Appendix G

Beach Design and Performance

INTRODUCTION

During storm events, waves can move sediment rapidly enough to change the shore geometry and its functions significantly. A process-based morphodynamic model for gravel beaches call XBeach-G (McCall *et al.*, 2015, Roelvink *et al.*, 2009) was used to evaluate the performance and evolution of the new design grade during typical and storm conditions. The model was applied in 1-dimension to model wave propagation, sediment transport, and estimate cross-shore profile changes (erosion and accretion) on the nearshore area, beach, and the backshore beach.

Waves are modeled non-hydrostatically to resolve wave by wave flow and surface elevations variations as waves collide with the shoreline. This approach captures the relevant swash zone process, including wave interactions with steep slopes, dynamic setup, complex bathymetry, and the response of the gravel beach. The use of a storm response model like XBeach-G allows a quantitative estimate of complex processes such as the peak wave runup, overtopping flow, and geomorphological changes. The modeling considers beach change over time at one profile and does not include longshore sediment transport.

Beach Design

This study evaluates a typical beach profile after construction (Figure 1) and the beach profile in front of the new seawall after construction (Figure 2). For the typical beach profile shown in Figure 1, the width of the backshore is 25 ft (The width varies on the design from a minimum of 20 ft on the north end to 30 ft at the south end of the beach) with a depth of 3 ft. The backshore goes from 12.5 ft, NAVD (upland) to 12.0 ft NAVD. The foreshore of the beach goes from EL. 12.0 ft to El 6.0 ft NAVD on a slope of 8:1. At elevation, 6.0 ft NAVD a lower bench with a width of 20 ft (width of the bench is reduced north of the site) would be constructed with the purpose to add material to the littoral system that can be move alongshore or cross-shore and allow the beach to have additional "buffer" material before it reaches a natural equilibrium.

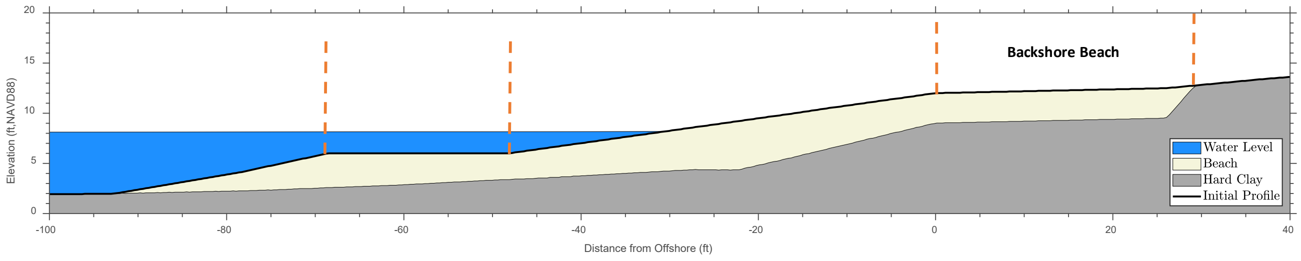

Figure 1. Typical Beach Design Profile, After Construction

The beach design profile in front of the seawall (Figure 2) differs from the typical beach profile (Figure 1). Within the first 10 ft from the seawall, a greater thickness of at least 4 ft. of beach material is placed above the MHHW (9.02, ft NAVD). The beach sediment is placed to compensate for scouring and erosion caused by wave reflection from the seawall.

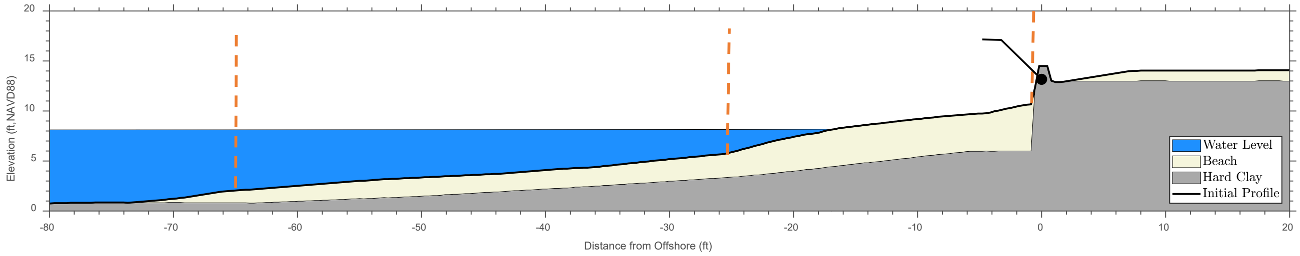

Figure 2. Beach design profile in front of the new Seawall, After Construction

WAVE AND TIDE CLIMATE

WAVES

To model the wave conditions near the site, ESA applied the industry-standard Simulating Waves Nearshore (SWAN) model. This 2-dimensional model predicts waves likely to occur in response to wind speed, wind direction, water level, shoreline geometry, and bathymetry. The reader is referred to Appendix A for details on the implementation and validation of the model. The model was used to generate a 33-year wave height and wave period time series offshore of Lowman Beach Park (Figure 3). Maximum wave heights are typically less than 5 ft, and typical events are below 2 ft. Wave periods are typically very short, and most wave periods were computed to be less than 3 seconds, and maximum wave periods are not higher than 3.5 seconds.

