Cates Park/Whey-Ah-Wichen Shoreline Restoration Plan

Design Report

Prepared by:

Northwest Hydraulic Consultants Ltd.
30 Gostick Place
North Vancouver, BC V7M 3G3
Tel: 604.980.6011
www.nhcwater.com

Prepared for:

Tsleil-Waututh Nation
3178 Alder Court
North Vancouver, BC V7H 2V6

Kate Menzies, BSc., MRM
Natural Resources Planning Manager
Treat, Lands & Resources Department

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Report prepared by:

Laura Ramsden, MSc, PEng
Coastal Engineer
Coastal Engineering

Pauline Martens, MSc AAg
Geomorphologist
Geomorphology

Report reviewed by:

PROFESSIONAL
PROVINCE
March 31, 2025
Dr. P. D. OSBORNE
41113
BRITISH COLUMBIA
GEOSCIENTIST

Phil Osborne, PhD, PGeo
Coastal Geomorphologist

EGBC Permit to Practice Number: 1003221

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1 INTRODUCTION

The səlilwətaɬ (Tsleil-Waututh) Nation and District of North Vancouver (DNV) retained Hatfield, Northwest Hydraulic Consultants (NHC) and LEES + Associates Consulting Ltd. (LEES) to provide a Shoreline Restoration Plan for the Whey-ah-Wichen or Cates Park (WaW) shoreline that enhances resilience to climate change using nature-based solutions, preserves the historical significance and enhances Tsleil-Waututh cultural use of the site, and integrates visitor usage and education (the Project). An overview map of the WaW shoreline is provided in Figure 1.1. The project site is divided into five reaches: West Beach, Central Beach, Roche Point, East Beach, and Little Cates.

This report provides the design basis required for developing the restoration concepts for the shoreline. NHC provided preliminary design drawings for permitting in November 2024 and revised design drawings for permitting in January 2025; the revised IFP drawings are provided in Appendix A. The design basis summarizes the results from the Coastal Processes Assessment (NHC, 2023) (Appendix B) including metocean conditions and geomorphology. The design basis summarized in this report also includes sediment characterisation at the site and sediment transport modelling using XBeach and XBeach-G (Deltares, 2018).

Figure 1.1 Overview map of WaW project site with the shoreline divided into five reaches including West Beach, Central Beach, Roche Point, East Beach, and Little Cates.

1.1 Project Background

The shoreline at WaW is vulnerable to erosion caused by the combined effects of high tides, storm surges, and wave action (Golder, 2013; NHC, 2023). Coastal erosion is projected to increase over the coming decades due to rising sea levels and shifting weather patterns associated with climate change (Bush and Lemmen, 2019; Greenan et al., 2018).

Increasing erosion hazard at WaW is likely due to many factors outside of WaW, including the climate related factors noted above, but is also being worsened by a significant sediment supply deficit (NHC, 2023). The sediment supply deficit is linked with the hard armour protection of the sediment bluffs within the park and on neighbouring shorelines that was implemented in previous decades. Hard shore protection was implemented in WaW in the mid-1980's.

By 2013, waves and high-water levels had cut a substantial scarp in the backshore at Roche Point exposing culturally and archaeologically significant stratigraphy of extensive midden deposits. A nourishment project was implemented in 2014 (Golder, 2013, 2019) to address the eroding midden by adding to the sediment supply and avoiding further disturbance of eroding archaeological deposits.

For future success in management and maintenance of the Park's shoreline, a sediment source will either need to be imported and maintained, or an equilibrium with the material available onsite will need to be established (NHC, 2023). This understanding of the site led to a nature-based beach restoration solution that involves sediment and rock placements intended to restore natural sediment transport processes, and preserve or enhance ecological, recreational and cultural assets of the site.

1.2 Project Datum

Elevations (including water levels) are referenced to CGVD2013 (Canadian Geodetic Vertical Datum of 2013) unless otherwise stated for the purpose of this project. Based on Benchmark M08C9006 at Vancouver Harbour (Fisheries and Oceans Canada, 2008), CGVD2013 can be converted to either Chart Datum (CD) or Canadian Geodetic Vertical Datum of 1928 (CGVD28) using the following formula:

$$Elev_{CGVD28} = Elev_{CD} - 3.0\ m$$

$$Elev_{CGVD28} = Elev_{CGVD2013} - 0.119\ m$$

2 STANDARDS AND DESIGN GUIDELINES

The following standards and design guidelines are referenced in this report:

- BC Ministry of Environment (2011c). Climate Change Adaption Guidelines for Sea Dikes and Coastal Flood Hazard Land Use – Sea Dike Guidelines.
- British Standards Institution (2013). Maritime works – Part 1-1: General – Code of practice for planning and design for operations. 110 pp.
- CIRIA, CUR, CETMEF (2007). The Rock manual: The use of rock in hydraulic engineering (2nd edition). Published by C683, CIRIA, London, London. 36 pp.
- Murphy, E., Cornett, A., van Proosdij, D., & Mulligan, R. P. (Eds.) (2024). Nature-Based Infrastructure for Coastal Flood and Erosion Risk Management – A Canadian Design Guide. ISBN 978-0-660-71886-6.
- Rogers, J., Hamer, B., Brampton, A., Challinor, S., Glennerster, M., Brenton, P., and Bradbury, A. (2010). Beach Management Manual.

3 COASTAL DESIGN BASIS

This section presents the rationale and design basis used to develop the shoreline protection design at WaW. It details the design philosophy, objectives and constraints and summarizes the coastal design conditions including water levels, wind analysis, and wave analysis. Lastly, a summary of the design criteria is discussed.

3.1 Design Philosophy

The design philosophy for a nature-based beach restoration project differs significantly from that typically applied to conventional (grey) infrastructure. The goal when designing conventional (grey) shore protection infrastructure is often to achieve a statically stable solution based on a single set of design conditions or design event.

For dynamic sediment-based solutions, a single design event may not be the critical condition resulting in loss of function. Performance should be assessed by monitoring and coastal processes modelling should be completed for a broader range of conditions or events ranging from frequently occurring to extreme. Iteration of design variables (such as sediment characteristics and material placement configurations) may be required to develop acceptable solutions and to adapt to changing conditions.

3.2 Design Objectives and Constraints

The main design objectives for this project are to provide protection from ongoing erosion along the WaW shoreline in a way that:

- Preserves and protects the cultural and archaeological value of WaW

- Enhances and accommodates current and future cultural and recreational use
- Maintains public access and amenities
- Results in a net positive eco-system benefit by increasing the area of forage fish habitat.

Constraints associated with these design objectives include:

- Avoiding excavation and protecting archaeological deposits at the shoreline during construction. The project should not result in adverse effects to archaeology in the post construction phase.
- The design should predominantly use sediments suitable for forage fish habitat and should avoid impact to the habitat in the lower intertidal area (below LLWMT).
- Shoreline interventions have the possibility to either promote or reduce sediment deposition in different areas along the shorelines at WaW. The project should avoid disrupting downdrift sediment supply that could exacerbate erosion in other areas both within the limits of the existing project and on neighboring shorelines.

The design is to protect against erosion and future erosion due to climate change and mitigate the potential for wave runup. The design does not mitigate flood risk as the berm at the top of the beach is permeable. This is to allow surface water to drain through the berm.. This means that the design will not significantly improve or change the flood protection of the upland area. The beach nourishments and mixed gravel cobble backshore protection will reduce wave run up and overtopping. However, neither the mixed gravel-cobble backshore berm nor beach nourishments are impermeable, and extreme water levels could still result in flooding of the upland area.

Additionally, the design is assumed to be dynamic over time and the beach nourishments are expected to reshape. The mobile and dynamic nature of sediment-based solutions means that a storm event or disturbance can cause changes (e.g., in morphology, vegetation health and coverage) which may be significant (Osborne et al., 2024). Also, some time may be required to recover and re-establish equilibrium, depending on factors such as the extent of damage, project scale (which influences capacity to absorb and self-repair), sediment supply, and seasonal conditions for coastal processes. Adaptive management including maintenance may also be required to support recovery and self-mitigation.

Current best practices in coastal zone management and coastal engineering indicate that construction and maintenance of shore protection is best achieved through an ongoing and iterative adaptive management approach (repeated investments in labour and materials over time). This is especially the case with increasing knowledge and awareness of coastal processes, a changing climate, sea level regime and sediment supply. As a result, future shoreline protection and restoration solutions will require ongoing adaptive maintenance rather than a "one and done" static solution, especially with regards to protecting archaeological resources. Adaptive management is generally consistent with the premise of nature-based approaches to shoreline management. Net losses of sediment may be inevitable over the long term, so ongoing monitoring is required to assess maintenance and adaptive management needs.

3.3 Design Water Levels

The design water level (DWL) for the project site includes the combined effect of astronomical, non-astronomical effects (storm surge) and relative sea level rise (RSLR) (Appendix B, NHC (2023)). The DWL for WaW summarized in Table 3.1Table 3.1 are based on the tidal elevations for Vancouver Harbour (Station ID 7735) (Fisheries and Oceans Canada, 2022) and the estimated joint probability of storm surge and tides calculated for Point Atkinson (NHC and Triton, 2006). Regional sea level rise (RSLR) is based on the global SLR allowance of 10 mm/year minus local uplift.

Table 3.1 Design Water Levels (DWL) for WaW

AEP (%)	Present Day	Near Future (assumed year 2050)	Distant Future (assumed year 2100)
10	2.4	3.0	3.5
2.0	2.6	3.2	3.7
1.0	2.7	3.3	3.8
0.5	2.8	3.4	3.9

3.4 Wind Analysis

WaW is exposed to wind-generated waves from the east and west, aligning with the orientation of the inlet, as well as winds from the north that are funneled down the Indian Arm. Although WaW is also exposed to winds from the south, the fetch[1] is small compared to other directions. The design wind speeds from NHC (2023) are summarized in Table 3.2 for Point Atkinson and Pam Rocks. Details for the wind analysis are provided in Appendix B.

Table 3.2 Design wind speeds for WaW.

AEP (%)	Easterly Design Speeds (Point Atkinson)		Westerly Design Speeds (Point Atkinson)		Northerly Design Speeds (Pam Rocks)	
	(m/s)	(km/hr)	(m/s)	(km/hr)	(m/s)	(km/hr)
100	18.8	68	17.9	64	23.4	84
20	20.4	73	20.6	74	26.9	97

[1] Fetch refers to the open water distance over which the wind blows to generate waves.

