Atmospheric Administration

NCMP	National Coastal Mapping Program
SLR	Sea Level Rise
SWL	Stillwater Level
TWL	Total Water Level
USGS	U.S. Geological Survey
WSPRC	Washington State Parks and Recreation Commission

1. Introduction

Westport Light State Park (Park) is located in the City of Westport, Grays Harbor County, Washington. The Park is at the northern end of a small sandy peninsula (Figure 1). The Pacific Ocean borders the western shoreline of the Park, with the South Jetty and the Half Moon Bay section of Grays Harbor forming the northern edge of the Park (Figure 2). The open coast shoreline generally consists of a flat, broad, dissipative beach backed by tall, vegetated coastal dunes. This shoreline is exposed to harsh winter storms with large waves that erode the beach and dunes and has a documented history of chronic, long-term shoreline retreat and episodic dune erosion during winter storms. The Half Moon Bay shoreline is more protected within Grays Harbor and consists of a steeper beach backed by lower, vegetated coastal dunes. The Half Moon Bay shoreline also has a documented history of chronic, long-term shoreline retreat.

In this report, “shoreline retreat” refers to chronic, multi-decadal shoreline retreat due to sea level rise (SLR), sediment transport, and wave exposure. “Erosion,” and specifically dune erosion, refers to rapid episodic erosion that occurs during winter storms. Dunes and beaches can sometimes seasonally recover, or partially recover, during the summer months after a winter storm, although recovery can be limited in areas with chronic shoreline retreat (Masslink and Hughes 2003).

1.1 Purpose of the Study

The purpose of this study is to identify areas of the Park that could be at risk due to future coastal retreat and erosion. Currently, the Park is mostly undeveloped. Existing development is limited to two parking lots with restroom facilities and a paved path along the coastal dune. Additional social trails meander through the interior of the Park. The interior is primarily composed of extensive interdunal wetlands between the paved parking areas (AECOM 2021). Approximately 15 years ago, prior to ownership by the Washington State Parks and Recreation Commission (WSPRC), a golf course was partially constructed in what is now the northern half of the Park. The project, known as Links at Half Moon Bay, was abandoned prior to completion. WSPRC is currently considering development of additional recreational facilities in the 603-acre Park.

WSPRC is developing a Master Plan for the Park that will indicate the areas and types of new development under consideration. The WSPRC Climate Change Vulnerability Assessment (Whitely-Binder et al. 2017) and WSPRC Adaptation Plan (Morgan et al. 2019) recommend that future climate change, including future SLR, be incorporated into planning and design projects in Washington State Parks. Following this guidance, AECOM conducted a high-level study to identify which areas of the Park could be at risk for future coastal retreat, erosion, and flooding associated with SLR. Future SLR may accelerate inland retreat of the beach and coastal dunes and subsequently generate flooding that impacts the developed features and natural resources of the Park, including the wetlands, parking lots, restroom facilities, and Westport Light Trail. AECOM used future long-term shoreline retreat analysis and storm-based dune erosion modelling to help the WSPRC understand when and where coastal erosion and flooding might occur under future SLR, and specifically when and where the wetlands might be impacted. This will ultimately help the WSPRC plan for climate change impacts at the Park and develop a comprehensive Master Plan.

1.2 Background Information on Westport Light State Park

Westport Light State Park is part of a sandy peninsula that forms the northern part of the Grayland Plains littoral subcell, a segment of the larger Columbia River Littoral Cell (CRLC). Sediment is supplied by the Columbia River to the south, and the beaches within the CRLC are currently retreating or accreting, depending upon local sand transport and wave exposure. The open coast shoreline of the Park consists of a flat, dissipative beach backed by vegetated coastal dune. The foredunes immediately south of the South Jetty have been significantly enhanced by nourishments and are up to 15 feet tall (Figure 3). Foredunes that border the southern border of the Park are smaller and up to 6 feet tall (Figure 4) (Ruggiero et al. 2013).

Figure 1. Westport Light State Park is located at the northern tip of Grayland Plains along the Washington open coast.

Figure 2. Westport Light State Park has the Pacific Ocean along its western shoreline and Half Moon Bay, within Grays Harbor, along its northern shoreline, and the City of Westport along is eastern border.

Figure 3. The shoreline and dunes at the Westport Light State Park, immediately south of the South Jetty. Sand nourishment has resulted in relatively tall dunes in this section.

Figure 4. The dunes and beach at Westport Light State Park, near the southern edge of the Park. The dunes are relatively short in this section.

Historical, multi-decadal shoreline retreat (i.e., chronic erosion) has been a problem for many decades at Westport Light State Park (Bridgeview Consulting 2018; Ruggiero et al. 2013; Stevens et al. 2020), and this problem will likely be exacerbated with future SLR. The U.S. Geological Survey (USGS) calculated high erosion rates between 1967 and 2002, with rates from 6-19 feet/year along the Park shoreline and over 26 feet/year near the South Jetty (Ruggiero et al. 2013). (As a side-note, Ruggerio et al. (2013) calculated long-term rates of accretion between 1886 and 2002; however, these rates include the construction of the jetty in the late 1800's and the subsequent progradation of the shoreline. Ignoring the pre-jetty shoreline, the USGS historical shorelines from the same study show long-term retreat between 1950 and 2002). Stevens et al. (2020) found areas of retreat along the southern portion of the Park shoreline between 2014-2019, as well as accretion immediately south of the jetty, although the study notes that the accretion is likely due to the recent placement of fill near the jetty. Bridgeview Consulting (2018), working with the Washington State Department of Ecology, calculated retreat rates varying from approximately 3 feet/year in Half Moon Bay, to 2-3 feet/year at the northwestern shoreline of the Park near the South Jetty, to 11 feet/year at the southwestern edge of the Park near the Westport by the Sea Condominiums between the years 2002 and 2016.

The WSPRC Climate Change Vulnerability Assessment (Whitely-Binder et al. 2017) notes that “Westport Light State Park has also experienced significant losses from beach erosion near the South Jetty for more than 25 years.” Historically, the beach built out after the South Jetty was completed in the early 1900’s until 1950, when the beach began to retreat (Bridgeview Consulting 2018). During a high erosion period in 1993, the dunes at the South Jetty terminus were breached. The US Army Corps of Engineers (USACE) has subsequently armored the dunes along the Half Moon Bay shoreline and nourished the beach for protection. In 2015 and 2016, waves eroded the dunes approximately 60 feet immediately south of the Park and threatened the Westport by the Sea Condominiums (Figure 5). A dynamic revetment was constructed in December of 2021. This area is outside of the Park boundary.

Figure 5. Long-term retreat of the beach and dunes has threatened the Westport by the Sea Condominiums, immediately south of the Westport Light State Park boundary. A dynamic revetment was built in December 2021.

The USACE regularly nourishes the open coast shoreline immediately south of the South Jetty and the Half Moon Bay shoreline (Table 1).The nourishments include both the offshore placement of sand in nearshore areas and the placement of sand on the beach and dunes.

Table 1. History of Nourishments at the Park between 2002-2016.

	Nearshore Sites		Beach and Dune Sites		
Year	South Beach (cy)	Half Moon Bay (cy)	Breach Fill (cy)	Half Moon Bay (cy)	Westport (cy)
2002	75,219	378,441	135,000		
2003	125,388	329,106			1,700
2004	262,176	289,652	29,553		
2005	217,909	102,184	22,779		
2006	55,170	126,892			
2007		140,406			
2008		171,353			
2009	214,502	144,975			
2010	118,182	91,720	30,000		
2011	298,251	177,150			
2012	142,213	111,205	30,000		
2013	477,637	86,147			
2014	498,440				
2015	506,330				
2016	544,980				
2017	499,001	101,019			

Notes: Table reproduced by Bridgeview Consulting (2018). "Nearshore" placement refers to sand placed offshore, "Beach and Dune" placement refers to sand placed on the dry beach or dunes to fill potential beaches.

The USACE dredges the Grays Harbor channel annually (USACE 2018). The amounts and frequency vary and are dependent on how rapidly the shipping channel fills in over time; however, the recent annual average has been approximately 3.7 million cubic yards. Due to logistical constraints and cost, most of the sediment (approximately 80-90%) is placed directly at two offshore disposal sites. Both these disposal sites are near Grays Harbor inlet, but they are situated such that the sand cannot migrate onshore to nourish the beaches and dunes. The remaining sediment (approximately 10-20%) is placed at two nearshore "beneficial use areas" and one upland/intertidal site in the Westport area. The upland/intertidal placement site is in Half Moon Bay, including the isthmus that connects the South Jetty to the peninsula. Nourishments at the beneficial use areas are intended to reduce erosion south of the South Jetty, though they do not directly supply sediment to the upper portions of the shoreline.

There was a recent proposal to place 250,000 cubic yards of dredged sediment between the South Jetty and the Westport-By-The-Sea condominiums to counteract or mitigate the rapid retreat at that location (Ecology 2022). This placement would be similar to the Half Moon Bay placement site; however, at the time of this study, the nourishment has not taken place.

Future SLR is generally expected to accelerate coastal retreat in this area. The historical (i.e., observed) rate of SLR is 0.38 millimeters/year at the National Oceanic and Atmospheric Administration (NOAA) Toke Point tide gauge, which is lower than the current global rate of SLR of 3.0 millimeters/year calculated by NOAA (Sweet et al. 2017). This is due to vertical land motion (VLM), as much of the Olympic Peninsula and Grays Harbor area is uplifting. Miller et al. (2018) report an uplift rate of 0.8 feet/century for the Westport area. This local uplift will counteract some of the future SLR at Westport if historical VLM trends continue into the future.

It is important to note that there is some uncertainty in the observations of SLR and VLM. NOAA reports a 95% confidence interval of +/- 0.78 millimeters/year for the observed SLR rate at the Toke Point tide gauge and Miller et al. (2018) report an uncertainty estimate of +/- 0.3 feet/century for the observed VLM. Furthermore, Miller et al. (2018) note that a subduction zone earthquake could suddenly cause a land elevation change between -3.9 and -5.1 feet (subsidence). The effects of earthquakes and tsunamis are beyond the scope of this study and were not included in the analysis.

There are three specific types of coastal retreat and erosion that will impact the future vulnerability of the wetlands and Park. The first is the continuation of the historical, long-term retreat trend, which is due to nearshore sediment transport patterns, sediment supply, and wave exposure. Westport has a documented history of coastal retreat, and as part of a conservative analysis approach, AECOM assumed that these retreat processes will continue into the future. The second type of erosion is future, long-term retreat, which will be due to accelerating SLR. Future SLR is widely expected to make current coastal erosion hotspots worse (Whitely-Binder et al. 2017). The third is event-based erosion due to winter storms. This type of erosion is sporadic and occurs during particularly severe winters, such as El Niño winters. Each of these components was included in the analysis and is described in detail in the following sections of the report.

As the coastal dunes currently protect the wetlands from flooding, widespread flooding of the wetlands will generally not occur until the dunes are breached. In this study, it was assumed that future coastal flooding will be directly linked with retreat and erosion of the backshore and dunes. Therefore, aside from examining how the future Federal Emergency Management Agency (FEMA) floodplain might change, AECOM did not conduct any flood analysis and modelling separate from the coastal erosion analysis and modelling in the coastal study.

2. Coastal Study Methodology

We followed a simple, one-dimensional (1D) transect-based approach to evaluate the potential impacts of future shoreline retreat and dune erosion at the Park. First, AECOM identified published, observed rates of historical shoreline retreat and future projections of SLR at the Park. A *modified* Bruun Rule (see Section 2.3) was applied with the observed rate of SLR (0.38 millimeters/year) to isolate the amount of historical retreat due to observed SLR and the amount of historical retreat due to other nearshore processes (e.g., littoral drift, sediment supply, etc.) at each transect. The amount of retreat due only to SLR was proportionally increased by the future, projected amounts of SLR by each decade (2030-2100) under each local SLR scenario. The specific retreat distances were then projected inland to estimate future shoreline retreat due to SLR by the decade at each transect. In a separate evaluation, a dune erosion model was run at each transect to estimate the amount of erosion due to specific storm conditions. At each study transect, the modeled erosion distance was added to the estimated shoreline retreat distance to estimate the combined effects of both future long-term shoreline retreat and storm-induced dune erosion. Maps of future coastal erosion hazard areas were based on these combined retreat and erosion distances. This study used data and results published by the USGS, National Data Buoy Center (NDBC), and FEMA.