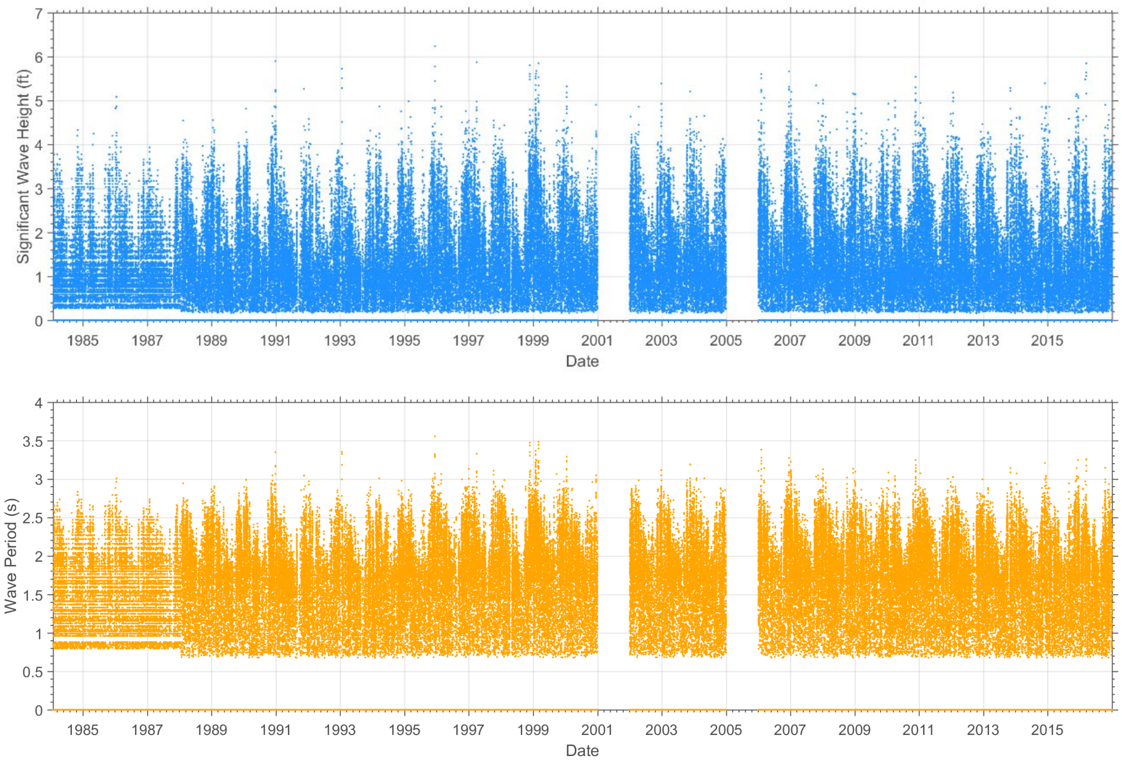

Figure 3. Simulated Significant Wave Height and Wave Period Time Series offshore of the park.

An extreme value analysis was conducted on the estimated wave height time series for 33 years from 1984 to 2016. A maximum wave height value for each year was found and fit to a Gumbell, Weibull, and GEV distribution (Figure 4).

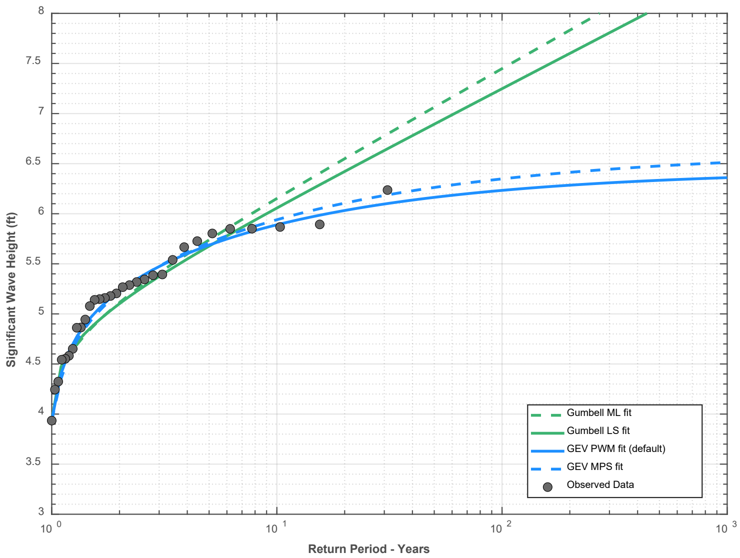

Figure 4. Significant Wave Height Extreme Value Analysis

The GEV distribution shows the best fit of the data. Table 1 summarizes the return periods from the GEV distribution. The fitted distribution indicates that the wave height difference between a 10-year event and a 100-year event is only 0.5 ft.

TABLE 1
EXTREME WAVE HEIGHT (FT)

Return Period (years)	Ho
1	3.9
2	5.2
5	5.7
10	5.9
20	6.1
50	6.3
100	6.4

TIDES

Water level records for the project site was obtained from the Seattle Tide Station (NOAA NOS# 9447130) 118 year from 1899 to 2016 was analyzed for this project. The station is located approximately 5.2 miles north of the site. Tidal datums and the probability and cumulative distribution of the water levels are shown in Figure 5.