AEP (%)	Easterly Design Speeds (Point Atkinson)		Westerly Design Speeds (Point Atkinson)		Northerly Design Speeds (Pam Rocks)	
	(m/s)	(km/hr)	(m/s)	(km/hr)	(m/s)	(km/hr)
10	20.9	75	21.8	78	28.1	101
2	22.0	79	24.5	88	30.8	111
1	22.5	81	25.7	93	31.9	115
0.5	22.9	82	26.8	97	33.0	119

3.5 Wave Analysis

The wave modeling results presented in NHC (2023) (Table 3.3) show that the west-central beaches are dominated by wind-generated waves from the west, with a yearly maximum significant wave height (H_s) of 0.8-1.1 m (100% to 0.1% AEP) and a corresponding peak period (T_p) of 3.0-3.7 s. East beach is dominated by waves from the NE, with a yearly maximum H_s of 1.0-1.3 m and a corresponding T_p of 4.0-4.4 s. Vessel wakes were assessed in NHC (2023), however, wind-generated waves exceeded those generated by vessels Therefore, the design wave conditions for west-central and east beach exposures are dependent on the westerly and northeasterly winds, respectively.

The difference in H_s between the 100% (1-in-1 year) AEP and 1% (1-in-100 year) AEP for both the westerly and northeasterly wind events is relatively small (0.3 m), suggesting the waves at WaW are fetch-limited. For this reason, the 5% AEP wave event is used as an approximate representation of the overall yearly maximum wave climate for preliminary design. An analysis of the mean wave conditions resulting in medium- to long-term morphological change to the shoreline, or morphological wave climate, should be completed in the next phase to determine nourishment maintenance volumes and intervals.

Table 3.3 Consolidated numerical modelling design conditions for wind-generated waves.

Beach(s)	AEP (%)	H_s (m) Note 1	T_p (s)	Storm Direction
West, Central	100	0.8	3.0	W
	20	0.9	3.3	W
	5	1.0	3.7	W
	1	1.1	3.7	W
East	100	1.0	4.0	NE
	20	1.1	4.0	NE

Beach(s)	AEP (%)	H_s (m) Note 1	T_p (s)	Storm Direction
	5	1.2	4.0	NE
	1	1.3	4.4	NE

Notes:

1. Wave heights are for water depths between 10 – 15 m and the waves would be subject to shoaling and refraction processes, reducing the heights as they propagate through the nearshore.

3.6 Design Criteria

The design working life of a structure is taken as “the specific period for which a structure is to be used for its intended purpose with planned maintenance” (British Standards Institution, 2013). This report considers a design working life of 30 years for the detailed design of shoreline protection at WaW corresponding to approximately the year 2050. The rationale for choosing this design working life is based on providing a design with a relatively low cost and considering that by year 2050 the science of sea level rise (SLR) will be better informed as to predictions of SLR levels in year 2100 and beyond, and the design will be adaptable to accommodate for additional SLR in the future beyond 2050.

For shore protection and restoration design we have adopted a crest elevation based on the near future AEP of 2% which is relatively frequent (in future) but in present day conditions it is a rare event (<<0.5% AEP) and therefore includes some allowance (up to 0.4 m) for present day wave effects as well as tides and storm surges. In addition, the project is designed for a 1-in-20 AEP wave event (i.e., 5% probability of occurrence in any given year). The joint probability of occurrence of these events (assuming the water level and wave event are independent for a NE and W wave event) is an approximately 1-in-100 AEP event. As discussed in Section 3.5, the waves at the site are fetch-limited, and the difference between a 1-in-200 AEP event and the 1-in-5 AEP event is relatively small. Therefore, using a joint probability of occurrence of 1-in-100 AEP is suitable for a nature-based erosion protection design for WaW.

A summary of the design criteria and expected maintenance requirements for each element in the project is provided in Table 3.4. The rock sizing was determined to be more sensitive to wave and wind conditions than water levels. To ensure the rock was sized using a 1-in-100 AEP, the 1-in-100 AEP wave event with a 1-in-10 AEP water level was used in the calculations. The beach nourishment design was completed for this preliminary design phase using the 1-in-10 AEP water level event and the 1-in-20 AEP wave event for determining beach crest elevation, slopes and initial sediment design. A range of morphological wave and water level conditions will be used in the next design phase to refine the design and establish acceptable maintenance volumes and intervals.

Table 3.4 Design criteria for WaW.

Design Element	Wind/Wave Event AEP	Near Future Water Level AEP (assumed year 2050)
Crest elevations • Rock headlands • Beach nourishment • Cobble berms	1-in-20	1-in-50
Rock sizing • Rock headlands • Boulder clusters	1-in-100	1-in-10
Beach nourishment design slopes and sediment gradations	1-in-20	1-in-10
Beach nourishment maintenance requirements design • Estimate re-nourishment volumes • Refine beach nourishment design to establish acceptable re-nourishment intervals	Range of AEPs from *average* winter storm event to 1-in-20 AEP's	Range of tidal cycle up to 1-in-10 AEP

4 SEDIMENT DESIGN BASIS

This section presents the results from a sediment grain size analysis at the Project site to characterize and establish sediment size distribution of native sediments present on the existing intertidal shoreline. These findings provide a quantitative basis for developing the initial specifications of beach nourishment sediments.

4.1 Design Sediment Gradations

Table 4.1 presents the material gradations for the beach nourishments proposed for the Project site. Figure 4.1 to Figure 4.4 show the target grain size distribution and acceptable range for each material type. These gradations were used in the sediment transport modelling presented in Section 5.

The gradation of Type 1 Mixed Gravel and Cobble (MGC1) is designed to provide a more robust protective element to reduce the potential for backshore erosion and provide a dynamic but permeable berm crest to absorb wave energy at relatively high water levels when placed behind and under the beach nourishment. The sediment gradations for beach nourishment are designed to be compatible with native (existing) beach sediments and meet criteria for forage fish spawning. Compatibility with existing sediments is desirable for achieving nourished beach profiles that are approximately consistent with existing conditions and appropriate for the predominant wave and water level exposure in each reach. Type 2 Mixed Sand and Gravel (MSG) 2 is similar to the sediment observed in samples at Roche Point, while Type 3 MSG3 is similar to the sediment sampled at East Beach (Table 4.2). The type 2 and type 3 materials both target the forage fish specifications presented in Section 4.3. Type 2 MSG2 is ideally suited to surf smelt and can also be suitable for the Pacific sand lance. Type 3 MSG3 is finer grained and targets Pacific sand lance specifications that prefer medium to coarse sand. Typical beach slopes provided in the Beach Manual (Rogers et al., 2010) are 1V:7H to 1V:12H for gravel with a D50 of 10 mm (similar to the type 2 MSG2). The typical beach slope for type 3 MSG3 with a D50 of 1.2 mm would be lower and is estimated to range from 1V:12H to 1V:20H. Type 4 mixed gravel and cobble (MGC2) is used at the toe of the East Beach MSG2 nourishment to anchor the beach slope and prevent erosion of the nourishment.

Table 4.1 Design sediment gradations.

Material type	D15(mm)	D50(mm)	D90(mm)	Description
Type 1. Mixed gravel and cobble (MGC1)	10	50	200	2-inch minus cobble with coarse to medium gravel base (rounded)
Type 2. Mixed sand and gravel (MSG2)	1	10	22	Medium to fine pebbles (rounded gravel) with coarse sand base
Type 3. Mixed sand and gravel (MSG3)	0.7	1.2	13	Fine (pea) gravel with medium sand base
Type 4. Mixed gravel and cobble (MGC2)	50	90	200	3.5 inch minus cobble with very coarse gravel (rounded)

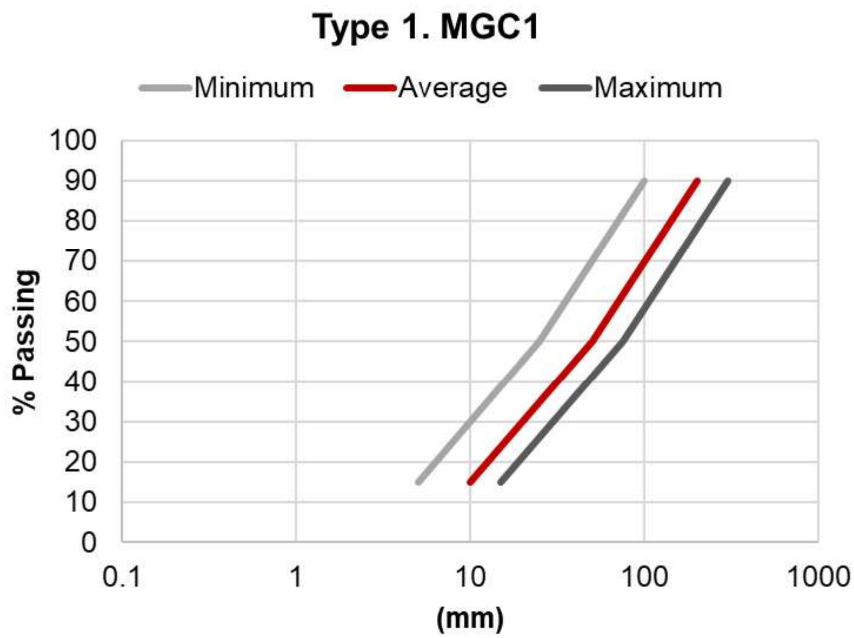

Figure 4.1 Material gradation for the Mixed Gravel Cobble (MGC1).

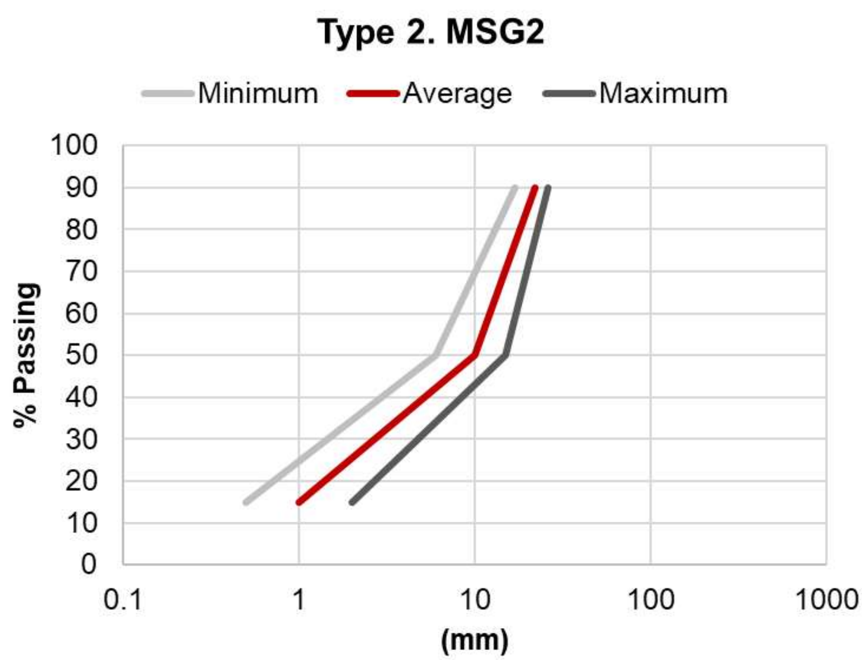

Figure 4.2 Material gradation for Mixed Sand and Gravel (MSG2).