Instead of analyzing many different combinations of historical shoreline change, SLR, and storm conditions, AECOM developed and analyzed two “bookend” scenarios that capture the range of potential future conditions at the project site—a *Moderate-Risk* Scenario and a *High-Risk* Scenario. The Moderate-Risk Scenario is intended to capture a combination of shoreline retreat and storm conditions that is likely to occur over the coming decades in response to natural shoreline dynamics and SLR. The High-Risk Scenario is intended to capture a possible, but less likely, combination of shoreline change and storm conditions. The High-Risk Scenario is intended to represent a more conservative assessment of potential retreat and erosion conditions at the project site to better understand the full extent of Park area that may be exposed to flood and erosion hazards in the future. Both the moderate- and high-risk scenarios will be useful for WSPRC assessment and future decision-making at the Park.

For each retreat and erosion process that will be evaluated in the analysis, the following factors were considered in developing the Moderate- and High-risk scenarios:

- **Historical long-term retreat trends:** There are various studies of historical shoreline change at the project site calculated. Using different methods and periods of record, nearly all show high rates of long-term retreat. As described in section 2.1, AECOM selected rates for the Moderate- and High-risk scenarios from a review of the published rates that reflect the high long-term retreat observed at the Park.

- **Future sea level rise:** There is considerable uncertainty in future greenhouse gas (GHG) emissions and projected rates of SLR at the project site. AECOM selected an appropriate GHG emission scenario and SLR projections to assume for the Moderate- and High-risk scenarios based on a review of the assumptions made in the Washington State Parks Climate Vulnerability Assessment (Whitely-Bender et al. 2017).

- **Coastal storm conditions:** Consideration of event-based storm erosion adds a factor of safety to projected rates of long-term shoreline retreat to account for additional erosion hazards posed by storm events; however, different organizations have different degrees of risk tolerance when planning for rare and unpredictable events such as coastal storms. AECOM assumed reasonable return periods of storm events for the Moderate- and High-risk scenarios based on the annual probability of occurrence.

Table 2 presents a summary of the assumptions for the Moderate-Risk and High-Risk analysis scenarios. The Moderate-Risk Scenario assumes a moderate level of risk for coastal erosion and flooding processes, including adoption of recent shoreline change trends, a high GHG emissions scenario, a 50% exceedance SLR projection, and a 30-Year coastal storm event. For SLR, the 50% probability of exceedance means that there is 50% chance that SLR will be above this projection under the high GHG scenario. For the coastal storm, a 30-Year coastal storm has 3.3% chance of occurring in any given year and is expected to occur once every 30 years on average. These conditions are consistent with a moderate level of risk. The High-Risk Scenario assumes a high level of risk for coastal erosion and flooding processes, including adoption of recent shoreline change trends, a high GHG emissions scenario, a 1% exceedance SLR projection, and a 100-Year coastal storm event. For SLR, the 1% probability of exceedance means that there is 1% chance that SLR will be above this projection under the high GHG scenario. For the coastal storm, a 100-Year coastal storm has 1% chance of occurring in any given year and is expected to occur once every 100 years on average. These conditions are consistent with a high level of risk. Including both a Moderate- and High-Risk scenario gives a range of potential future flood and erosion hazard zones that WSPRC can use in planning for future conditions. Additional details and discussion for each coastal retreat and erosion process are provided in Sections 2.1, 2.2, and 2.3.

Table 2. Coastal Conditions and Planning Scenarios Evaluation in the Coastal Study

Coastal Erosion and Flooding Process	Moderate-Risk Scenario	High-Risk Scenario
Historical Long-Term Retreat Trends	Grays Harbor Hazard Mitigation Plan Historical Retreat Rates from 2002-2016[1]	Grays Harbor Hazard Mitigation Plan Historical Retreat Rates from 2002-2016[1]
Future SLR	High Greenhouse Gas Emission Scenario (RCP 8.5) 50% Exceedance SLR Projection[2]	High Greenhouse Gas Emission Scenario (RCP 8.5) 1% Exceedance SLR Projection[2]
Coastal Storm Conditions	Moderate Storm Conditions (30-Year event)	Severe Storm Conditions (100-Year event)

Notes: [1] Grays Harbor Hazard Mitigation Plan (Bridgeview Consulting 2018); data collected and analyzed by the Washington State Department of Ecology; [2] Washington State SLR Guidance (Miller et al. 2018)

Key: RCP = Representative Concentration Pathway; SLR = sea level rise.

It is important to note that this study did not consider the effects of man-made features (e.g., parking lots, fill, paved paths, etc.) on long-term retreat and erosion as these features are often undermined by erosion and not designed to be coastal erosion protection structures. In addition, their specific construction details and future maintenance are unknown. Finally, most of the dunes are generally undeveloped and free of man-made features with the exception of a single paved path, and it is reasonable to treat them as undeveloped.

The effects of beach grass and other vegetative plantings on long-term retreat and erosion were not directly considered, but indirectly incorporated into the analysis and modelling. There is evidence that beach grasses, including non-native European and American Beach grass, help trap wind-blown sand and allow for bigger and wider dunes, that can provide more erosion and flood protection, even potentially against future SLR (Komar 1998; Seabloom et al. 2013). Native beach grasses do not trap as much sand, and only allow for the formation of small dune hummocks. These non-native grasses were introduced to the west coast specifically to trap wind-blown sand. Because the non-native grasses were introduced to this area in the early 1900's (Komar 1998) it is likely that the historical retreat rates reflect their presence and any long-term retreat protection they might afford. Furthermore, the dune erosion modelling incorporates the taller, wider dune geometries created by the introduced beach grasses. Therefore, the effects of the non-native beach grasses were indirectly incorporated into the study through the historical retreat rates and the large dune geometries.

Unless otherwise noted, all elevations in this study are referenced to the North American Vertical Datum of 1988 (NAVD88). The current tidal datums from the NOAA Toke Point Tide Gauge (NOAA Station #9440910) are listed in Table 3.

Table 3. Tidal Datums at Toke Point Tide Gauge (in feet NAVD88)

Vertical Datum	Toke Point Tide Gauge (#9440910)
Highest Observed Tide	13.59 (11/14/1981)
Highest Astronomical Tide	10.62 (12/12/1985)
Mean Higher High Water	8.10
Mean High Water	7.36
Mean Sea Level	3.96
NGVD29	3.34
Mean Low Water	0.55
NAVD88	0.00
Mean Lower Low Water	-0.82
Lowest Astronomical Tide	-3.81 (06/23/1986)

Note: Dates are included for the Highest Observed Tide, Highest Astronomical Tide, and Lowest Astronomical Tide. Tidal datums are based on the National Tidal Datum Epoch of 1983-2001.

Key: NAVD88 = North American Vertical Datum of 1988; NGVD29 = National Geodetic Vertical Datum of 1929.

AECOM developed a 1D transect layout for the Park, with 41 transects along the open coast shoreline and 9 transects along the Half Moon Bay shoreline (Figure 6). The USGS calculated historical rates of shoreline retreat along the open coast of Washington as part of the National Assessment of Shoreline Change (Ruggiero et al. 2013). AECOM used these transects for the open coast shoreline of the Park. Along the Half Moon Bay shoreline of the Park, AECOM placed transects oriented perpendicular to the shoreline and the State Park Access Road.

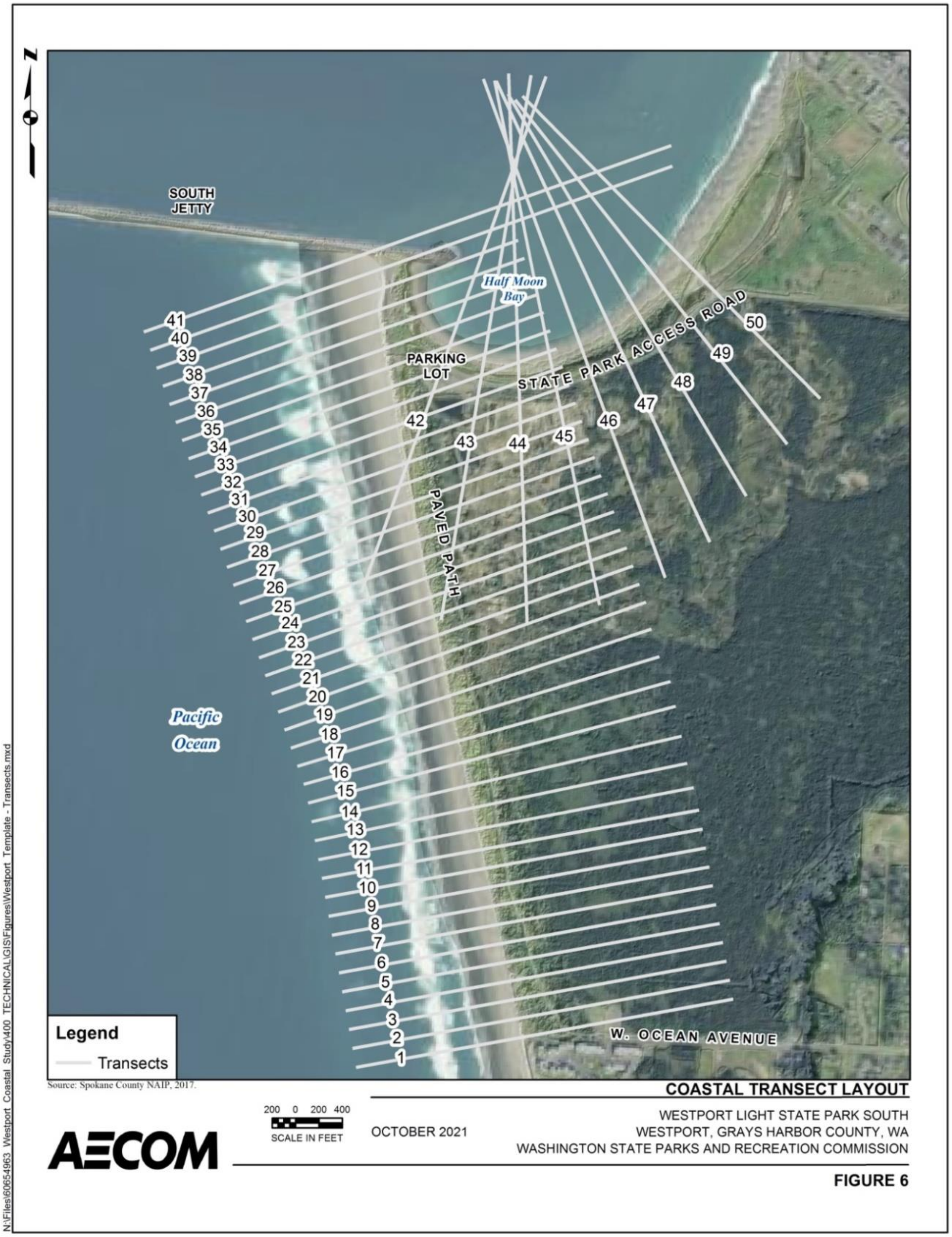

Figure 6. The 1D transect layout used for the study.

Analysis of the beach and dunes in this study required topographic and bathymetric data. Airborne topographic Light Detection and Ranging (LiDAR) data were collected along the Washington coast in 2017 and subsequently processed by the USGS. The data are high resolution (approximately eight survey points per square meter), with a horizontal accuracy of 1.50 feet (0.46 meters) and a vertical accuracy of 0.28 feet (0.09 meters) (OCM Partners 2021). AECOM downloaded the “Olympic Peninsula Area 2” subset of the “2017 USGS LiDAR: Olympic Peninsula, WA” from NOAA’s Digital Coast Website (https://coast.noaa.gov/digitalcoast/) then extracted 1D cross-shore profiles from the LiDAR along each transect (Figure 7). The cross-shore profiles show the beach, backshore, dune, and wetland elevations for the Park. AECOM also downloaded an accompanying digital elevation model (DEM) to aid review of results in GIS.