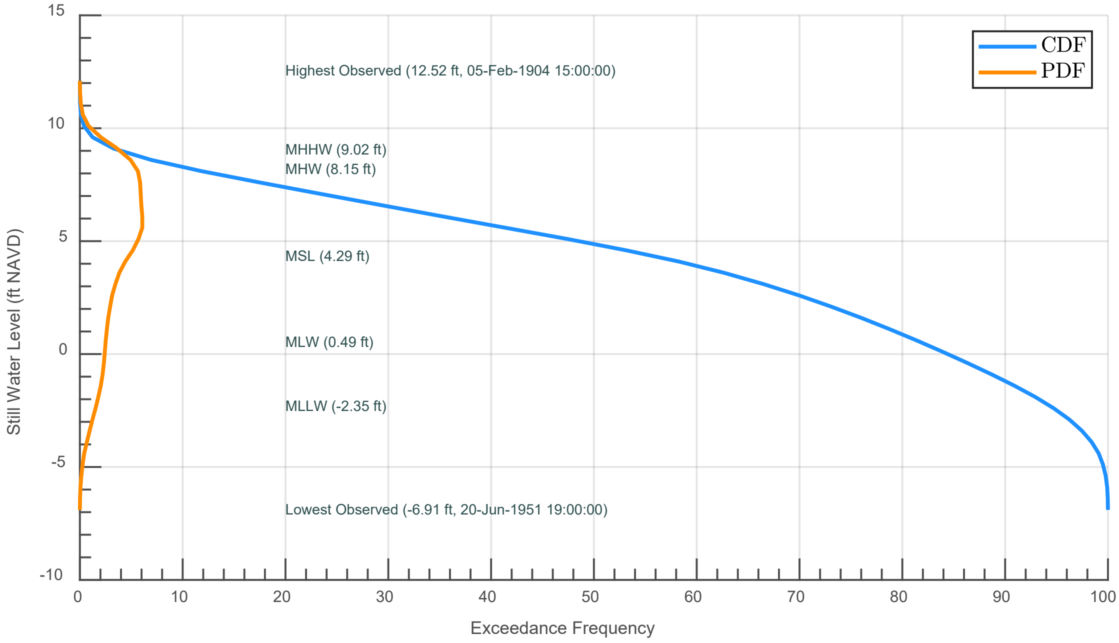

Figure 5. Still Water Level Probability (orange) and Cumulative Distribution (blue)

An extreme value analysis of 118 years of the recorded water levels from 1899 to 2016 was conducted based on the detrended tide data at the Seattle tide station. The reader is referred to Appendix A for more information on the conducted extreme analysis. Table 2 summarizes the extreme SWL's based on the detrend tide data.

TABLE 2
EXTREME STILL WATER LEVEL VALUES FOR PRESENT-DAY SEA LEVELS

Return Period (years)	Elevation, feet NAVD88
1	10.3
2	11.4
5	11.8
10	12.0
20	12.1
50	12.3
100	12.4

TYPICAL CONDITIONS AND STORM RESPONSE MODELING

Typical conditions and storm conditions were analyzed to evaluate the impacts on the beach after construction. The model was run through a tide cycle (Figure 6) that includes a 20-year water level event. For other events, the tide curve wave modified to peak at the selected high water level for 3-hours. Water levels below 4 ft will not reach the designed beach, and therefore there were not considered on this modeling.

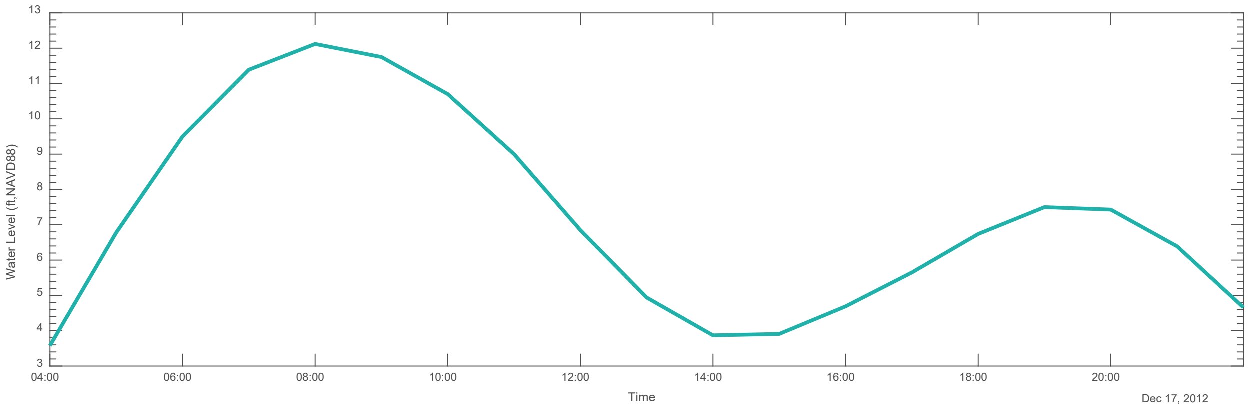

Figure 6. High Tide Event on December 17, 2012. (Sta. 9447130, NOAA, 2019)

Table 3 shows a summary of all the scenarios evaluated and used to run the XBeach-G model for the typical beach design (beach) and the beach in front of the seawall (seawall). A typical wave event was defined as an event with a wave height of 2.6 ft and an associated peak period of 3 s. The 10-year storm wave event has a wave height of 5.9 ft and an associated peak period of 4 sec. During low tides, the waves would break offshore of the profiles shown in Figures 1 and 2.