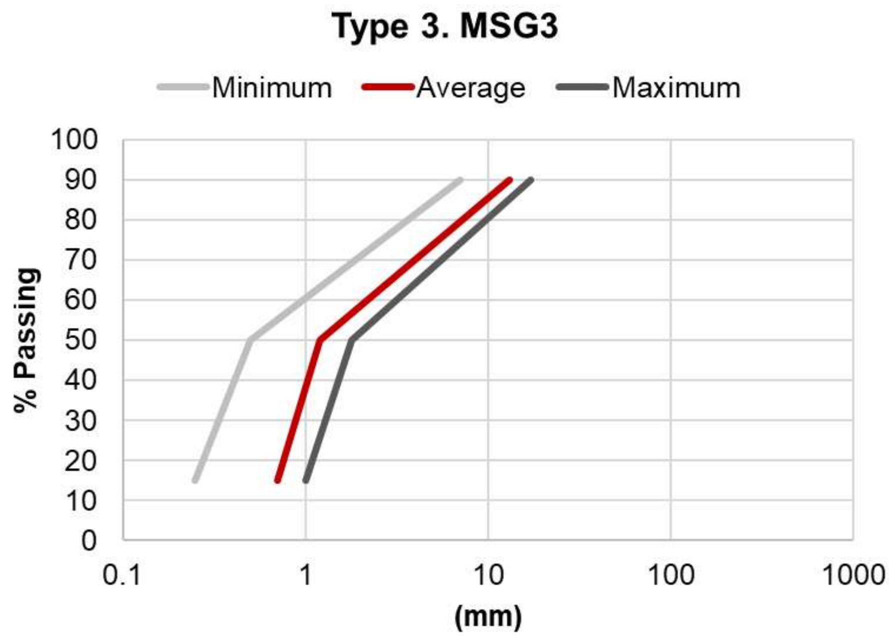

Figure 4.3 Material gradation for the finer Mixed Sand and Gravel (MSG3).

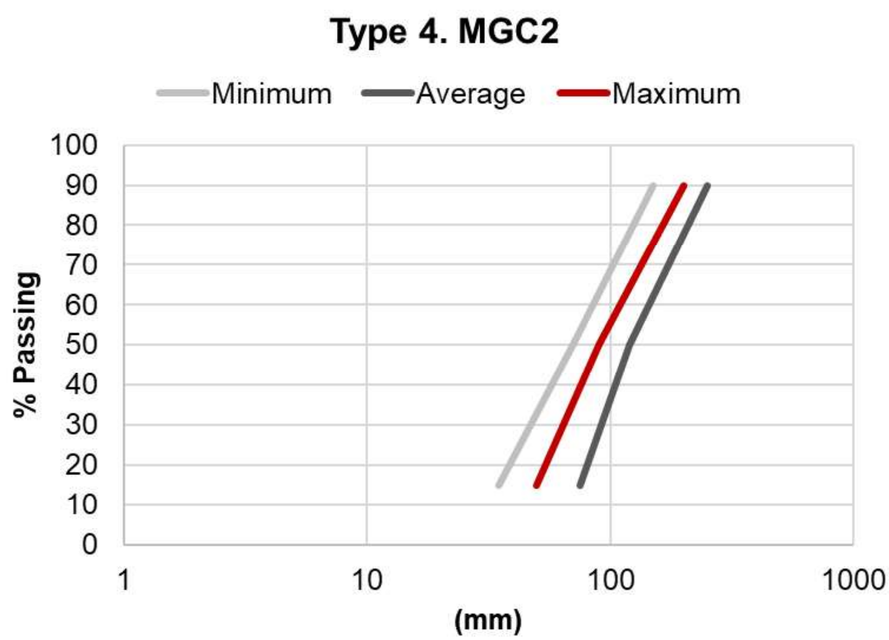

Figure 4.4 Material gradation for the finer Mixed Gravel Cobble (MGC2).

4.2 Sediment Sampling Results

The sediment characterization is based on six sediment samples and eight plan view images collected during site surveys on July 26, 2023 and August 30, 2024. The six sediment samples were collected at Roche Point and East Beach during the site survey on August 30, 2024. The grain size distribution of each of these samples was characterized by conducting a sieve analysis. A Wolman pebble count was also conducted to sample the gravel sized sediment at Roche Point during a site visit on July 26, 2024. The results are consistent with preliminary characterization maps presented in NHC (2023). The location of the sediment samples and plan view images of sediment is shown in Figure 4.5.

The locations and sample numbering for the sieved samples collected at Roche Point and East Beach are shown in Figure 4.6 and Figure 4.7. The grain size distributions are shown in Figure 4.8 and Figure 4.9. The sediment at Roche Point and East Beach consists of medium to coarse grained sand (0.25 mm to 2 mm) with fine to coarse gravel (2 mm to 32 mm). The sediment at East Beach is finer than at Roche Point; the East Beach samples contain a larger fraction of medium to coarse sand (up to 43%) compared to Roche Point (up to 35%), and consist of less coarse gravel (2 to 5% > 16 mm) at East Beach relative to 16-30% at Roche Point. The different characteristic grainsizes for the three Roche Point and three East Beach samples are presented in Table 4.2.

Table 4.2 Summary characteristic grain sizes for the Roche Point and East Beach samples derived from sieve analysis.

Characteristic Grain Size	Roche Point	East Beach
Percentile finer than	Size (mm)	Size (mm)
D84	19.2	10.4
D50	8.2	3.6
D16	0.9	0.7

Figure 4.5 Locations of the 2023 (yellow) and 2024 (orange) surface sediment images and the sieved sediment sample locations (red).

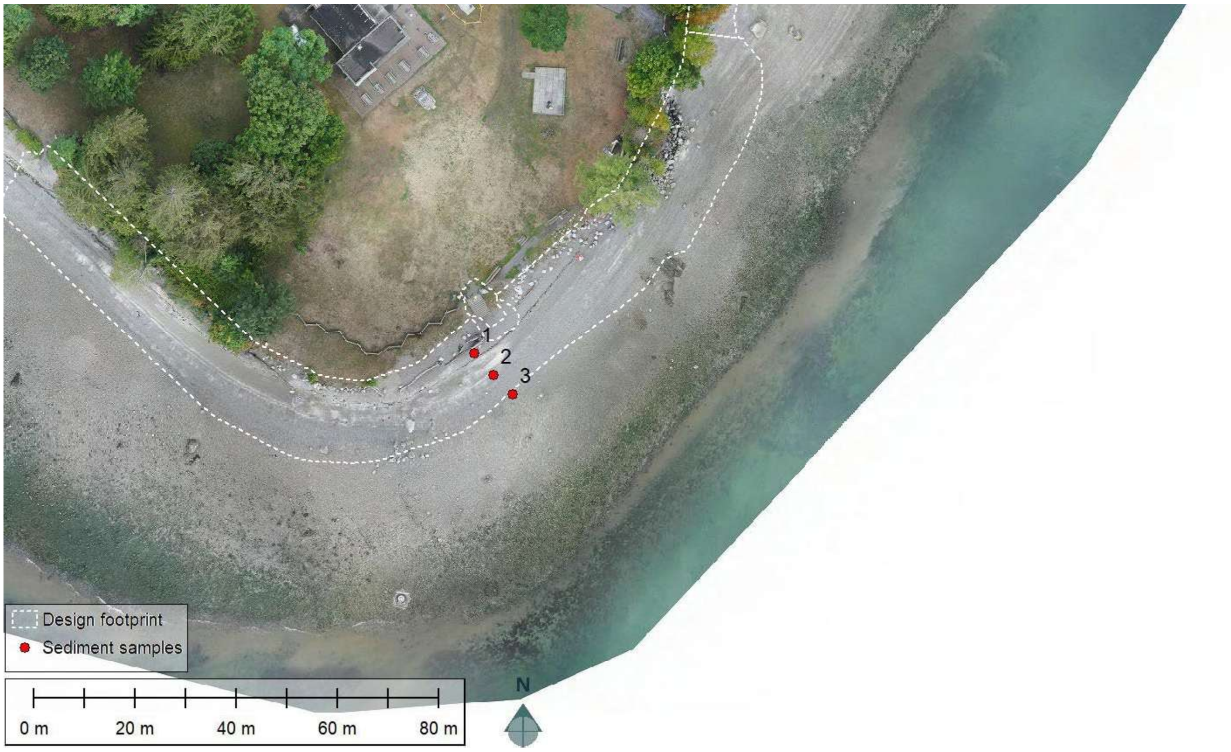

Figure 4.6 Locations of the sieved sediment sample locations and ID's at Roche Point.

Figure 4.7 Locations of the sieved sediment sample locations and ID's at East Beach.

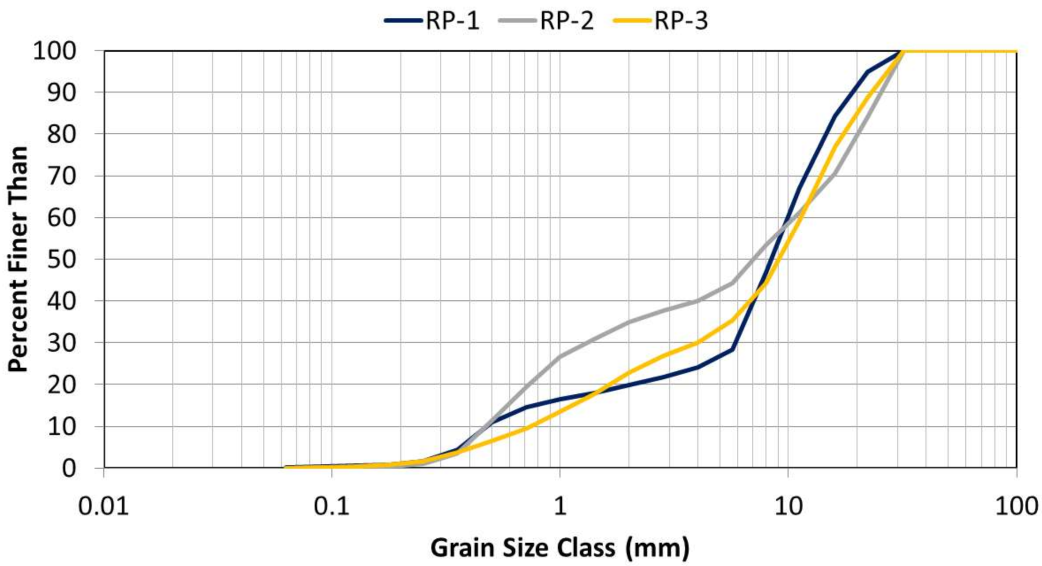

Figure 4.8 Size distribution of sediment samples collected at Roche Point from sieve analysis.