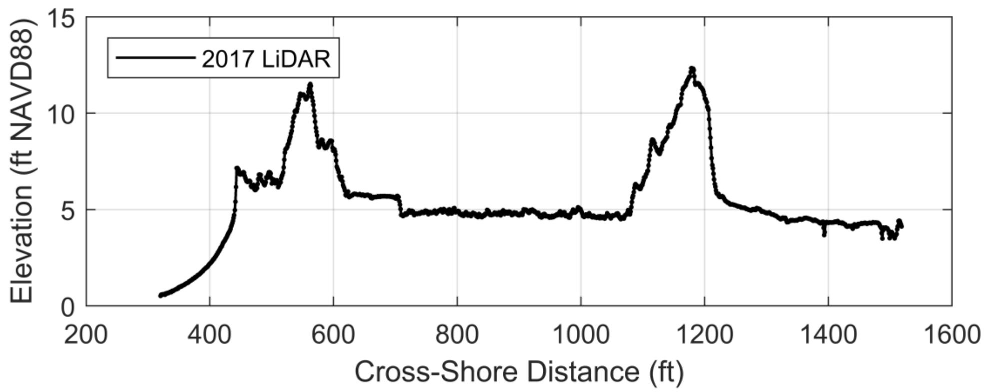

Figure 7. Cross-shore profile extracted along Transect 1 from the 2017 LiDAR data.

AECOM also obtained bathymetric elevations to calculate offshore slopes at each transect; however, the 2017 LiDAR survey only extended seaward to approximately mean low water (MLW) (Figure 7). The NOAA National Center for Environmental Information developed a bathymetric DEM for offshore wave modelling (the US Coastal Relief Model Vol. 8 – Northwest Pacific; NOAA 2003). Similar to the 2017 LiDAR data, the DEM was used to extract cross-shore profiles along each transect. Since the NOAA bathymetric DEM is older and more coarse that the 2017 LiDAR data, AECOM only used this model to calculate offshore slopes. The 2017 LiDAR was used for all other parts of the analysis and modelling.

AECOM identified geomorphic parameters (dune toes, crests, and heels) on the cross-shore profiles extracted from the 2017 LiDAR (Figure 8). These parameters are critical to long-term shoreline retreat analysis and erosion modelling. The dune toe is generally defined as the seaward junction between the beach and dune. The dune crest was identified as the tallest crest along each profile. The heel is defined as the landward junction between the dune and wetland and/or backshore. These parameters were first identified visually on each cross-shore profile. They were then reviewed in GIS and compared against the 2017 DEM, hillshade, and aerial photos. Both the spatial locations and elevations of the parameters were refined as necessary in GIS.

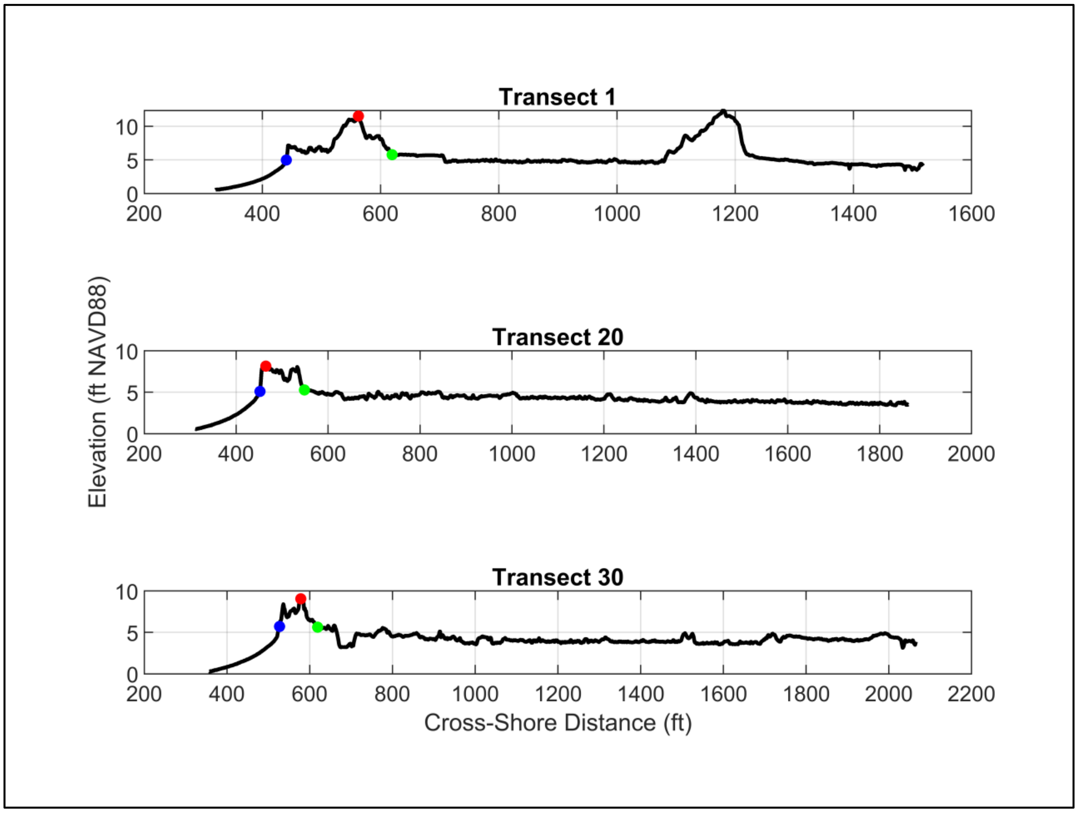

Figure 8. Geomorphic parameters, including the dune toes (blue), crests (red), and heels (green), were identified on each cross-shore profile.

2.1 Historical Long-Term Retreat Trends

Because long-term shoreline retreat has been well documented in this area since the 1950's, it is critical to incorporate historical trends of shoreline retreat into the analysis. Estimation of historical shoreline change rates is somewhat sensitive to the seasonal timing of shoreline surveys and the period over which rates are calculated. Currently, the beach at the Park is retreating at a moderate to high rate, depending on the specific location (Bridgeview Consulting 2018). Bridgeview Consulting (2018), working with the Washington State Department of Ecology, calculated retreat rates varying from approximately 3 feet/year in Half Moon Bay, to 2-3 feet/year at the northwestern shoreline of the Park near the South Jetty, to 11 feet/year at the southwestern edge of the Park near the Westport by the Sea Condominiums between the years 2002 and 2016.

There is no specific guidance in the Washington State Parks Vulnerability Assessment (Whitely-Binder et al. 2017) on which retreat conditions to assume for a coastal study. AECOM selected the most recently observed retreat rates (2002 – 2016) in the Grays Harbor Hazard Mitigation Plan (Bridgeview Consulting 2018), as they are the best available data, reflect the most current state of the beach, and capture the chronic erosion documented at the site over a recent time period. It is important to note that the open coast and Half Moon Bay shorelines, immediately south of the South Jetty, were nourished annually in this time period (Table 1). Although the observed retreat rates show retreat everywhere, they show less retreat near the South Jetty. These lower retreat rates near the South Jetty likely include the effects of the nourishments. It is possible that without the nourishments, the retreat rates near the South Jetty would be larger, possibly similar to the large retreat rates the USGS observed between 1967 – 2002. Further south, the retreat rates are higher, suggesting that the current nourishments might not be protecting the areas to the south.

By using the 2002 – 2016 retreat rates in the future retreat analysis, which include current levels of nourishments, AECOM made the assumption that some amount of the current level of nourishments would extend into the future. AECOM did not assume that there would be a future increase in nourishments or coastal erosion protection projects that may mitigate future erosion.

These current rates of coastal retreat were used for both the Moderate-Risk Scenario and the High-Risk Scenario (Table 2). These rates were assigned to the nearest analysis transect in the transect layout for the study (Figure 9).

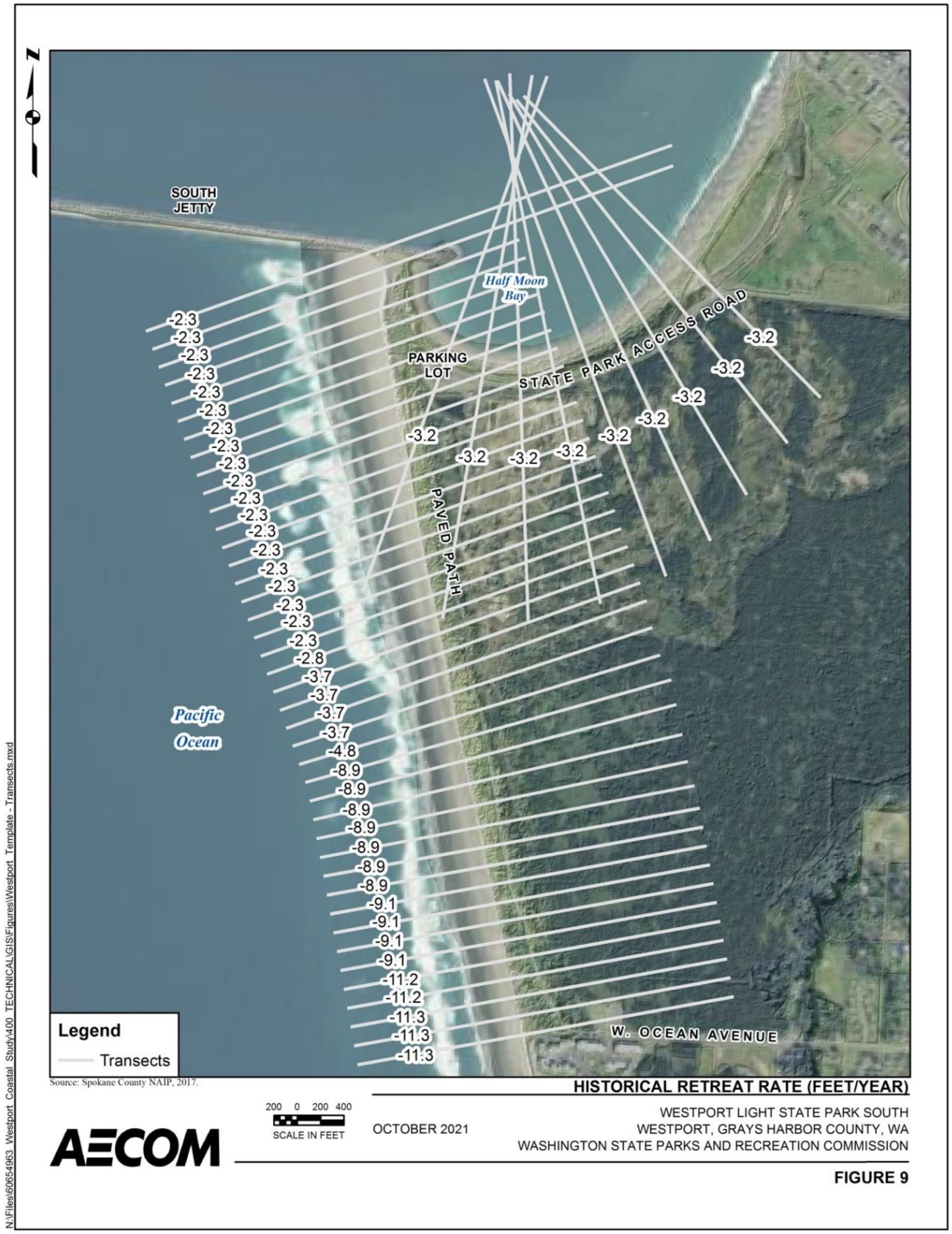

Figure 9. Historical (2002-2016) shoreline retreat rates used at each analysis transect.