TABLE 3
SELECTED WATER LEVEL AND WAVE CONDITIONS

ID	Shoreline	Tide	Wave Event
	Beach Profile		
B1		Tide Cycle	Typical
B2		Tide Cycle	10-Year Storm
B3		MHW (8.15,ft)	10-Year Storm
B4		1-Year Event (10.3, ft)	10-Year Storm
	Seawall		
S1		Tide Cycle	Typical
S2		Tide Cycle	10-Year Storm
S3		MHW (8.15,ft)	10-Year Storm
S4		1-Year Event (10.3,ft)	10-Year Storm
S5		100-Year Event (12.4,ft)	10-Year Storm

BEACH PERFORMANCE

BEACH

The results of a typical wave event during the tide cycle (Figure 6) shows that the typical waves will have little or no effect on the accretion/erosion of the design beach profile. A 10-year storm event with the full tide cycle will have significant effects on the beach profile (Figure 7) eroding the lower bench, pushing the lower material upwards and building a storm berm before the backshore of the beach and maintaining the foreshore at the same location, maintaining a foreshore slope of 8:1. The resulted beach profile mimics existing natural beach profiles found south of the site and other places in the Puget Sound (Johannessen *et al.*, 2014).

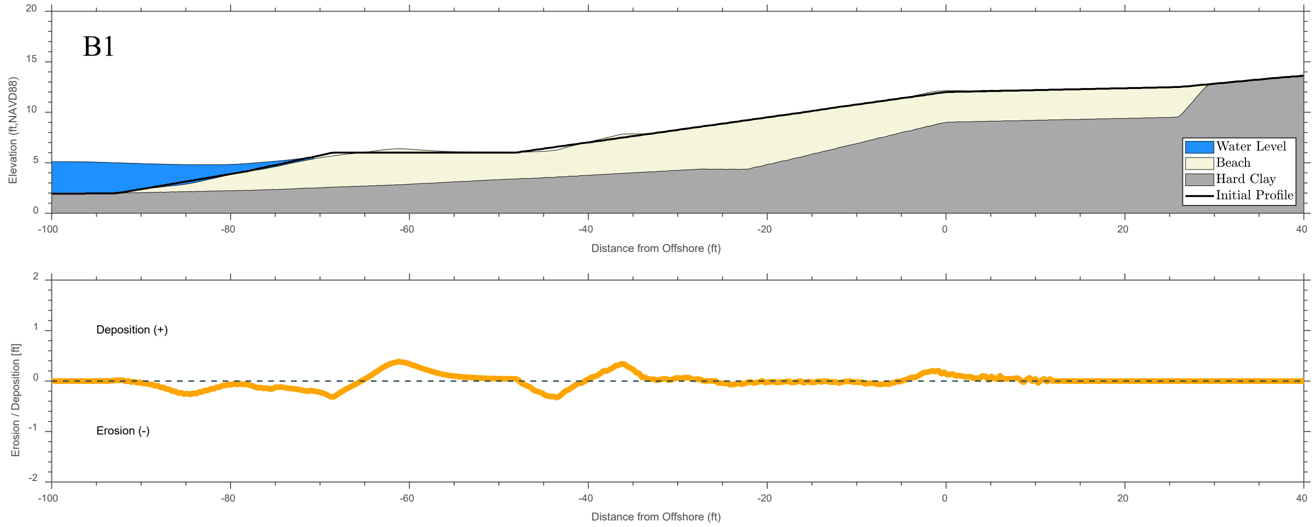

Figure 6. Beach Profile Response Under Typical Wave Conditions and Full Tide Range.