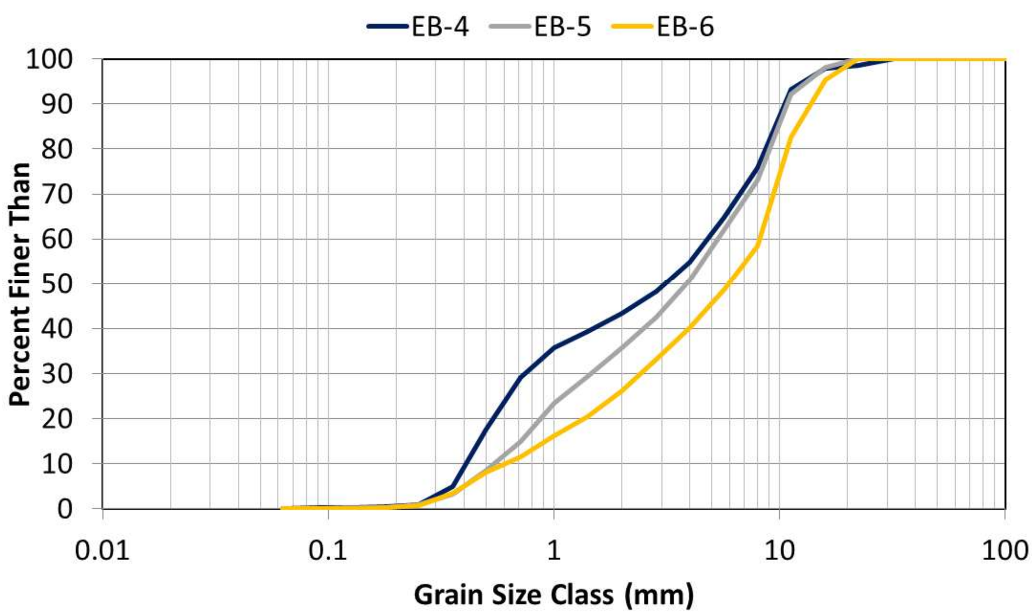

Figure 4.9 Size distribution of sediment samples collected at East Beach from sieve analysis.

The eight selected plan view images of the beach sediment were analyzed using SplitEng software. SplitEng is used for automated grain size analysis and provides quantitative information on the distribution of sediment sizes within the image. This automated analysis is used for the analysis of gravel and cobble sediment and provides an alternative to Wolman pebble counts. The results from SplitEng can be less reliable than Wolman counts and the sediment sample sieve results presented above, but when used in combination with sampled results they can provide a useful and rapid indication of the surface sediment types in key locations.

The results from the most reliable images processed with SplitEng are presented below. In total there are eight image samples; four collected on July 26, 2023 and four images collected on August 30, 2024. Figure 4.10 and Figure 4.11 show the grain size distributions at the locations shown on Figure 4.5.The surface sediment images are provided in Appendix C.

The grain size distributions obtained from the surface sediment images range from fine gravel to cobble. Two plan view images were collected nearby the locations for the sieve sediment sample. Image 2024-1 was collected at East Beach and image 2024-3 was collected at Roche Point. These samples both consist of fine to medium gravel (see Photo 5 and Photo 7 in Appendix C) with an estimated D50 of 9.7 mm and 16.3 mm, respectively. This is coarser than the sediment samples collected for sieve analysis but consistent with the Wolman pebble count collected at Roche Point. This is in part related to the surface sediment layer being coarser than the sediment below surface, due to the fines winnowing from the surface layer over time. It also reflects the heterogeneity of the beach sediment with variation depending on the location and elevation along the beach.

The sample collected at Central Beach (2024-2) west of the boat ramp and at the west end of Little Cates (2023-2 and 2023-4) are coarse and consist mainly of medium gravel to cobble. The other sample collected at Central Beach (2023-3) has a higher fraction of fine gravel, but is similarly coarse in the upper 50% of the distribution (see Photo 3 in Appendix C). The sample collected at West Beach (2023-1) consists of fine to medium gravel, however most of the surface sediment at West Beach is coarse compared to the other reaches consisting of gravel and a high amount of cobble. The sample collected in between Roche Point and East Beach (2024-4) has a similar distribution compared to the sample at East Beach (2024-1) consisting of fine to medium gravel.

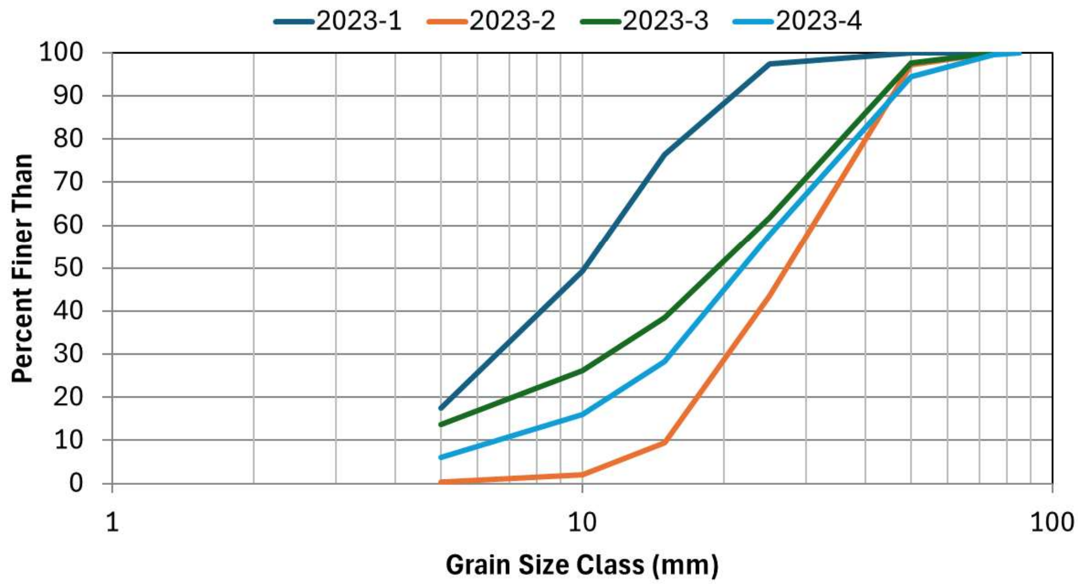

Figure 4.10 Grain size distributions for the surface sediment images collected in 2023.

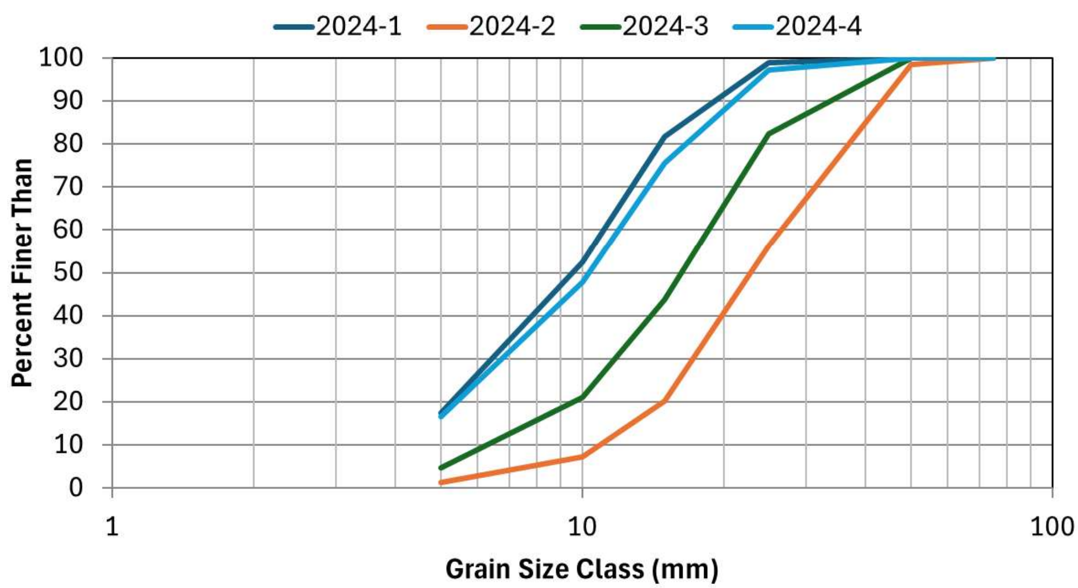

Figure 4.11 Grain size distributions for the surface sediment images collected in 2024.

4.3 Forage Fish Habitat requirements

Forage fish habitat requires specific sediment types for spawning. To create and maintain habitat for forage fish, the foreshore construction will use material types that are suitable for forage fish spawning, specifically for Pacific sand lance and surf smelt. Figure 4.12 shows the range of different sediment types that are suitable for these two species.

Pacific sand lance spawn from November to mid-February and prefer medium sand that is 0.25 mm to 0.5 mm in diameter. Spawning has also been documented in coarse sand and fine pebble sediments from 1.0 mm to 7.0 mm in diameter (MABRRI, 2020). Surf smelt have been found to spawn year round in coarse sand to fine pebble sediment mixes ranging from 1.0 mm to 7.0 mm in diameter (MABRRI, 2020).

Figure 4.12 Beach sediment types preferable for Pacific sand lance and surf smelt spawning (MABRRI, 2020).

Sediments that are not suitable for Pacific sand lance and surf smelt spawning include large cobble, mud and silt (MABRRI, 2020). Although forage fish embryos can attach to large cobble, they are less likely to survive. Additionally, mud and silt is too fine and compact, making it difficult for respiration to occur and increasing the likelihood of embryo smothering (MABRRI, 2020). Section 6 describes the different material types proposed for the foreshore design with beach fill sediments that meet the requirements for both Pacific sand lance and surf smelt.