2.2 Sea Level Rise

The Washington State Parks Vulnerability Assessment (Whitely-Binder et al. 2017) notes that future SLR is widely expected to exacerbate future coastal flooding and erosion and should be included in State Park projects and planning. The assessment uses the Representative Concentration Pathway (RCP) 8.5 GHG emissions scenario and the 1% exceedance SLR projection under that scenario in its analyses. Based on discussions with WSPRC, AECOM analyzed SLR projections under this scenario. Although this assumes a worst-case scenario, it has been documented that to date, atmospheric carbon dioxide concentrations continue to track on, or above, RCP 8.5 (Boden et al. 2017; Le Quéré et al. 2018; Schwalm et al. 2020). AECOM included the 50% exceedance SLR projection in the Moderate-Risk Scenario and the 1% exceedance SLR projection for the High-Risk Scenario (Figure 10). Values of the different scenarios are also listed in Table 4.

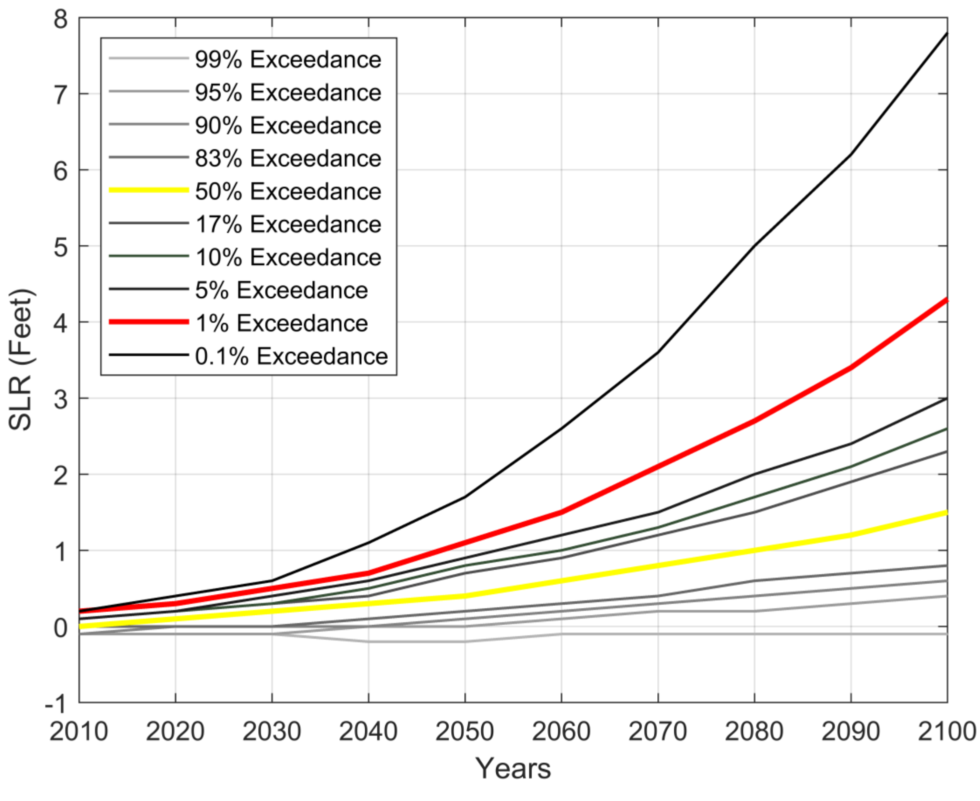

Figure 10. SLR projections under the high global greenhouse gas emissions scenario RCP 8.5 for Westport.

Note: Miller et al. (2018) refers to the probability of exceedance of each specific projection as a likelihood. The two recommended SLR projections are shown above in yellow (50% probability of exceedance projection for the Moderate-Risk scenario) and red (1% probability of exceedance for the High-Risk scenario).

Table 4. SLR Projections for Westport

	SLR (feet)									
	Probability of Exceedance									
Year	**99%**	**95%**	**90%**	**83%**	**50%**	**17%**	**10%**	**5%**	**1%**	**0.1%**
2010	-0.1	-0.1	-0.1	0	0	0.1	0.1	0.1	0.2	0.2
2020	-0.1	-0.1	0	0	0.1	0.2	0.2	0.2	0.3	0.4
2030	-0.1	-0.1	0	0	0.2	0.3	0.3	0.4	0.5	0.6
2040	-0.2	0	0	0.1	0.3	0.4	0.5	0.6	0.7	1.1
2050	-0.2	0	0.1	0.2	0.4	0.7	0.8	0.9	1.1	1.7
2060	-0.1	0.1	0.2	0.3	0.6	0.9	1	1.2	1.5	2.6
2070	-0.1	0.2	0.3	0.4	0.8	1.2	1.3	1.5	2.1	3.6
2080	-0.1	0.2	0.4	0.6	1	1.5	1.7	2	2.7	5
2090	-0.1	0.3	0.5	0.7	1.2	1.9	2.1	2.4	3.4	6.2
2100	-0.1	0.4	0.6	0.8	1.5	2.3	2.6	3	4.3	7.8

Note: The highlighted columns for 50% and 1% probability of exceedance correspond to the SLR projections analyzed for the moderate- and high-risk scenarios (A and B), respectively.

Key: SLR = sea level rise.

Figure 10 and Table 4 show future SLR projections for Westport that are lower than those predicted for other areas of Washington's coastlines. This is due to VLM, as much of the Olympic Peninsula and Grays Harbor area is uplifting. This local uplift will counteract some of the future SLR at Westport, resulting in SLR of 1.5 feet by 2100 for the 50% probability of exceedance scenario and 4.3 feet under the 1% probability of exceedance scenario. Even though the projected future SLR is lower for Westport than other areas in the state, SLR is still expected to accelerate erosion and flooding. Note that these SLR projections do not account for rapid land uplift or subsidence that could occur during a large future earthquake, which is beyond the scope of this study.

2.3 Future Long-Term Shoreline Retreat

Future, long-term shoreline retreat is complex, and predicting the inland extent of shoreline retreat due to SLR, particularly to the end of the century, can be difficult. The Bruun Rule is a simplified, yet widely applied approach in coastal management and engineering studies for predicting shoreline retreat due to future SLR. The Bruun Rule generally estimates the inland retreat distance by projecting the specific amount of SLR inland along the Bruun slope, which is calculated between a point on the beach and the seaward limit of sediment transport between the nearshore and offshore, also known as the depth of closure (DOC):

$$R_B = SLR/s \qquad \text{(Equation 1)}$$

where R_B is the predicted inland retreat distance, SLR is the specified amount of SLR, and s is the Bruun slope (Figure 11). A major shortcoming of this approach is that it assumes the beach has no longshore sediment transport, and future retreat is limited to cross-shore sediment transport. Therefore, AECOM applied a modified Bruun Rule in this study to account for observed rates of shoreline retreat, which could include longshore sediment transport patterns. This modified Bruun Rule approach has been used in multiple shoreline retreat studies, including the FEMA SLR Pilot Study in San Francisco County, California (BakerAECOM 2016).

Bruun slopes (*s*) were calculated in two different ways. On the open coast, Bruun slopes were estimated using offshore profile data from Westport presented in Stevens et al. (2020). An average slope of 0.007 (i.e., 1V:140H) was calculated and applied to all transects. In Half Moon Bay, a best-fit line was fit to each bathymetric cross-shore profile between mean higher high water (MHHW) and the DOC. The DOC for each transect was estimated using modeled wave conditions reported in the FEMA coastal flood study (detailed in Section 2.5).

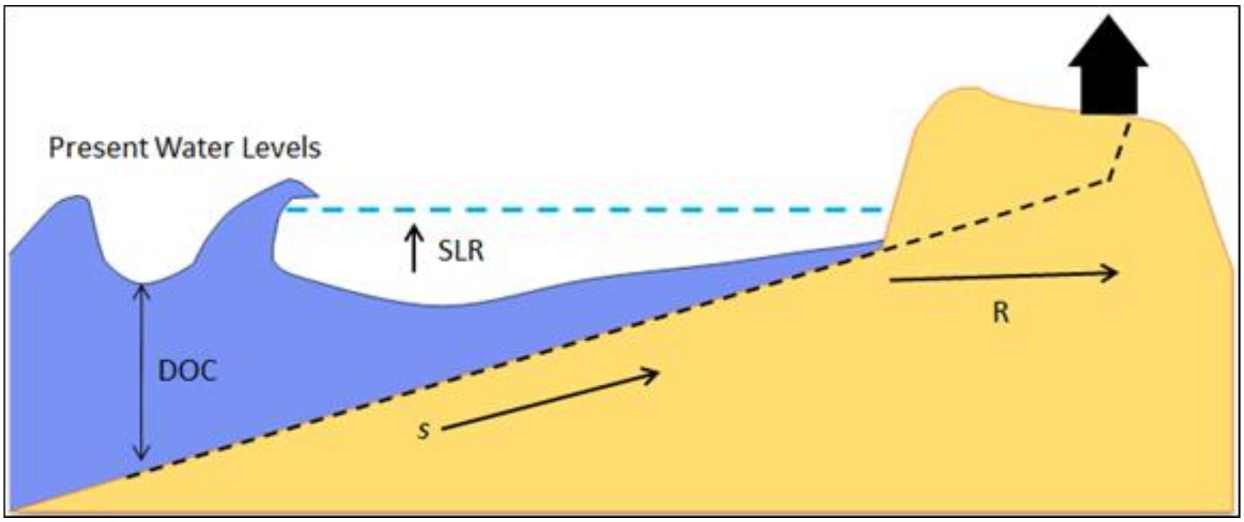

Figure 11. A conceptual diagram of the Bruun Rule.

Note: DOC = depth of closure, SLR = sea level rise, s = Bruun slope, and R = retreat distance

In general, the modified Bruun Rule accounts for future SLR in addition to continuation of historical shoreline change trends, which might include both erosion and accretion. In this study, the Bruun Rule was first applied at each analysis transect with the observed rate of SLR from the NOAA Toke Point tide gauge (0.38 millimeters/year) to estimate the theoretical retreat due to observed SLR. At each transect, the difference between the historical rate of shoreline change and the theoretical Bruun Rule response was assumed to be due to alongshore sediment transport patterns not related to SLR (e.g., littoral drift, sediment supply, etc.). These historical erosion rates due to SLR were then subtracted from the actual historical shoreline change rates to estimate the shoreline change rates due to nearshore coastal processes. The rates of change due to nearshore processes were assumed to remain constant in the future, while the rates of change to observed SLR were assumed to increase at a rate proportional to the projected increase in future SLR. The shoreline change rates due to SLR were increased by linear factors to increase the fraction of shoreline change due to SLR.

To quantify the acceleration in future SLR projections, an average rate of SLR was calculated between each future decade (2030-2100) and the year of the LiDAR survey (2017). The ratio of this rate to the observed SLR rate at the local tide gauge was then calculated. This can be simply expressed as:

$$F = l/b \qquad \text{(Equation 2)}$$

where F is the factor of increase, l is the average rate of SLR between the year of interest and LiDAR survey year, and b is the observed SLR rate. For example, the predicted average rate of SLR for the 1% probability of exceedance scenario is approximately 14.8 millimeters/year between the years 2017 and 2089. The observed rate of SLR at the Toke Point tide gauge is 0.38 millimeters/year. The factor of increase is then F = 14.8/0.38 = 38.95. The calculated factors for all years and scenarios are listed in Table 5.

Table 5. Calculated Factors of Increase (F) Between the Observed and Future Rates of SLR

Year	50% Exceedance	1% Exceedance
2030	8.02	14.19
2040	8.02	15.00
2050	8.02	20.17
2060	9.89	22.94
2070	11.05	27.70
2080	11.84	30.94
2090	12.42	34.39
2100	13.82	38.95

Key: SLR = sea level rise.

After calculating the factor of increase between the observed rate of SLR and future rates of SLR, this information was incorporated in the modified Bruun Rule approach using the following steps.