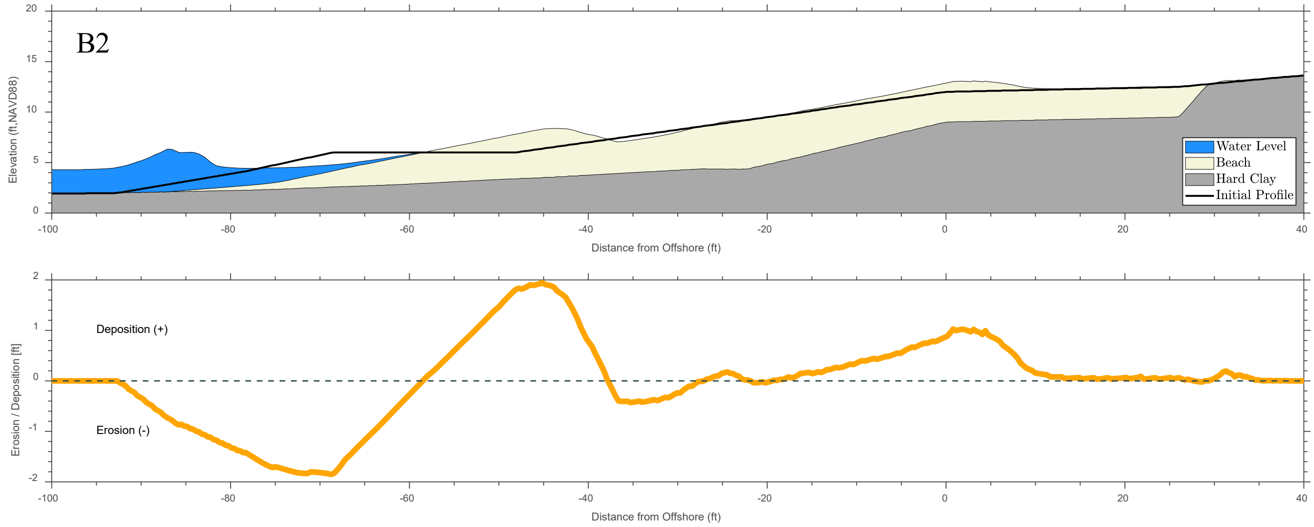

Figure 7. Beach Profile Response Under Storm Wave Conditions and Full Tide Range.

During a 10-year wave storm, event, and MHW water level (Figure 8), the beach responds by eroding the lower berm and moves the sediment up and landwards. The berms flatten at a slope of 15:1, which is close to the beach slope of the reference beach to the south. During a 1-year water level event (Figure 9) the lower portions of the profile slightly eroded, and the material was transported landward and accretes the backshore of the beach.

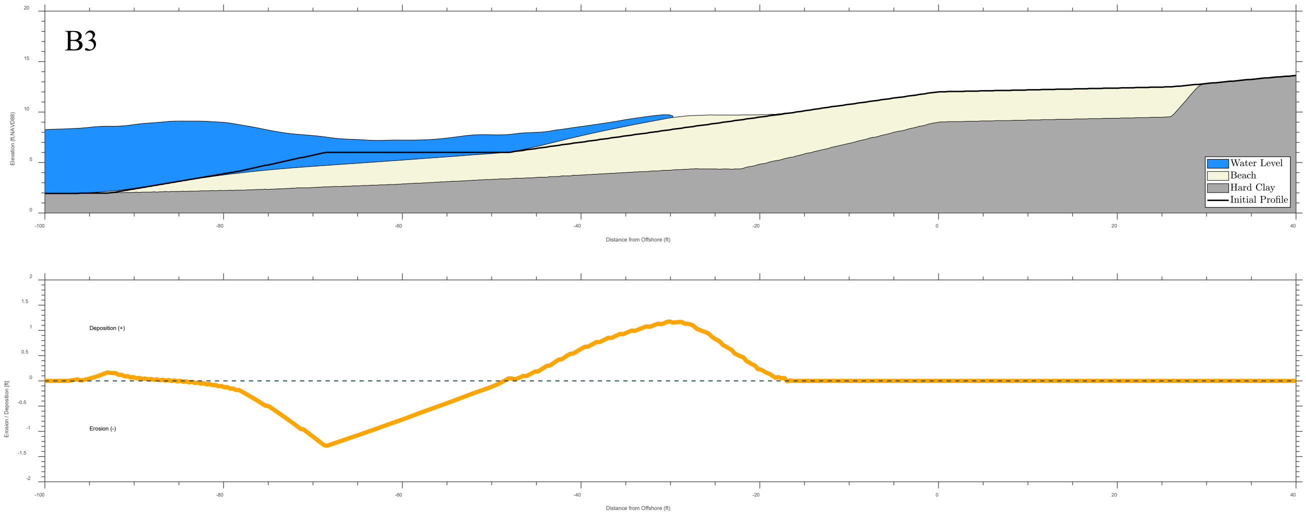

Figure 8. Beach Profile Response Under Storm Wave Conditions and MHW Tide.