5 SEDIMENT TRANSPORT MODELLING

NHC has undertaken an assessment of wave-generated sediment transport along the shoreline of WaW using the numerical model XBeach. XBeach is an open source, one dimensional (1D) or two dimensional (2D) numerical model used to assess hydrodynamic and morphodynamic processes on coastlines for a variety of domain sizes and time scales (Deltares, 2018). *XBeach v1.24.6057 Halloween* release was used in this study.

The hydrodynamic processes resolved by the XBeach model include transformation of short and long period (infragravity) waves, wave-induced setup, currents, overwash, and inundation. The hydrodynamics can be solved using either the hydrostatic (stationary or surfbeat) or non-hydrostatic mode, depending on the model time scale being investigated. Morphodynamic processes include sediment transport (bed and suspended load), bed updating, breaching, and dune face avalanching.

The model was originally developed by Deltares and the U.S. Geological Survey with funding by the U.S. Army Corps of Engineers for assessing the impact of hurricanes on sandy coasts for the *Morphos* project. Later, the capabilities of the model were expanded to include dune safety assessments funded by the Dutch Public Works Department. The model has been validated for both dissipative and reflective beaches for a variety of conditions and coastlines around the European Union through support from the European Commission. Throughout the development of the model for these applications, XBeach was validated by the developers using analytical, laboratory, and field test cases.

The 2D XBeach model for WaW (Section 5.1.1) was run using the surfbeat mode where long waves are fully solved (non-stationary) but short waves are solved using wave energy equations and are solved on the scale of wave groups (stationary). Infragravity motion has been shown to be particularly important as a mechanism for beach morphodynamic response.

The gravel and cobble beaches were modelled using 1D XBeach-G in non-hydrostatic mode for select design sections. XBeach-G is a morphodynamic, depth-averaged, cross-shore profile model, based on the XBeach model for sandy coasts (Roelvink et al., 2009). The model simulates the morphological response of gravel beaches and barriers to storms by solving: (1) intra-wave flow and surface elevation variations using a non-hydrostatic extension of the non-linear shallow water equations; (2) groundwater processes, including infiltration and exfiltration, using a Darcy-Forchheimer-type model; and (3) bed load transport of gravel using a modification of the van Rijn (van Rijn, 2012) bed load transport equation to include flow acceleration effects, which are shown to be an important factor on coarse-grained beaches. The model is extensively validated for hydrodynamics, groundwater dynamics and morphodynamics using detailed data collected in physical model experiments, as well as field measurements (McCall et al., 2014) and has been widely applied in design.

The XBeach model domains for surfbeat (2D) and gravel (1D) are shown in Figure 5.1Figure 5.1. The model setup and results are discussed in the following sections. The 2D surfbeat domain is divided into two grids to capture both the northeasterly and westerly storm events that impact the eastern and southwestern shorelines, respectively. XBeach-G 1D sections were created for both sides of Roche Point and a selected typical section on East Beach.

The initial XBeach modelling (surfbeat 2D and XBeach-G 1D) was completed for the preliminary design provided in the Issued for Permitting (IFP) Revision 0 (Rev. 0) design drawings submitted on November 12, 2024. The initial XBeach modelling setup and results for the preliminary design are provided in Section 5.1 and Appendix D. Due to the initial XBeach-G model results, changes to the design slopes were made to the Roche Point and East Beach sections. These changes were incorporated in the Issued for Permitting (IFP) Revision 1 (Rev. 1) design drawings submitted on February 2, 2025 (Appendix A). The updated XBeach-G models of the design changes at Roche Point and East Beach are provided in Section 5.2.

Figure 5.1 XBeach model domains.

5.1 Preliminary Design for Review

This section provides the XBeach modelling (surfbeat 2D and XBeach-G 1D) results for the preliminary design. The surfbeat model was run with both the MSG2 and MSG3 sediment types to provide an understanding of the impact of longshore sediment transport on the design (Section 5.1.1); however, the XBeach surfbeat mode is not validated for sediment types coarser than sand (D50 > 2 mm). Therefore, beach morphological change of the sediment types MSG2 and MGC1 are more accurately assessed using XBeach-G (Section 5.1.2).

5.1.1 2D XBeach Model

The 2D XBeach model was run for the scenarios provided in Table 5.1 for the design storm directions (NE and W) and design sediment types MSG2 and MSG3. The 2D XBeach model results provide the response of the Central Beach and Little Cates beach nourishment to the design storm event. The sediment characteristics of MSG2 and MSG3 are described in Section 4. Due to the mixed sand and gravel nature of the sediment types MSG2 and MSG3, avalanching parameters were set to the default values used in the XBeach-G model. The lateral boundaries are set to *wavecrest* mode due to the oblique nature of the offshore waves. All other parameters are set to the default for XBeach 2D surfbeat models.

Table 5.1 XBeach 2D surfbeat model scenarios completed with and without project.

Model Domain	Wind/Wave AEP (%)	Significant Wave Height (m)	Peak Period (s)	Water Level AEP (%)	Water Level (m CGVD28)	Storm Direction	Sediment Type
East	5	1.2	4.0	10	2.4	NE	MSG2
							MSG3
		0.6	2.3	10	2.4	E	MSG2
							MSG3
Southwest	5	1.0	3.7	10	2.4	W	MSG2
							MSG3

The results of the 2D XBeach models include cumulative bed changes from combined sedimentation and erosion (Figure 5.2 and Figure 5.3) for the duration of the model run for the existing beach (without project) and the design surface (with project) including the beach nourishment, cobble berms, and headlands; the model results for all scenarios are provided in Appendix D. Model results for NE and W events for MSG3 are shown in Figure 5.2 and Figure 5.3, respectively. The model results are summarized below:

- **Sediment type MSG2 with NE/E storm directions (Appendix D; Figure 1, Figure 2)**
  - Minor bed level changes to design surface at DWL with sediment type MSG2 along the western shoreline.
  - The project effectively reduces erosion of the upper backshore during high water level events (less bank erosion) compared to the existing condition.
- **Sediment type MSG2 with W storm direction (Appendix D; Figure 3)**
  - Like the NE/E storm direction, the project effectively reduces the bank erosion of the upper backshore in comparison to the existing condition.
  - Minor erosion of sand occurs at Roche Point for the DWL storm event (<0.2m) with waves coming from the west. Sediment is moved around Roche Point to the east and northeast and deposited on the lee side of the point.
  - Some reshaping of the lower beach at West Beach as the storm event re-distributes the sediment with the 3H:1V toe placement behind the headlands.
- **Sediment type MSG3 with NE/E storm directions (**Figure 5.2**)**
  - The headlands at Little Cates trap sediment from the north (assuming sediment is available).
  - There are no significant changes to the beach nourishment occur during the DWL. Storm events from the NE or E occurring at low water levels may cause reshaping of the lower beach to achieve an equilibrium profile) for the East Beach design (see XBeach-G 1D model discussion).
  - The project effectively mitigates erosion of upper beach/backshore during high water level events.
- **Sediment Type MSG3 with W storm direction (**Figure 5.3**)**
  - The MSG3 area at Central Beach shows some lowering of the beach nourishment after the 5% AEP storm event from the W. Increasing the height of the headlands could mitigate this erosion. However, some re-shaping of the beach nourishment is expected here due to the placement configuration.

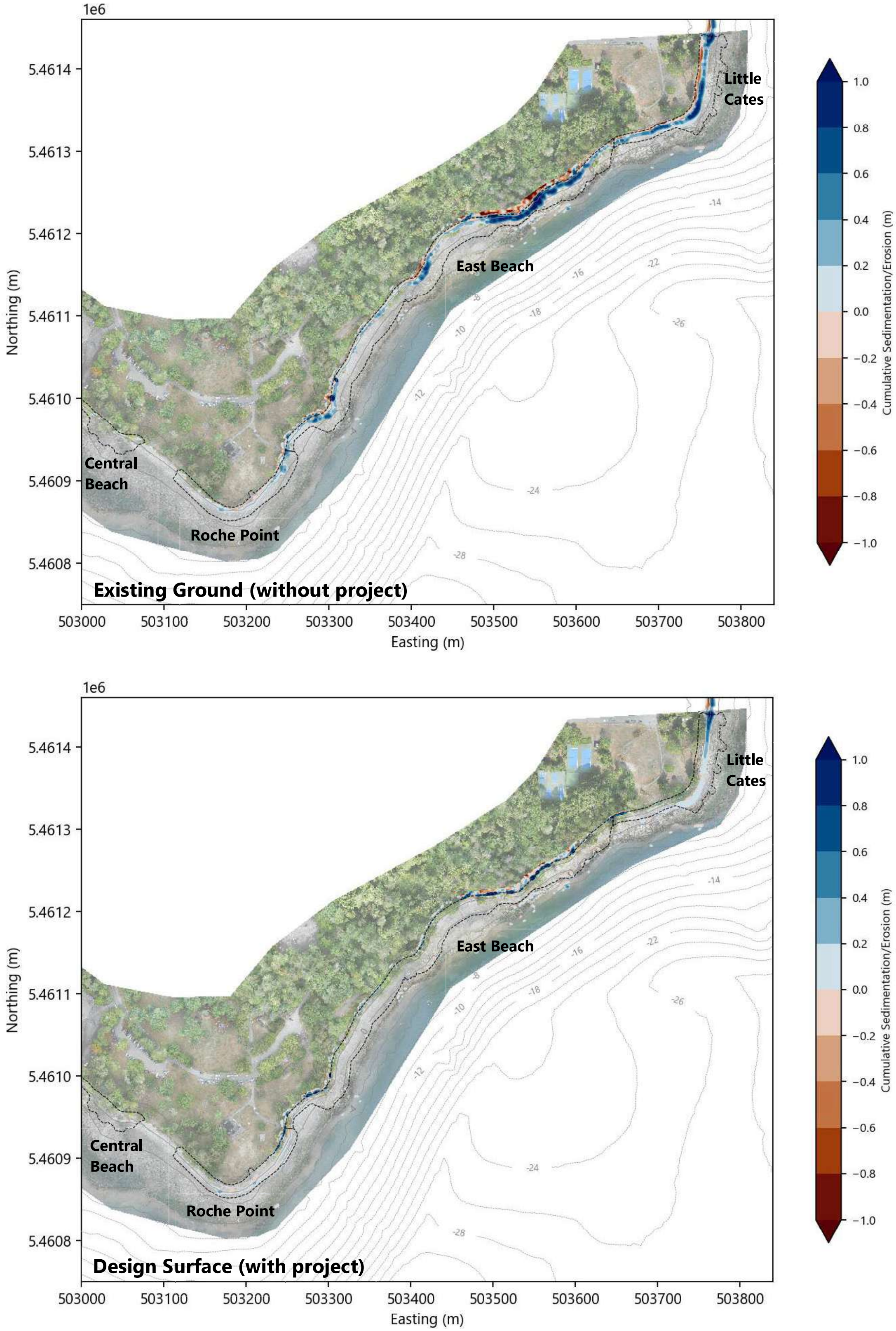

Figure 5.2 Cumulative sedimentation/erosion during 5% AEP NE wind event occurring during a 10% AEP water level event with the existing beach (top) and the design surface (bottom) with sediment type MSG3. The black dashed line shows the project design footprint.