AECOM first assumed that the historical rates of shoreline change were a combination of two components:

$$r_h = r_{coastal} + r_{h,SLR} \qquad \text{(Equation 3)}$$

where r_h is the historical shoreline change rate at each transect, $r_{coastal}$ is the amount of the historical shoreline change rate due to nearshore coastal processes, and $r_{h,SLR}$ is the amount of the historical shoreline change rate due to observed rates of SLR at each transect. The subscript "h" stands for historical. Predicted future rates of shoreline change (r_f) are then:

$$r_f = r_{coastal} + r_{f,SLR} \qquad \text{(Equation 4)}$$

which is a combination of the continuation of the historical shoreline change rate due to nearshore coastal processes, assumed to be the same in the future, and the rate of shoreline change due to future SLR ($r_{f,SLR}$).

To estimate $r_{h,SLR}$, the Bruun Rule was applied:

$$r_{h,SLR} = \frac{b}{s} \qquad \text{(Equation 5)}$$

where *b* is the observed rate of SLR from the Toke Point tide station, and *s* is the Bruun slope. The shoreline change rate due to nearshore coastal processes was then calculated by re-arranging Equation 4:

$$r_{coastal} = r_h - r_{h,SLR} \qquad \text{(Equation 6)}$$

The future rate of shoreline change due to SLR was then estimated by increasing the historical rate of shoreline change due to SLR and scaling by factor F for a particular time frame and SLR scenario:

$$r_{f,SLR} = r_{h,SLR} \times F \qquad \text{(Equation 7)}$$

Values of F or each time frame and SLR scenario are found in Table 5. The predicted future retreat distances for a particular SLR scenario and time frame were then found by multiplying the rate by time:

$$R_f = r_f \times t \qquad \text{(Equation 8)}$$

It is important to highlight that this approach preserves the historical trends in shoreline change due to nearshore coastal processes. For example, if a beach has historically prograded (i.e., built out), the predicted future retreat response may be small, because SLR will be working against the processes that have historically caused accretion. If a beach has historically eroded, the predicted future retreat response might be large, as SLR will be combining with the processes that have historically caused erosion.

The retreat distances estimated for each decade under each SLR projection were combined with dune erosion distances under the Moderate-Risk Scenario High Risk Scenario. These combined distances were applied inland from each dune to estimate the future retreat and erosion for each future decade.

2.4 Inland Retreat of the Dunes into the Wetland

The future retreat distances were also used to estimate the future, inland retreat of dunes into the existing wetlands due to SLR. In a natural system, as SLR increases, it is expected that the coastal dunes will retreat (i.e., migrate) inland as they come into equilibrium with the higher coastal water levels (Masselink and Hughes 2003). The inland migration of beach sand could impact the wetlands at the Park. To estimate the impacts of this, AECOM projected the future retreat distances under Scenarios A and B inland from each dune heel at each decade (2030-2100). Unlike the future retreat and erosion of the dune toe described in the previous section, the 30- and 100-Year storm erosion distances were not applied to the dune heels. This is because the landward migration of the dunes is due to the long-term equilibrium between the dunes and SLR, not event-based storm erosion, from which the beaches and dunes can subsequently partially recover (Masselink and Hughes 2003).

2.5 Dune Erosion from the 30- and 100-Year Storms

The open Pacific coast of Washington is home to severe winter storms with wave heights exceeding 10 meters (Allan and Komar 2000). In addition to long-term coastal retreat, the beach at Westport has rapidly eroded in specific areas during particularly severe storms and winters (Allan and Komar 2002). Because of this, AECOM modeled and incorporated event-based (i.e., storm-induced) dune erosion into the erosion hazard mapping. This modelling estimates erosion of the dune toe, which is the natural barrier to erosion and flooding of the interior of the Park, during specific storm conditions. The estimated storm erosion distances were subsequently added onto the predicted long-term retreat due to SLR each decade. This provides estimates of future dune and beach erosion for each decade, with the assumption that a coastal storm could hit the coast at any time in the future and lead to erosion and flooding of Park assets. Similar to the long-term retreat analysis, it was assumed that the frequency and magnitude of nourishments observed and averaged between 2002 – 2016 would continue into the future. It was not assumed that nourishments would increase beyond this average.

To develop storm conditions, AECOM followed an event selection approach which is widely used in coastal engineering. AECOM selected storm conditions (e.g., wave height, wave period, storm duration, etc.) from a storm corresponding approximately to a 30-Year return period for the Moderate-Risk Scenario (Table 2). Conditions from a storm corresponding approximately to a 100-Year return period were used for the High-Risk Scenario. The Washington State Parks climate change vulnerability assessment (Whitely-Binder et al. 2017) includes analyses using 100-Year storm conditions. Using the 100-Year storm conditions is also consistent with the FEMA coastal flood study conducted in this area.

AECOM conducted dune erosion modelling with the Kriebel and Dean (1993) analytical erosion model, which is widely used in coastal engineering, including FEMA coastal flood studies (FEMA 2005). The model is a simple, 1D analytical model that estimates the erosion (i.e., landward retreat) of the dune toe for a given set of storm conditions. The model considers storm duration, sediment grain size, wave height, wave period, beach slope, total water level (TWL), and the overall height of the dune. The TWL is the elevated water level at the shoreline during storms due to a combination of astronomical tides, storm surge, wave setup, and wave runup. AECOM applied the model at each transect with transect-specific parameters to approximate the 30- and 100-Year coastal storms for this area. There are no single, complete, published sources for all of these specific parameters for both the open Pacific coast and Half Moon Bay shorelines at the Park. Therefore, storm parameters were selected by AECOM based on analysis of historical wave and water level data, review of available research and literature, and professional judgment. The sources of these parameters are listed in Table 6; the values for each transect and storm are found in Appendix A.

Table 6. Sources of 30- and 100-Year Storm Parameters Used in Dune Erosion Modelling

30-Year Coastal Storm Parameters (Moderate-Risk Scenario)		
Transect Numbers	**1-41 (Open Coast)**	**42-50 (Half Moon Bay)**
Storm Duration (T_D)	March 1999 Storm of Record Hydrograph	
Sediment Grain Size (D_{50})	Gelfenbaum and Kaminsky (2000)	
Offshore Wave Height (H_0)	EVA of NDBC Wave Record	FEMA Coastal Flood Study
Peak Spectral Wave Period (T_p)	NDBC Wave Record	FEMA Coastal Flood Study
Still Water Level (SWL)	FEMA Coastal Flood Study	FEMA Coastal Flood Study
Total Water Level (TWL)	AECOM Calculated	AECOM Calculated
100-Year Coastal Storm Parameters (High-Risk Scenario)		
Storm Duration (T_D)	March 1999 Storm of Record Hydrograph	
Sediment Grain Size (D_{50})	Gelfenbaum and Kaminsky (2000)	
Offshore Wave Height (H_0)	Allan and Komar (2000)	FEMA Coastal Flood Study
Peak Spectral Wave Period (T_p)	NDBC Wave Record	FEMA Coastal Flood Study
Still Water Level (SWL)	March 1999 Storm of Record SWL	March 1999 Storm of Record SWL
Total Water Level (TWL)	AECOM Calculated	AECOM Calculated

Key: EVA=extreme value analysis; FEMA = Federal Emergency Management Agency; NDBC=National Data Buoy Center.

The March 1999 storm noted in Table 6 was an intense winter "storm of record" that struck the northern Washington coastline. The hydrograph of the storm was recorded at the Toke Point tide gauge. The storm duration in Table 6 was calculated at the number of hours that the observed water level exceeded MHHW (15.7 hours). A median sediment grain size (D_{50}) of 0.2 millimeters was used at all transects, as reported by Gelfenbaum and Kaminsky (2000).

For the open coast transects (Transect 1-41), wave conditions were generally taken from National Data Buoy Center (NDBC) Buoy #46005, offshore of Westport, or documented studies of the buoy (Allan and Komar 2000). Data from this offshore buoy have been used in previous studies (e.g. Allan and Komar 2000). This offshore buoy also captures deepwater wave conditions which are required for calculations of wave setup and runup. This buoy also has a complete, long-term record of wave conditions making it well suited to calculating wave statistics (Allan and Komar 2000). Peak spectral wave periods (T_p) were estimated from the buoy data (Figure 12) using the largest wave periods observed with more extreme wave heights. Allan and Komar (2000) presented significant wave heights (H_0) for the 100-Year storm; however, no studies presented values of H_0 for the 30-Year storm. To estimate this, AECOM conducted an Extreme Value Analysis (EVA) on the NDBC buoy data. An EVA is a statistical analysis in which a best-fit curve is applied to annual maximum values of wave height plotted with respect to their probability of exceedance (Figure 13). The 30-Year wave height for the open coast transects was estimated to be approximately 43.6 feet.

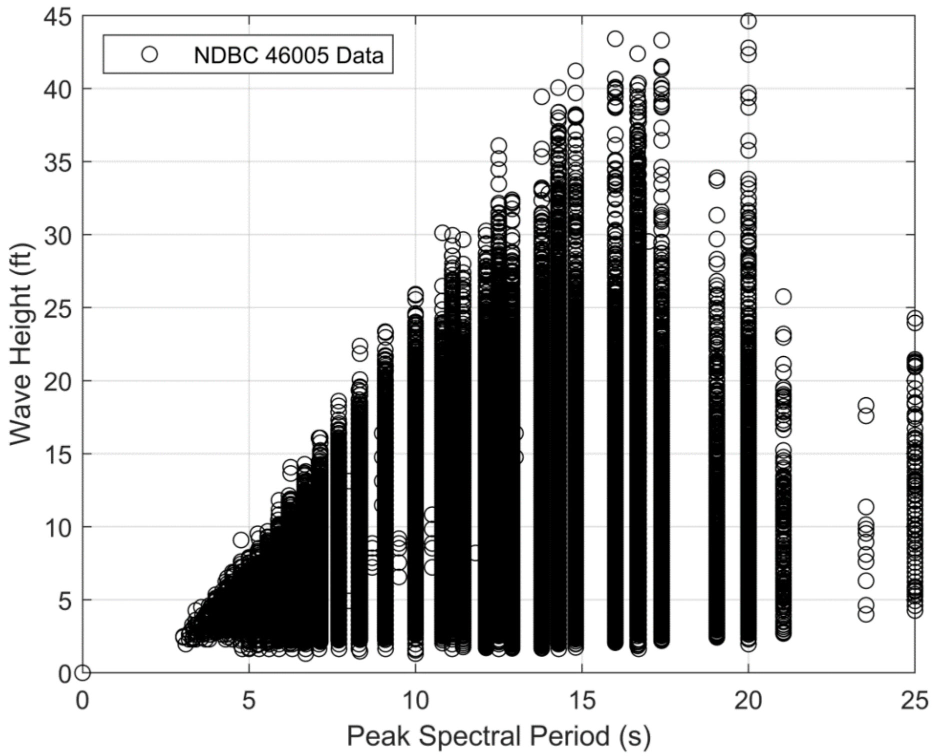

Figure 12. Wave conditions observed at NDBC Buoy #46005, offshore of Westport, Washington.