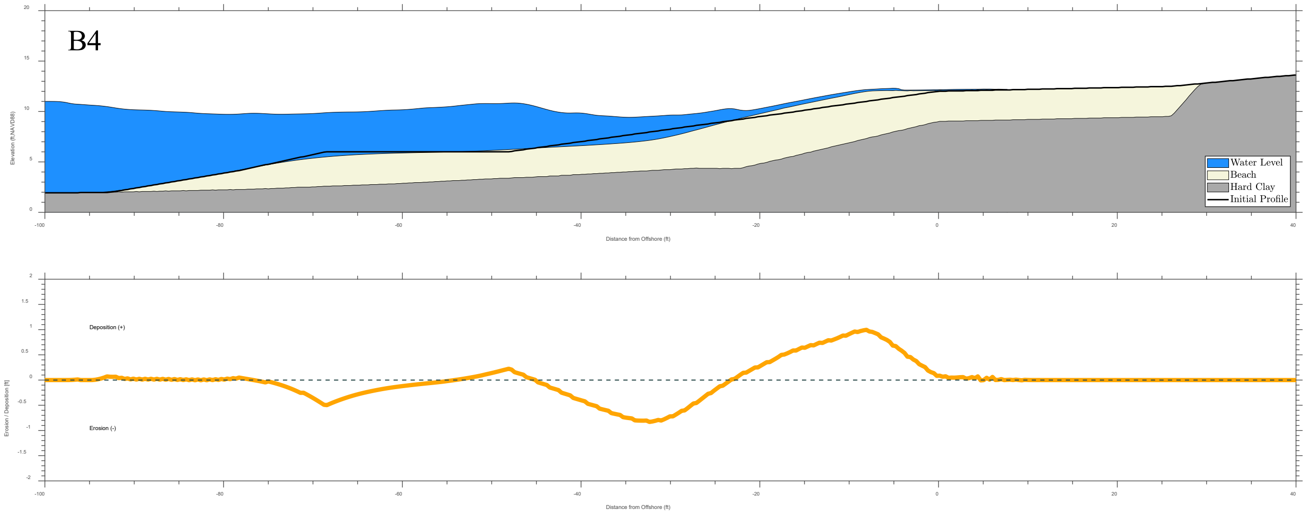

Figure 9. Beach Profile Response Under Storm Wave Conditions and 1-Year SWL Event

SEAWALL

The results of a typical wave event during the tide cycle on the beach front of the seawall (Figure 10) shows that the typical waves will have minor effects on the initial beach by causing some small erosion on the lower end, adjusting the slope to be close to a steep slope of the foreshore between 5:1 to 6:1. Moreover, causing some accretion and minor erosion in front of the seawall. A 10-year storm event with the full tide cycle will have significant effects on the beach, front of the seawall by adjusting the beach profile by eroding the lower bench, accreting the foreshore of the beach, and eroding the beach below the seawall. The beach will then adjust to a more natural state on a slope of approximately 8:1.

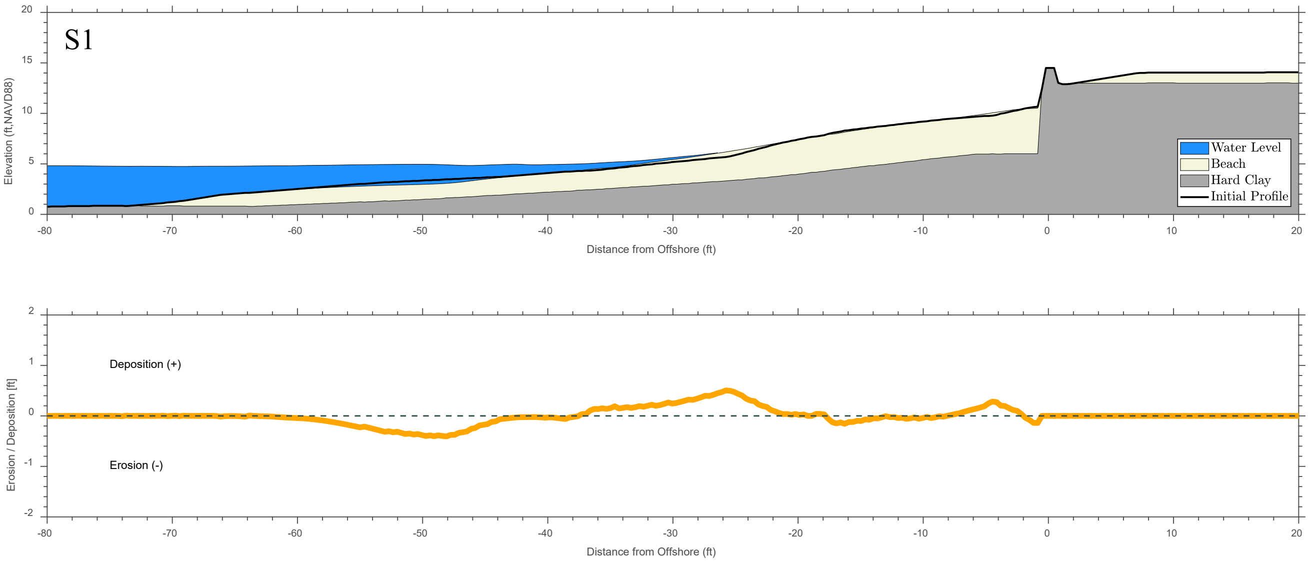

Figure 10. Seawall-Beach Profile Response Under Typical Wave Conditions and Full Tide Range.