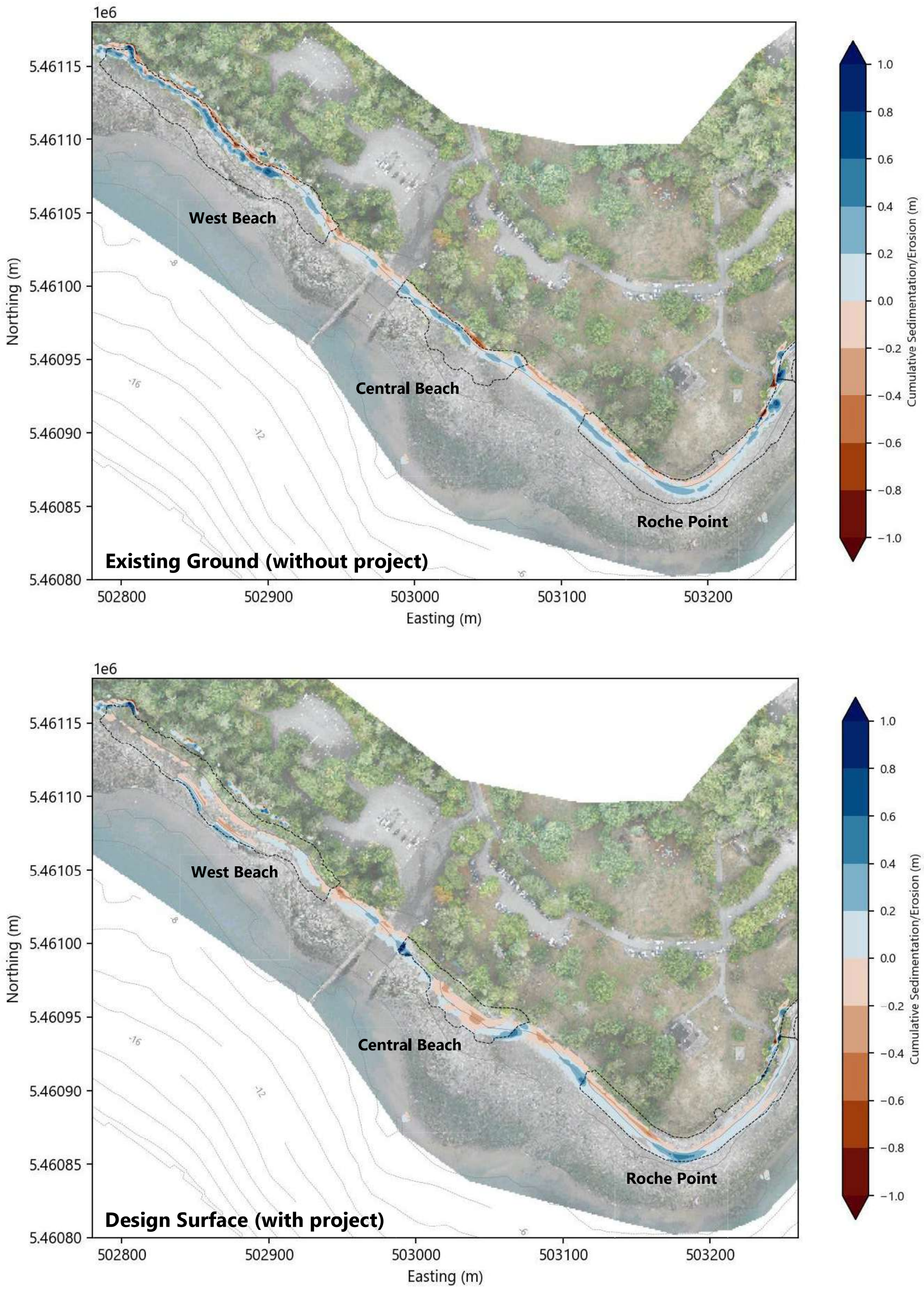

Figure 5.3 Cumulative sedimentation/erosion during 5% AEP W wind event occurring during a 10% AEP water level event with the existing beach (top) and the design surface (bottom) with sediment type MSG3. The black dashed line shows the project design footprint.

5.1.2 XBeach-G 1D Model

The XBeach-G 1D model was run for the scenarios provided in Table 5.2 for the 5% AEP wave event and the 10% AEP DWL for the present day at Roche Point SW and E section and East Beach; the design sections at Roche Point and East Beach are shown in Figure 5.4. The model was used to assess morphological changes to the beach nourishment after a storm event for the design grain size diameter and beach slope. The sensitivity of the design sections to water level was analysed by running the model with water level set to MWL, and elevation 0.5 m CGVD28, -0.5 m CGVD28. The model results showing the beach profile before and after the storm event are provided in Appendix D. The XBeach model defines the origin of the computational grid as the offshore boundary; therefore, the output sections are shown with the offshore boundary on the left-hand side of the section (flipped from the design drawing sections shown in Figure 5.4). The XBeach-G model parameters are set to the defaults for all runs.

Table 5.2 XBeach-G 1D model scenarios for preliminary design.

Section	Wind/Wave AEP (%)	Significant Wave Height (m)	Peak Period (s)	Water Level AEP (%)	Water Level (m CGVD28)	Sediment Type	Results Figure (Appendix D)
Roche Point – SW (D-5)	5	0.8	3.7	10	2.4	MSG2	Figure 7
Roche Point – E (D-7)	5	0.7	2.3	10	2.4	MSG2	Figure 8
				-	0.5	MSG2	Figure 9
East Beach (D-9)	5	0.6	4.0	10	2.4	MGC1	Figure 10
				MWL	0.1	MSG2	Figure 11
				-	-0.5	MSG2	Figure 12

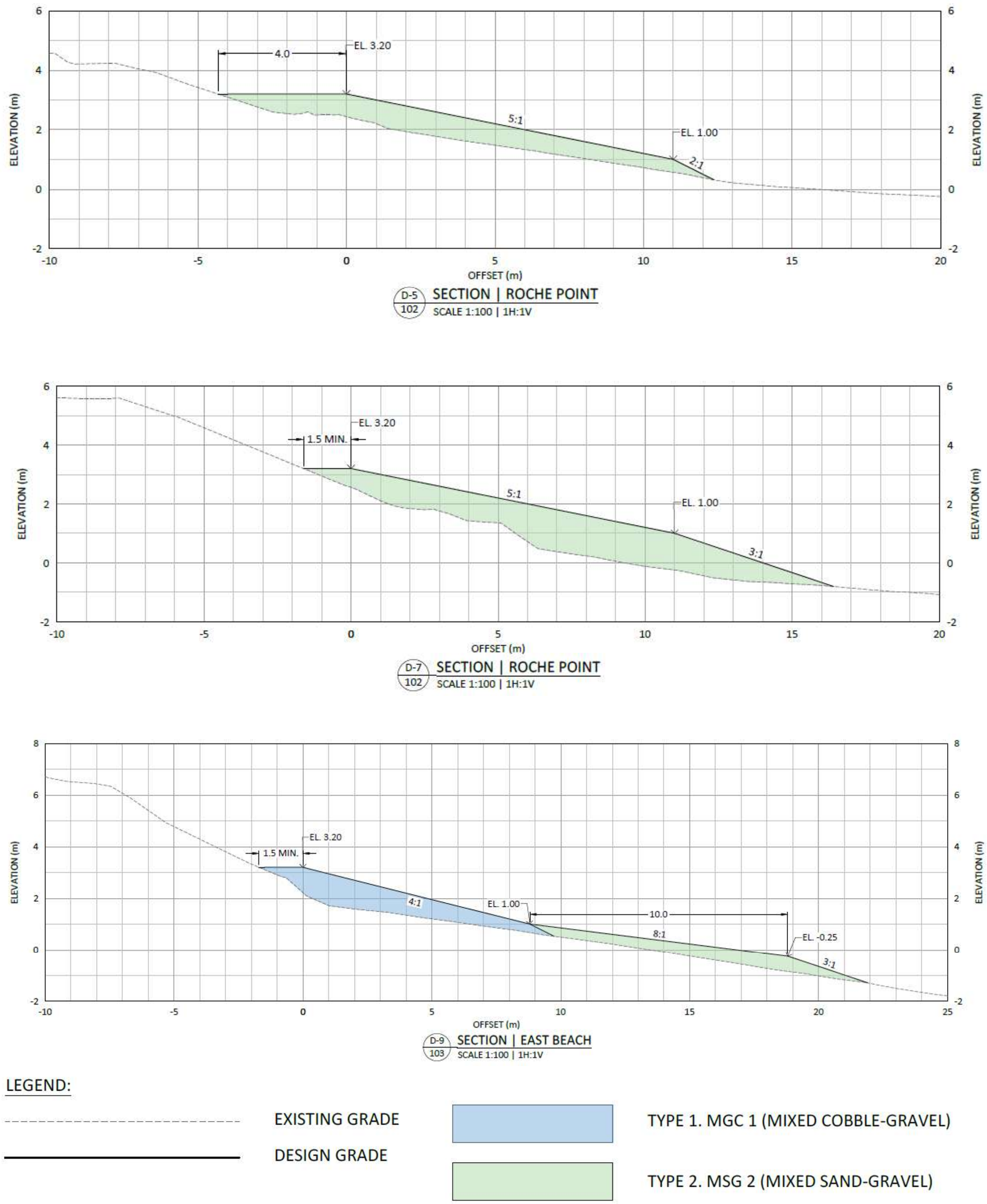

Figure 5.4 XBeach-G 1D sections for Roche Point southwest and east design sections (top, middle) and East Beach design section (bottom) from the IFP R0 design.