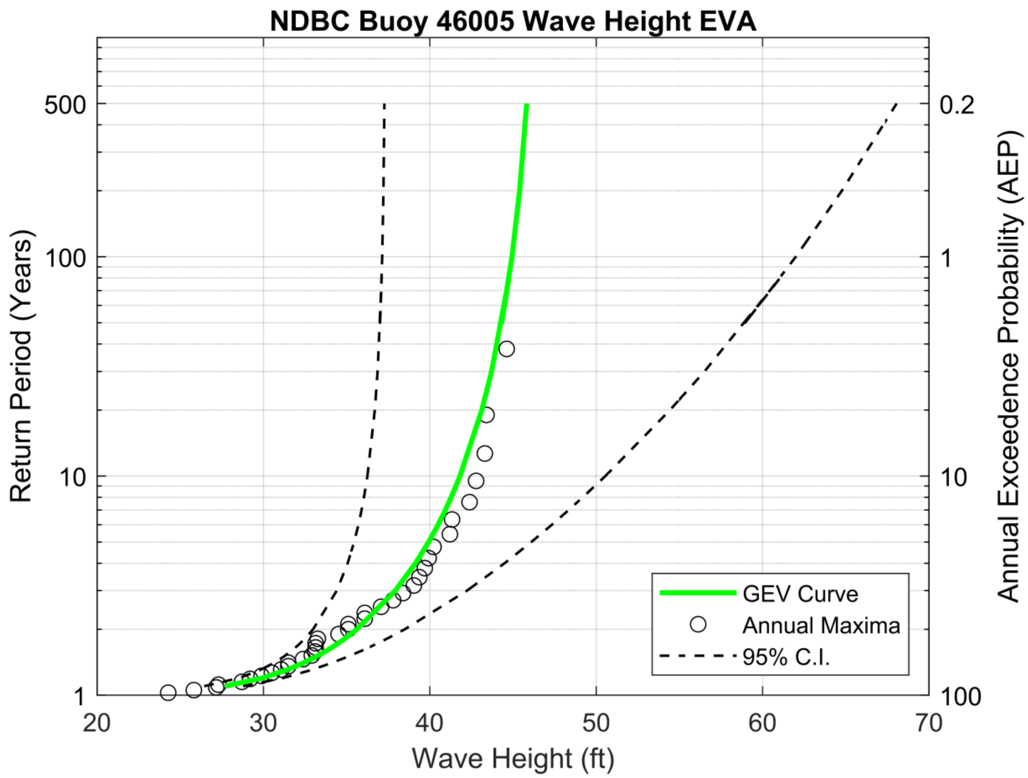

Figure 13. Statistical EVA of the wave heights observed at NDBC Buoy #46005, offshore of Westport, Washington.

For the Half Moon Bay Transects (Transects 42-50), AECOM generally relied on wave modelling results from the FEMA coastal flood study. FEMA ran simulations of 50 storms for all wind directions. For each transect, AECOM applied the wave results for the corresponding storm and wind direction. AEOM used an EVA to estimate the 100-Year wave heights.

In several instances noted in Table 6, AECOM had to calculate the TWL, which is the combination of the still water level (SWL) and wave effects. The SWL is the water elevation at the shoreline due to astronomical tides and storm surge. It was estimated from the sources noted in Table 6. The TWL is the combination of the SWL and wave effects, including wave setup and runup. To calculate wave setup and runup heights, AECOM applied the Stockdon empirical equation, which is widely used in coastal engineering. Using this equation, setup and runup are calculated as:

$$R_{2\%} = 1.1\left[0.35\beta_f\sqrt{H_0 L_0} + \frac{\sqrt{[H_0 L_0(0.563\beta_f{}^2 + 0.004)]}}{2}\right] \qquad \text{(Equation 9)}$$

where $R_{2\%}$ is the 2% exceedance wave setup and runup height, β_f is the beach slope, H_0 is the offshore wave height, and L_0 is the offshore wave length (Stockdon et al. 2006). Wave setup and runup heights were then added to the SWL to estimate the TWL (in feet NAVD88) at each transect for the 30- and 100-Year storms.

In general, the storm conditions for the 30- and 100-Year storms agree with the observed conditions from the March 1999 storm and the theoretical storm conditions developed by Allan and Komar (2000).

Erosion distances were modeled for the 30- and 100-Year storms using the Kriebel and Dean (1993) analytical model. The distances were combined with the long-term shoreline retreat distances to map the future retreat and erosion of the dunes under Scenarios A and B.

2.6 Evaluation of Future Flooding

At the time of this study, the coastal dunes generally prevent flooding in the Park during winter storms. FEMA recently completed a coastal flood study for the area, and the coastal flood map (Figure 14) depicts the relatively low current flood risk. The map shows flooding from the 100-Year storm restricted to the dunes and not inundating inland areas of the Park. At beaches where the dunes are predicted to partially (but not fully) erode during the 100-Year flood event, FEMA maps the coastal base flood elevation (BFE) inland to the dune heel location. The coastal flood map in Figure 14 depicts this approach. Along the western shoreline of the Park, the coastal BFE of 18 feet NAVD88 is mapped inland to the dune heel.

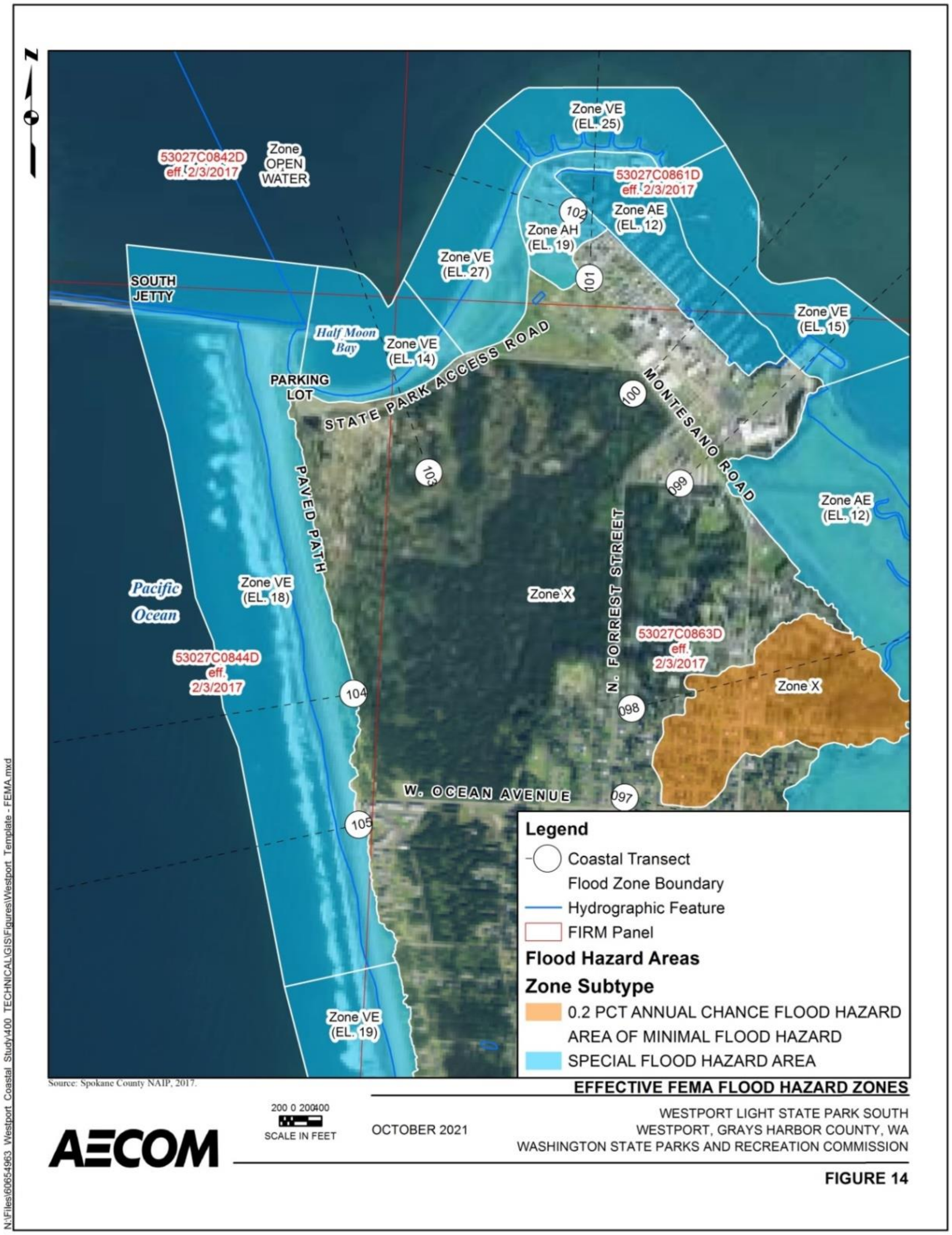

Figure 14. The mapped coastal flood zones for Westport Light State Park developed by FEMA.

Note: The maps show the flooding from the 100-Year coastal storm event is generally restricted to the dunes. This may change with future SLR as the dunes retreat and erode..

As future SLR reshapes the shoreline, inland areas could be exposed to coastal flood waters. With no flood and erosion control measures, more areas of the Park could be at risk of flooding during both the 30- and 100-Year coastal flood event. AECOM conducted a high-level analysis to evaluate when inland flooding might begin.. To do this, AECOM first selected Transect 34 south of the South Jetty. Transect 34 covers important assets at the Park, as the large coastal dune currently protects a large parking lot and restrooms from flooding. AECOM then applied the erosion and retreat values calculated each decade to the dune toe to estimate when the dune would completely retreat and erode to the parking lot under each scenario (A and B). It was assumed that wave overtopping and inland flooding of the parking lot and associated facilities could begin when the dune was completely eroded. This approach is illustrated conceptually in Figure 15. AECOM also included the FEMA 100-Year coastal BFE in this analysis to determine when the FEMA floodplain might expand inland, as this could also present regulatory issues for future park development.

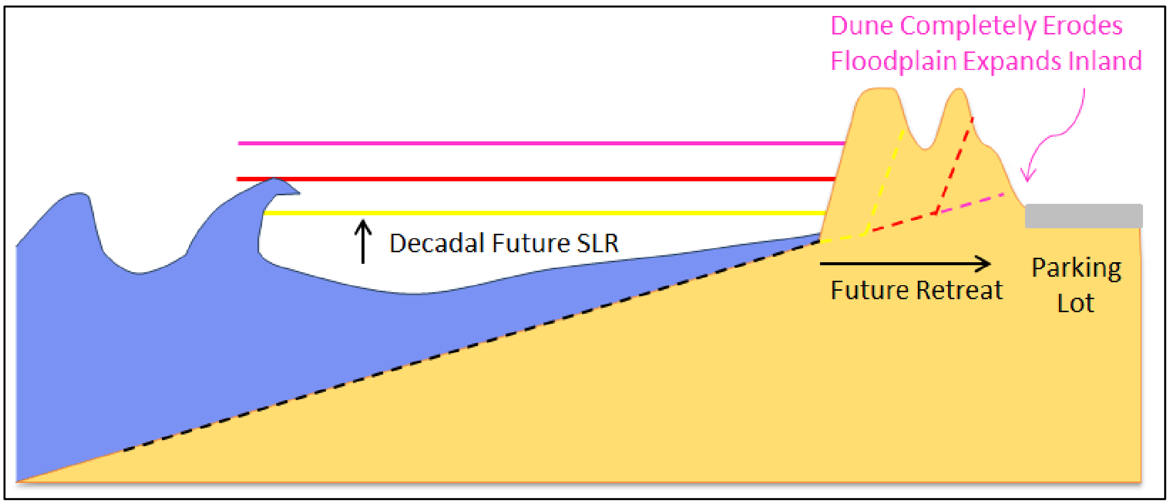

Figure 15. A conceptual illustration of how flooding might Park as the dunes completely retreat and erode due to future SLR.

Note: Dune retreat and erosion amounts, modelled every 10 years, were applied to the cross-shore profile at Transect 34 to estimate the time when the dunes protecting the parking lot would be completely eroded.

It is important to mention that the NOAA SLR Viewer (https://coast.noaa.gov/digitalcoast/tools/slr.html) shows the Park first flooding from the east, across the entire low-lying City of Westport, with increasing future SLR. This future flooding scenario was not considered as part of this study as it assumes that the City of Westport does not implement any future flood control to protect homes and businesses, which is unlikely.

3. Results

The detailed results of the future dune retreat and erosion, and landward dune migration, under the Moderate- and High-Risk Scenarios are listed in Appendix A. Maps of the results are shown in the following sections. Larger, higher resolution versions of the maps that show more detail are included in Appendix B.

3.1 Combined Future Shoreline Retreat and Erosion

The future long-term shoreline retreat and dune erosion estimates under Scenarios A and B are shown in Figure 16 and Figure 17, respectively. Each line on the map shows the calculated inland retreat of the dune toe for a particular decade (2030-2100) combined with the corresponding modeled storm erosion distance (from either the 30- or 100-Year storm). Over future decades, the beaches and dunes are expected to erode at faster rates than those observed historically due to SLR. The maps depict a "worst-case scenario," where there have been decades of long-term shoreline retreat and then a 30- or 100-Year storm strikes the coast. The mapped line shows the inland retreat and erosion of the dune toe before the dune has had a chance to seasonally recover from storm erosion. *Therefore, each line shows the area potentially at risk due to future long-term retreat and storm erosion through the decades*.