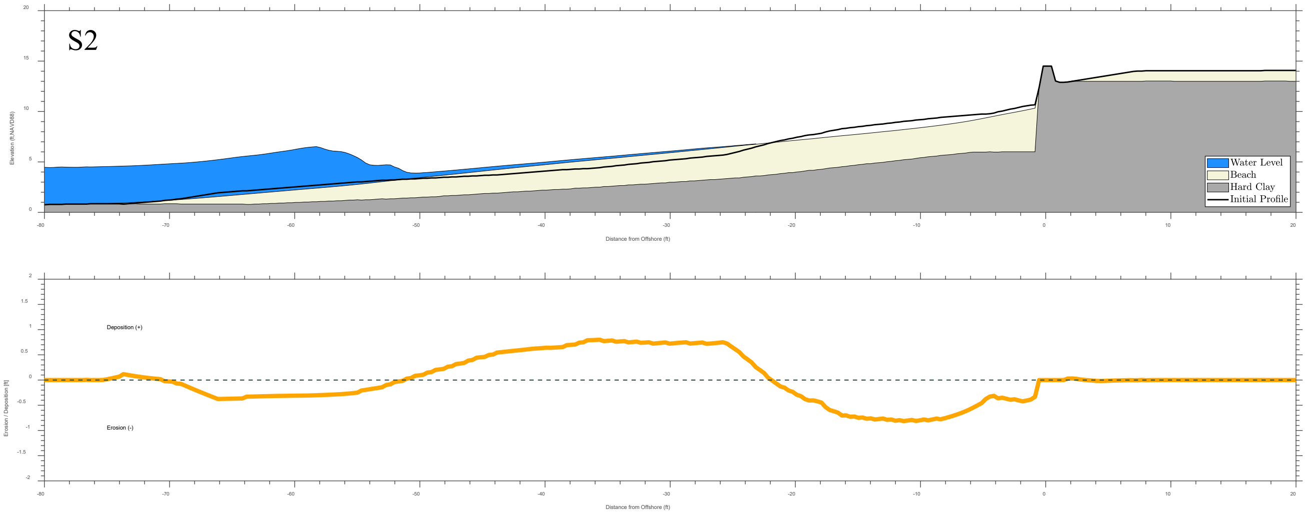

Figure 11. Seawall-Beach Profile Response Under Storm Wave Conditions and Full Tide Range.

During a 10-year wave storm, event, and MHW water level (Figure 12), the beach in front of the seawall will show relatively small changes, specifically eroding the lower foreshore of the beach and accreting material on the top of the beach adjacent to the seawall. Some erosion of the beach below the seawall is also present during these conditions. A 10-year wave storm event. During a 1-year water level event (Figure 13) shows that the beach in front of the seawall will experience some accretion of the material on the upper part and that the slope of the beach will become steeper to approximately 5:1. A small amount of accretion below the seawall is present during these conditions.

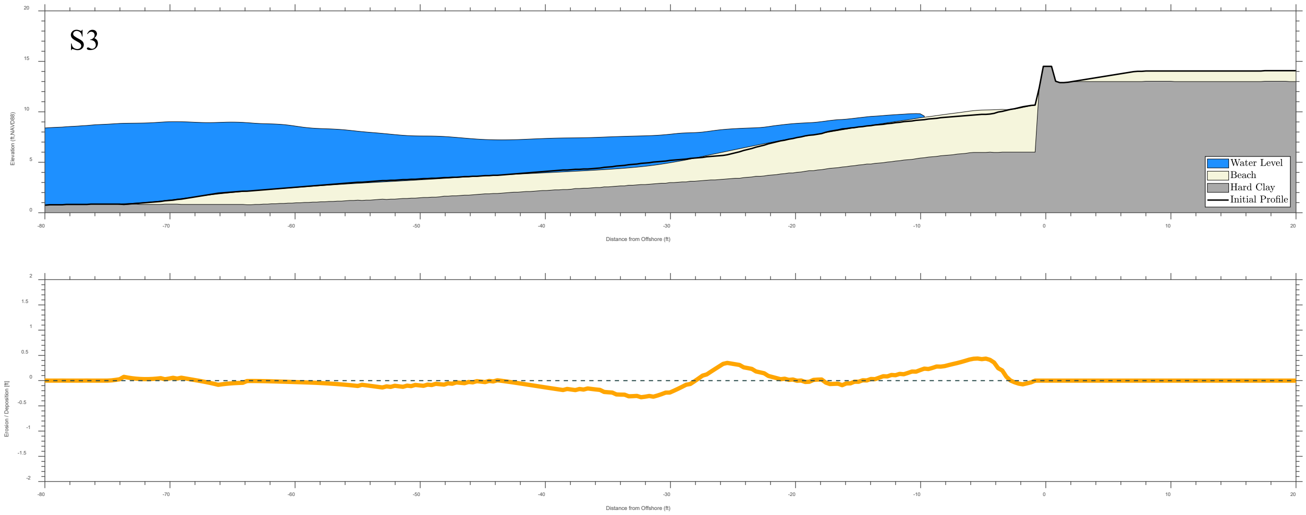

Figure 12. Seawall-Beach Profile Response Under Storm Wave Conditions and MHW Tide.