The MSG2 beach nourishment at Roche Point is relatively stable for a 5H:1V beach slope for the 5% AEP storm event. However, significant re-shaping of the lower beach should be expected after a 5% AEP storm event occurring at a water level between 1.- and -1 m with a 3H:1V toe slope. Allowing the beach to re-shape naturally will likely result in an equilibrium beach profile after exposure to a winter storm season; however, erosion of sediment and lowering of the beach profile is likely given this design configuration. Section 5.2 presents refinements to the design based on the modelling results to reduce the erosion of sediment and lowering of the beach profile.

The MCG1 cobble beach berm at East Beach is relatively stable for a 4H:1V beach slope for the 5% AEP storm event. Like Roche Point, the MSG2 beach nourishment is relatively stable at a beach slope of 5H:1V; however, shows more erosion of the beach after exposure to the wave event. Significant re-shaping of the 3H:1V toe of the East Beach nourishment between elevation -0.5 m CGVD28 and 0 m CGVD28 should be expected with this beach configuration.

5.2 IFP Revision 1 Design Revised Design

Given the results of the XBeach-G models, the beach design configurations were refined to remove the 3H:1V slope at the toe of the nourishment at Roche Point and East Beach where possible. The 3H:1V toe was kept in place for areas of the shoreline that could not accommodate a 6H:1V or 5H:1V slope; for example, in cases where the slope of the nourishment would extend past the LLWMT contour. The MSG2 sediment at the toe was replaced with a small cobble toe berm to anchor the beach nourishment. The following items summarize the design revisions following review of the preliminary XBeach-G modelling:

- **Roche Point (Figure 5.5)**
    - Reduce beach slope to 6H:1V
    - Extend 6H:1V beach slope to intersect with existing ground (remove 3H:1V toe slope)
- **East Beach (Figure 5.6)**
    - Replace 3H:1V toe slope sediment type (previously MSG2) with 4H:1V cobble (MGC2) toe
    - Extend 8H:1V beach slope to intersect with existing ground in the pocket beach (Section D-11 in Figure 5.6)

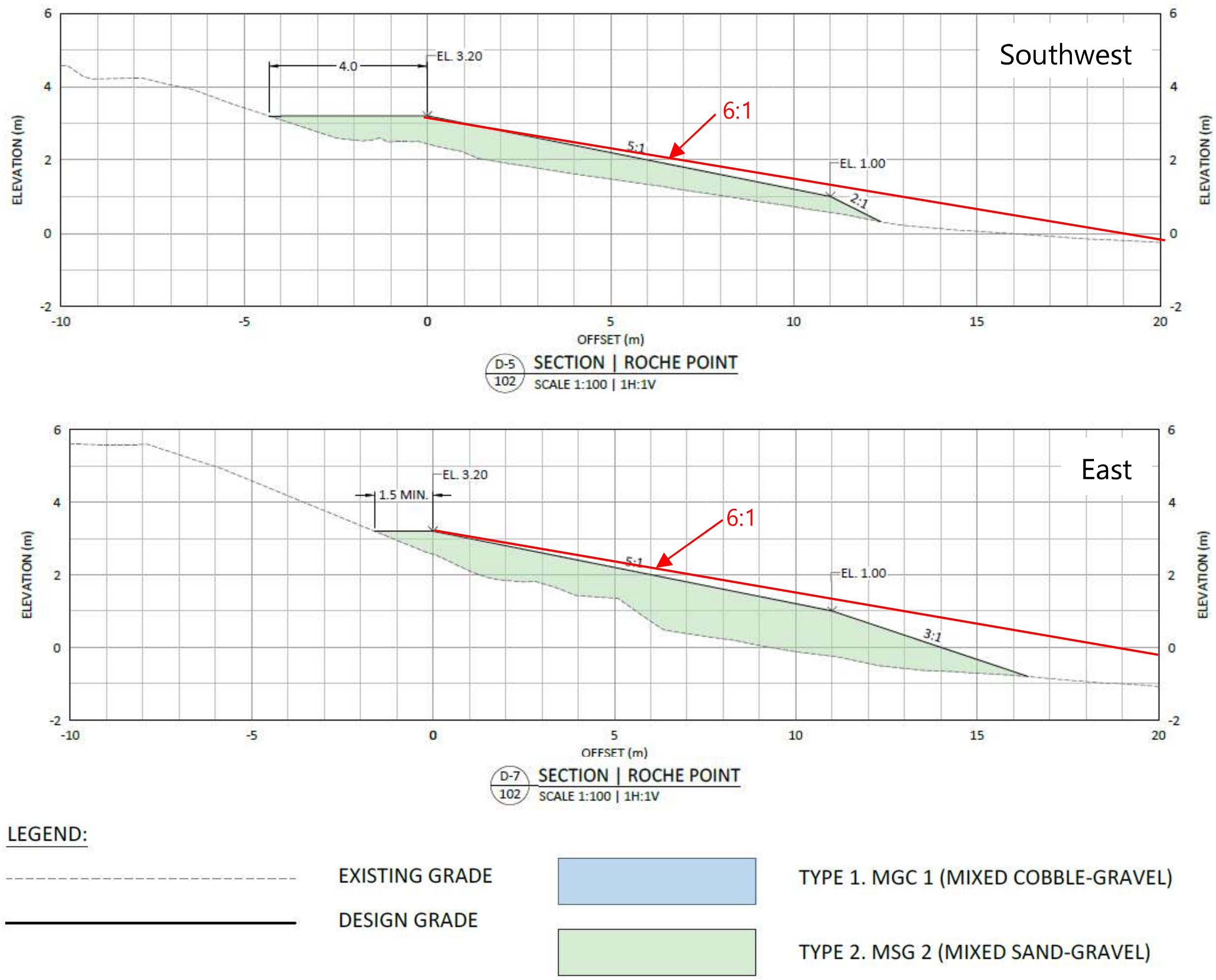

Figure 5.5 XBeach-G 1D sections for Roche Point southwest (top) and east (bottom) design sections. The revised design elements are shown in red.

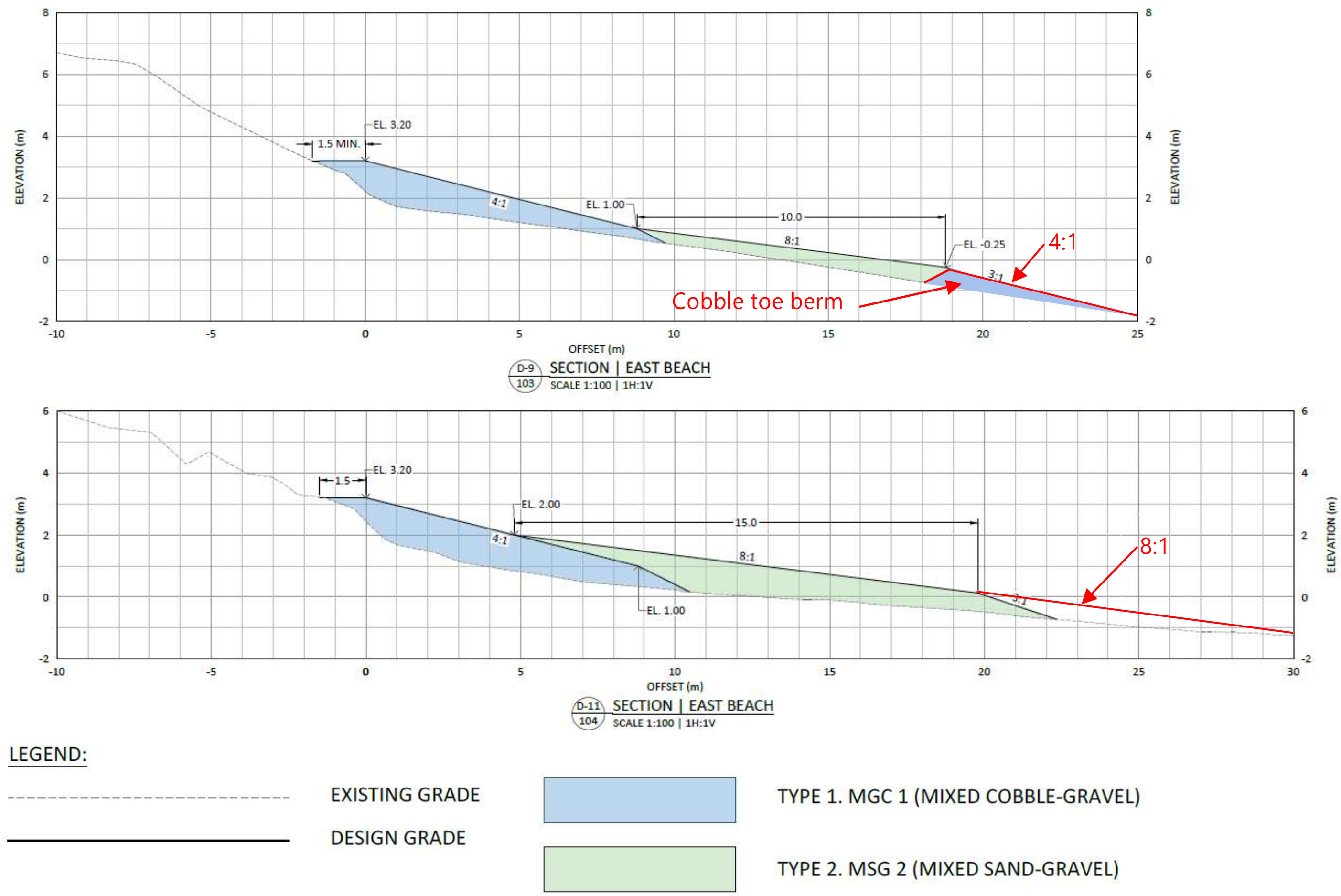

Figure 5.6 XBeach-G 1D sections for East Beach (top) and East Beach – Pocket (bottom) revised design sections. The revised design elements are shown in red.

5.2.1 XBeach-G 1D Model

The revised design sections were run in XBeach-G for the scenarios provided in Table 5.3 for the 5% AEP wave event and the 10% AEP DWL for the present day at Roche Point SW and E section and East Beach; the revised design sections at Roche Point and East Beach are shown in Figure 5.5 and Figure 5.6, respectively. The changes to the design from the IFP Rev. 0 drawings are shown in red. The model was used to assess the impact of the design revisions and check the morphological changes to the beach after the storm event. The model results showing the beach profile before and after the storm event are provided in Appendix D.

Table 5.3 XBeach-G 1D model scenarios for revised design.