In general, slower inland retreat and a higher amount of erosion are predicted for the Moderate-Risk Scenario (Figure 16) than the High-Risk Scenario (Figure 17). Under the Moderate-Risk Scenario, the northern section of the paved dune path could be at risk after 2050, and the southern section could be at risk after 2030. The northern edge of the parking lot along Half Moon Bay and the restroom facilities could be at risk after 2050. Under the High-Risk Scenario, the dunes are predicted to retreat and erode more rapidly. The northern section of the paved dune path could be at risk after 2040, and the southern section could be at risk this decade. The northern edge of the parking lot along Half Moon Bay and the restroom facilities could be at risk after 2040.

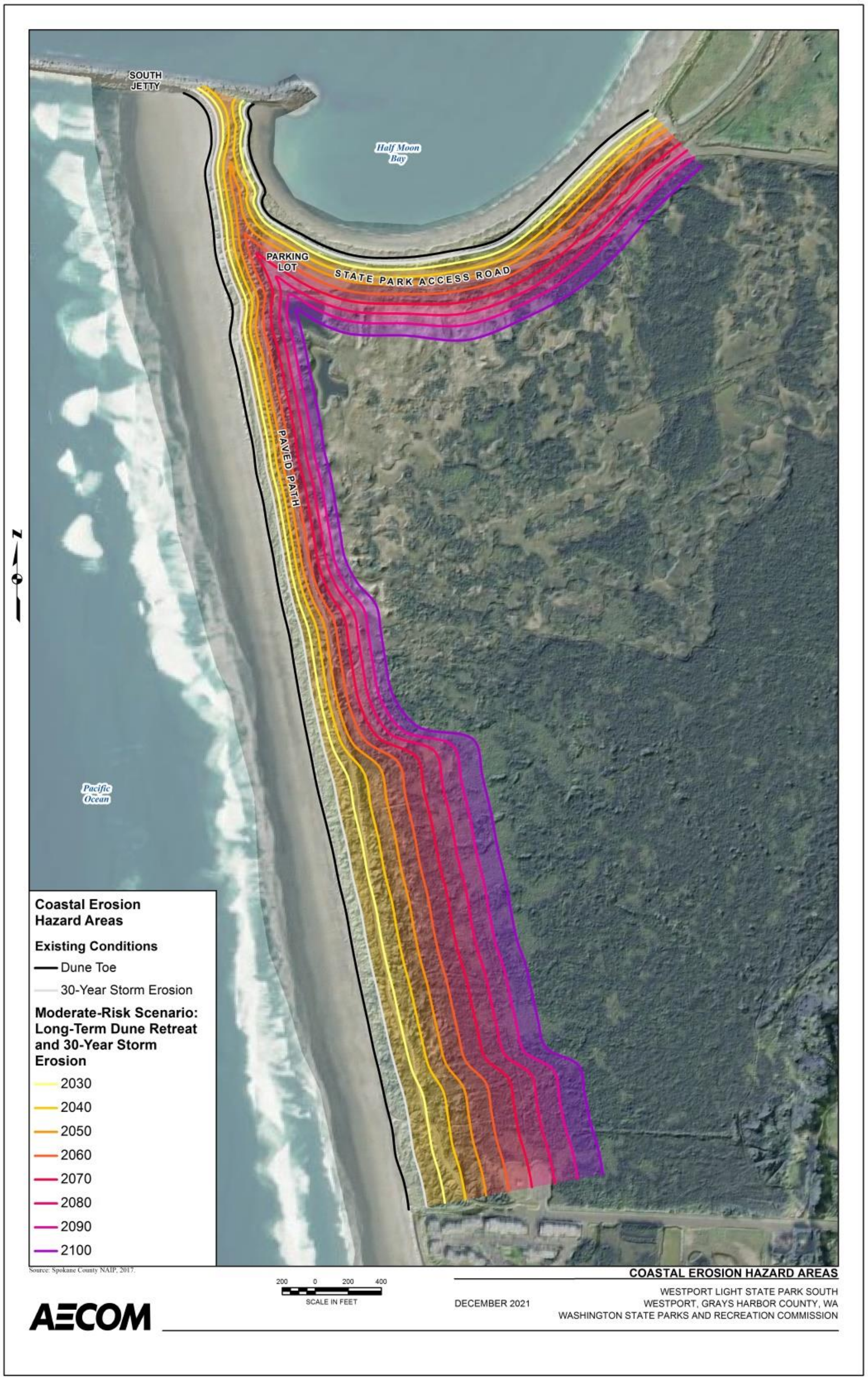

Figure 16. Park areas at risk due to future dune retreat and erosion under the Moderate-Risk Scenario.

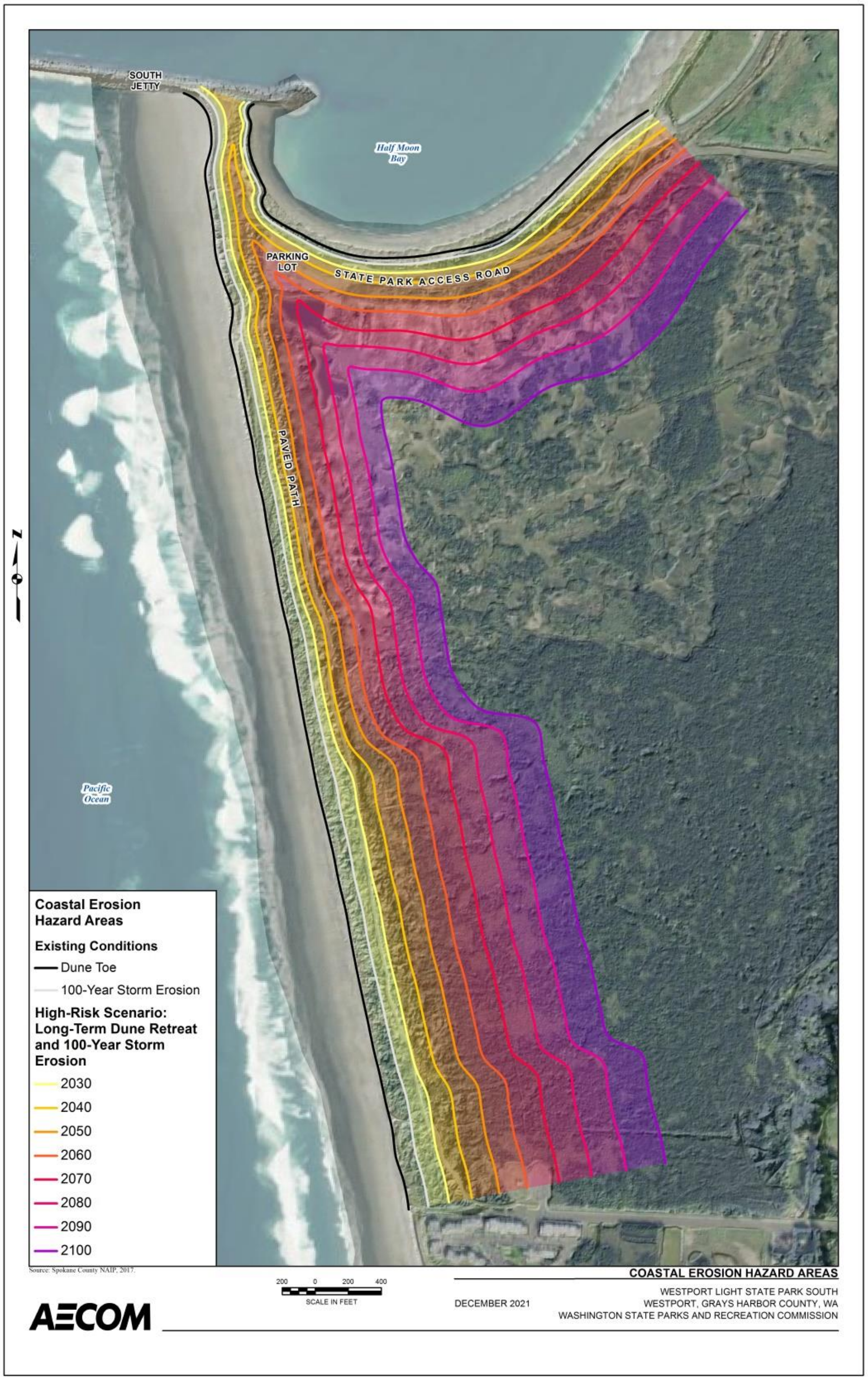

Figure 17. Park areas at risk due to future dune retreat and erosion under the High-Risk Scenario.

3.2 Retreat of Dunes into Wetland

The future potential landward retreat of the dune heel into the Park under the Moderate- and High-Risk Scenarios is shown in Figure 18 and Figure 19, respectively. In natural beach and dune systems, where there is no human intervention to prevent landward retreat, it is possible that the dunes will retreat (i.e., migrate) inland as the dune system comes into equilibrium with SLR. This will occur as aeolian transport (i.e., wind blown sand) pushes further inland in balance with the retreating shoreline (Masselink and Hughes 2003). In this study, the beach and dunes were treated as a natural system. Therefore, dune sand could begin to impact inland areas of the park, including the wetland, parking lots, trails, or other low-lying areas. This is a separate impact of future SLR from the long-term retreat and erosion depicted in the previous set of maps. Figure 18 and Figure 19 show the landward retreat of the dune heel due to future long-term retreat and SLR only (not storm erosion from the 30- and 100-Year storms). The landward retreat is less extensive under the Moderate-Risk Scenario and more extensive under the High-Risk Scenario.

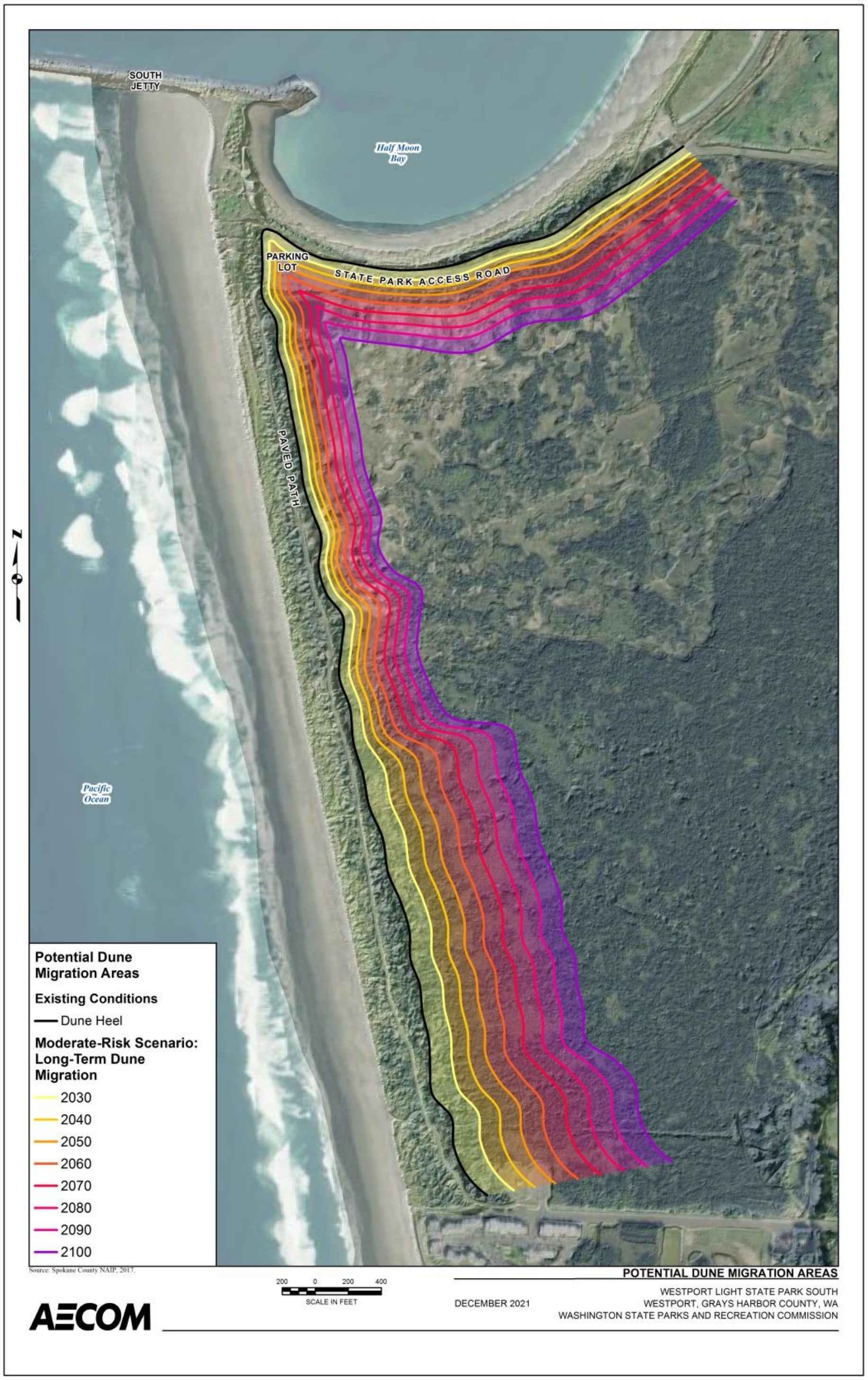

Figure 18. Future landward retreat of the dune heel into the Park under the Moderate-Risk Scenario.