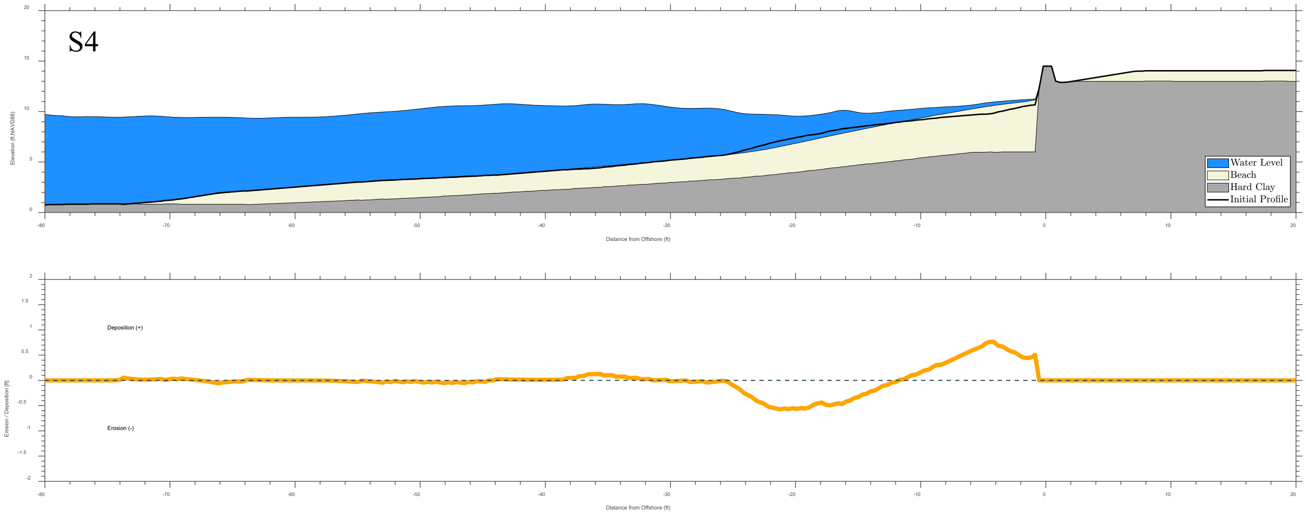

Figure 13. Seawall-Beach Profile Response Under Storm Wave Conditions and 1-Year SWL Event.

An unlikely extreme event with a combined 10-year storm wave event with a 100-year water level event (Figure 14) was also considered to evaluate the performance of the beach in front of the seawall. The results show that during this event some wave overtopping will occur and that the beach material below the seawall will significantly erode and move seawards. The lowest part of the beach does not show significant changes during this event.

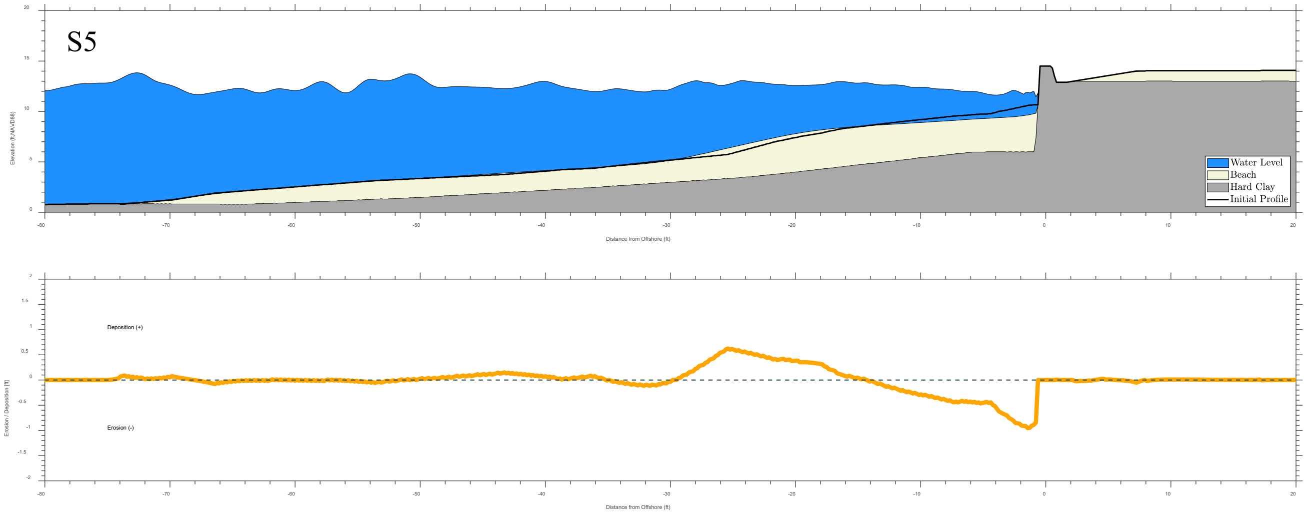

Figure 14. Seawall-Beach Profile Response Under Storm Wave Conditions and 100-Year SWL Event

CONCLUSIONS

Typical conditions have little effect on the design. Storm events will adjust the beach after construction to a more natural state. The lower berm is expected to erode and evolve into a more natural slope under all conditions shown here. Accumulation and movement of beach material are expected during storm events the location of where this material is placed will vary depending on the water levels present at the time. This could mean that the material could be placed on the foreshore forming a berm during most water level conditions or accreting the backshore during high tide events.

The beach in front of the seawall is expected to flatten over time and form a more natural foreshore slope around 8:1. During storm events, different levels of erosion are expected below the seawall. The amount of erosion will depend on the interaction of the waves with the seawall and the water level below them. The performance of the beach in front of the seawall was also evaluated for an unlikely severe storm event consisting of a 10-year wave event and a 100-year high water level. Under these conditions, a larger erosion of the beach below the seawall is expected.

Adding extra material below the seawall is recommended to reduce erosion on the seawall area in the first years after construction. This study shows that the beach design performs well and as expected on all conditions under typical and storm events at different water levels listed in Table 3. The actual beach response will also depend on the alongshore transport of sediment that was not modeled. The modeling used sediment sizes consistent with the design specifications; different sediment sizes will affect beach responses.

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