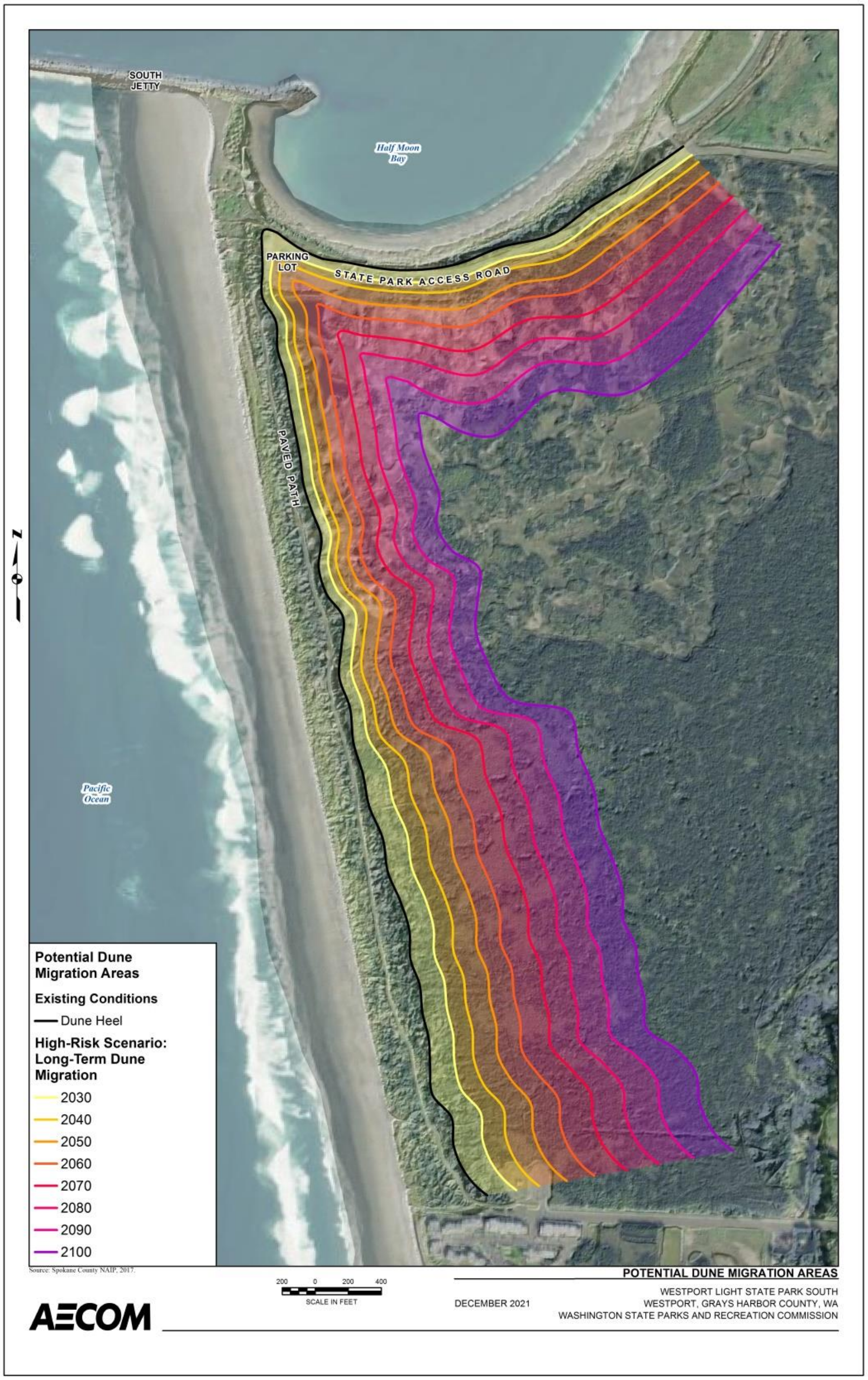

Figure 19. Future landward retreat of the dune heel into the Park under the High-Risk Scenario.

3.3 Evaluation of Future Flooding

AECOM conducted a high-level evaluation to determine when the open-coast dune might completely retreat and erode, leading to more inland flooding. The combined retreat and erosion distances for each decade were applied to the dune toe at Transect 34, which intersects the northern parking lot and restrooms at the Park. This transect was selected as future flooding will impact these assets. The results under the Moderate-Risk Scenario are shown in Figure 20, and the results under the High-Risk Scenario are shown in Figure 21. The results show that the dune could completely retreat and erode after 2060 under the Moderate-Risk Scenario and after 2050 under the High-Risk Scenario. This suggests that inland areas of the Park could be at risk for flooding from both the 30- and 100-Year storms after 2060 under the Moderate-Risk Scenario and after 2050 under the High-Risk Scenario.

The current FEMA 100-Year BFE is also shown in the figures for comparison. If the mapped FEMA floodplain expands inland, it could create regulatory issues that might impact future development of the Park. The current FEMA BFE does not include future SLR, and this will likely increase with future SLR. AECOM assumed that future flooding would begin when the dune completely erodes; however, with an increasing BFE, wave overtopping and limited flooding could begin before 2060 under the Moderate-Risk Scenario and before 2050 under the High-Risk Scenario. This evaluation could have different results if applied to a transect where the dune height and width are different, such as the dunes along the southwestern shoreline.

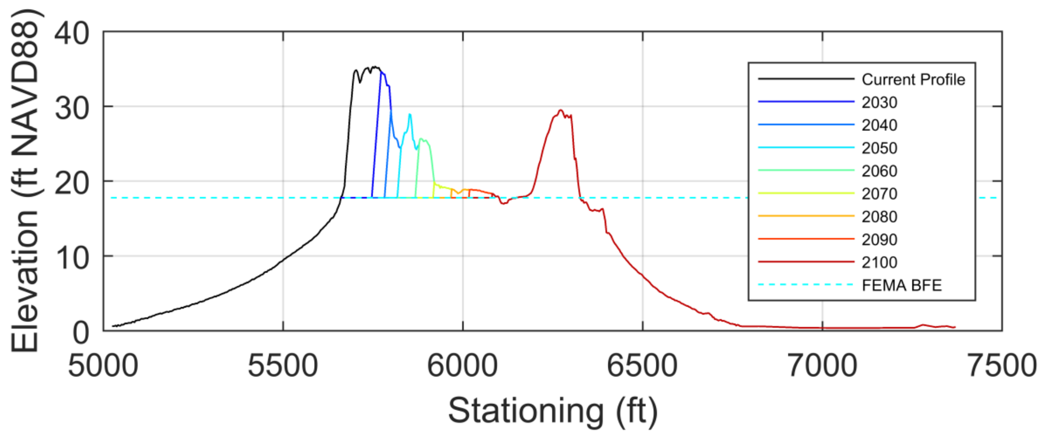

Figure 20. The timing of future flooding under the Moderate-Risk Scenario at Transect 34. The current parking lot is located at approximately 6,000 feet. The analysis suggests that dune is completely eroded after 2060 and the parking lot at facilities may be impacted by flooding.

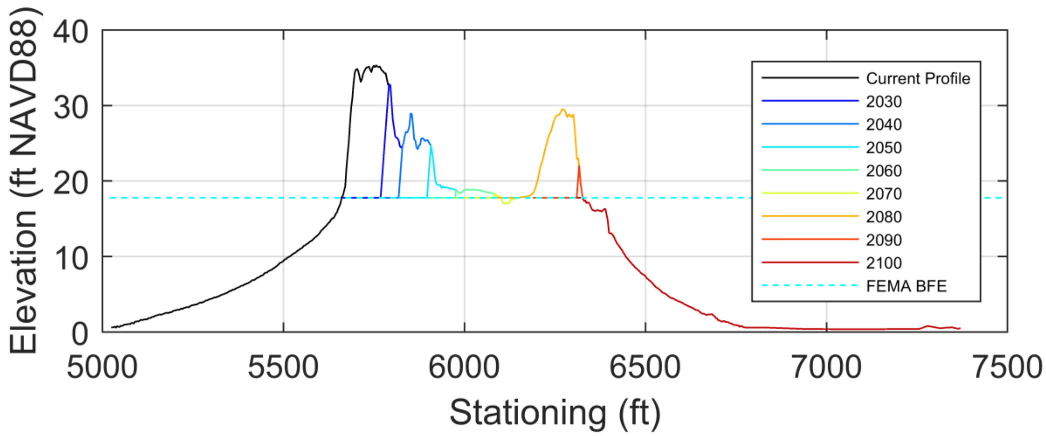

Figure 21. The timing of future flooding under the High-Risk Scenario at Transect 34. The current parking lot is located at approximately 6,000 feet. The analysis suggests that dune is completely eroded after 2050 and the parking lot at facilities may be impacted by flooding.

4. Conclusions

The beach and dunes at Westport Light State Park have historically undergone long-term, chronic retreat and rapid erosion during winter storms. AECOM analyzed future long-term shoreline retreat due to SLR and episodic dune erosion due to a 30- and 100-Year coastal storm to evaluate future impacts to the Park and its resources and found that the long-term retreat will intensify with future SLR. Under higher SLR, and longer time frames, more inland areas will be at risk to retreat, erosion, and flooding.

In general, slower retreat and less erosion are predicted for the Moderate-Risk Scenario than the High-Risk Scenario. Under the Moderate-Risk Scenario, the northern section of the paved dune path could be at risk after 2050, and the southern section could be at risk after 2030. The northern edge of the parking lot along Half Moon Bay and the restroom facilities could be at risk after 2050. Under the High-Risk Scenario, the dunes are predicted to retreat and erode more rapidly. The northern section of the paved dune path could be at risk after 2040, and the southern section could be at risk this decade. The northern edge of the parking lot along Half Moon Bay and the restroom facilities could be at risk after 2040.

AECOM also developed maps to show the potential future inland retreat (i.e., landward migration) of the dunes into the interior of the Park due to SLR for future decades (2030-2100). Separate from future retreat and erosion, this could impact the interior as the current vegetation is impacted by dune sand. AECOM used future dune retreat and erosion modelling to estimate the timing of future changes to the FEMA-mapped coastal floodplain. The analysis shows that the 100-Year coastal floodplain could expand landward of the current open-coast dunes after 2060 under the Moderate-Risk Scenario and after 2050 under the High-Risk Scenario.

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Appendix A – Calculation and Model Results

Appendix B – Coastal Retreat and Erosion Maps

Detailed, high resolution coastal retreat and erosion maps.