Section	Wind/Wave AEP (%)	Hs (m)	Tp (s)	Water Level AEP (%)	Water Level (m CGVD28)	Sediment Type	Results Figure (Appendix D)
Roche Point - SW (D-5)	5	0.8	3.7	10	2.4	MSG2	Figure 13
Roche Point - E (D-7)	5	0.7	2.3	10	2.4	MSG2	Figure 14
East Beach (D-9)	5	0.6	4.0	-	-0.5	MGC2	Figure 15
East Beach – Pocket (D-11)	5	0.6	4.0	-	-0.5	MSG2	Figure 16

The MSG2 beach nourishment at Roche Point is stable for a 6H:1V beach slope for the 5% AEP storm event. Some re-shaping of the beach after exposure to a winter season of storms is still likely, however, the response is expected to be less pronounced given the revised beach configuration. Further modelling of the broader wave climate will be completed in the next phase of the design to estimate re-nourishment volumes and intervals.

The MCG2 grain size distribution for cobble toe at East Beach was determined using XBeach-G to provide a stable *anchor* for the 4H:1V beach toe. The MGC2 cobble sediment D15, D50, and D90 are provided in Table 5.4.

Table 5.4 D15, D50, and D90 for MGC2 for East Beach cobble toe berm.

Sediment Type	D15 (mm)	D50 (mm)	D90 (mm)
MGC2	50	90	200

5.3 XBeach Model Limitations

Key limitations applicable to the XBeach 2D and XBeach-G 1D modelling are summarized as follows:

- The models were run at a single DWL for the duration of the storm event. This is a conservative assumption because the water level will vary over time with the tidal cycle, spreading out the wave energy across the beach profile.
- The models were run for a single design wave event; however, sediment transport occurs over a broad spectrum of wave conditions and the design wave event may not be the critical condition for beach nourishment design. Therefore, additional scenarios will be run in the final design phase to further refine the design and establish re-nourishment intervals.
- The coastal process models do not include vegetation which could result in varying bed friction along the shoreline.
- The model was not verified due to a lack of bed level change data.

The following summarizes the key limitations of the 1D coastal process modelling, along with recommendations for future work that could be carried out to improve the model and results:

- Longshore sediment transport gradients are not included in the XBeach-G 1D model; this may lead to error in the prediction of the cross-shore profile response for coasts with oblique wave forcing. XBeach-G is solved in one dimension and does not account for variations in forcing in the longshore direction and only computes the cross-shore components of sediment transport. Waves with incident angles up to 30 degrees resolve refraction reasonably well; however, incident wave energy may be overestimated for incident angles greater than 30 degrees (McCall, 2015).
- The 1D model does not include effects from variations in bathymetry in the longshore direction and is based on the wave characteristics on the offshore boundary and the angle of the shoreline relative to the mean wave direction. Therefore, refraction and diffraction may not be accurate where the shoreline is not longshore uniform.
- One sediment type was assumed representative of each section to understand a preliminary model-based understanding of sediment transport potential for each design component (ie, cobble berm and MSG2 beach nourishments).

6 DETACHED HEADLAND AND BOULDER CLUSTER DESIGN BASIS

The type 5 Boulders will be used for the detached headlands and smaller boulder clusters at West Beach, Central Beach, East Beach and Little Cates and are designed to be stable under more extreme wave conditions. The purpose of detached headlands and boulder clusters is to dissipate wave energy and protect the sediment placed behind the detached headland from longshore and cross shore transport. The beach nourishments placed behind the headlands and clusters are expected to reshape into small dynamically stable pocket beaches. The detached headlands are designed based on the design water level and offshore wave height discussed in Section 3.6. The stable rock diameter (D_{n50}) and stable rock mass (M_{n50}) was calculated using the methodology according to (Hughes, 2003) for determining stable armour rock size using the wave momentum flux as outlined in the United Sates Army Corps of Engineer Coastal and Hydraulics Engineering Technical Note 71 (CIRIA, CUR, CETMEF, 2007). The boulder gradation was determined using the methods outlined in the Rock Manual (CIRIA, CUR, CETMEF, 2007).

Table 6.1 Design detached headland and boulder cluster type 5 boulder gradations by size.

Classification	D_{n15} (mm)	D_{n50} (mm)	D_{n90} (mm)
Type 4. Boulders by size	320	390	460

Table 6.2 Design detached headland and boulder cluster type 5 boulder gradations by mass.

Classification	M_{n15} (kg)	M_{n50} (kg)	M_{n90} (kg)
Type 4. Boulders by mass	85	155	250

Table 6.3 Design detached headland and boulder cluster type 5 boulder gradations.

Finer by Mass (%)	Mass (kg)
97-100	420
70-100	250
50-90	190
10-50	120
0-10	50
0-2	20

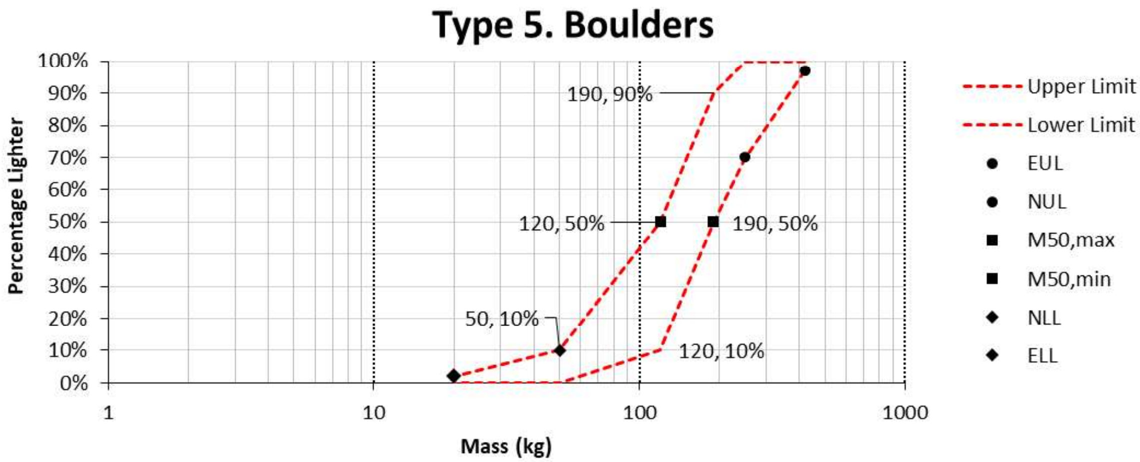

Figure 6.1 Material gradation for the Type 5 Boulders.

7 SHORELINE DESIGN ELEMENTS

The proposed hybrid Nature-based solution (NBS) consists of the following elements: Backshore mixed gravel and cobble berm, detached headlands composed of riprap or boulder clusters, and foreshore nourishments of mixed sand and gravel. Mixed sediments (cobble, gravel, sand) berms, nourishments, boulder clusters and detached headlands are used to attenuate coastal waves by acting as a 'sponge' for wave energy. Mixed sediment berms are intended to be dynamic and reshape over time and exposure to wave action resulting in a stable or equilibrium beach profile and allowing the ongoing natural function of beach processes to occur. Further wave energy dissipation and protection as well as retention of placed sediments can be achieved with appropriate use of detached headlands or boulder clusters and protecting the fringe of nourishment with a cobble apron. A beach nourishment with detached headlands or boulder clusters is likely to be more stable and require less maintenance in comparison to a beach nourishment without the 'grey' elements. The headlands and boulder clusters together with the nourishments are intended to form a series of small dynamically stable pocket beaches in which sediment is retained in place rather than being directly transport offshore and alongshore. Pocket beaches provide habitat and additional recreational space and offset the impact of the offshore energy dissipation structures. The structures also provide habitat in the void spaces between the rock and provide holdfasts for aquatic life and refuge for fish.

The designs are specific to each reach dependent on the topography, orientation of the area, and combination of coastal processes affecting the reach. Below is a description of the design for each reach:

- **West Beach:** the design for West Beach includes backshore protection consisting of MGC1 with a placement of MSG3 along the backshore placement. The three detached headlands and two smaller boulder clusters are intended to reduce wave energy and retain the MSG3 sediments in pocket beaches.

- **Central Beach:** the design for Central Beach includes backshore protection consisting of MGC1 with a placement of MSG3 along most of the backshore placement. The three boulder detached headlands are intended to reduce wave energy and retain the MSG3 sediments creating small pocket beaches.
- **Roche Point:** consists of a beach nourishment of MSG2 with a slope ranging from 6H:1V to 7H:1V. The placement does not extent below the LLWMT level to prevent impacting the habitat in the lower intertidal. The crest width of the placement is 4 m along the west end of Roche Point and part of the east side, reducing to a 0.5 m crest width at the east end of the reach.
- **East Beach:** the design for East Beach includes backshore protection consisting of MGC1 with a placement of MSG3 along most of the backshore placement. Seven small boulder clusters are intended to focus wave energy on headlands and help retain the MSG3 sediments in pocket beaches.
- **Little Cates:** the design for Little Cates includes backshore protection consisting of MGC1 with a placement of MSG3 along most of the backshore placement. Five detached headlands are intended to dissipate wave energy and help retain the MSG3 sediments in a series of pocket beaches.

9 SUMMARY

This report provides the design basis required for developing the restoration concepts for the Whey-ah-Wichen or Cates Park (WaW) shoreline that enhance resilience to climate change using nature-based solutions. NHC provided preliminary design drawings for permitting in November 2024 and a coastal processes report in 2023, which described the geomorphology, sediments, and coastal processes operating at the site. This report is provided in support of the Issued for Permitting (IFP) Revision 1 (Rev. 1) design drawings and specifications provided in Appendix A.

The shoreline restoration design for WaW (Appendix A) includes both beach nourishment and headlands and boulder clusters with beach nourishment. Beach nourishments supply coarse sands and gravel to the areas where erosion is occurring and are considered temporary protection because the nourishment is a sacrificial layer of material that is expected to erode in the long term. Replenishment of a beach nourishment project is considered a maintenance requirement and adds to the overall lifecycle costs of these protection and restoration measures. Headlands and boulder clusters with beach nourishment are likely to be more stable and require less maintenance in comparison to a beach nourishment without headland control structures. Renourishment intervals and volumes will be estimated prior to the Issue for Tender (IFT) package.

Monitoring of the beach after placement is recommended to gain a better understanding of sediment transport processes and provide a more accurate re-nourishment timeline. Some public education on the likely changes to the beach nourishment after a winter season may be beneficial to negate public perception of the project.

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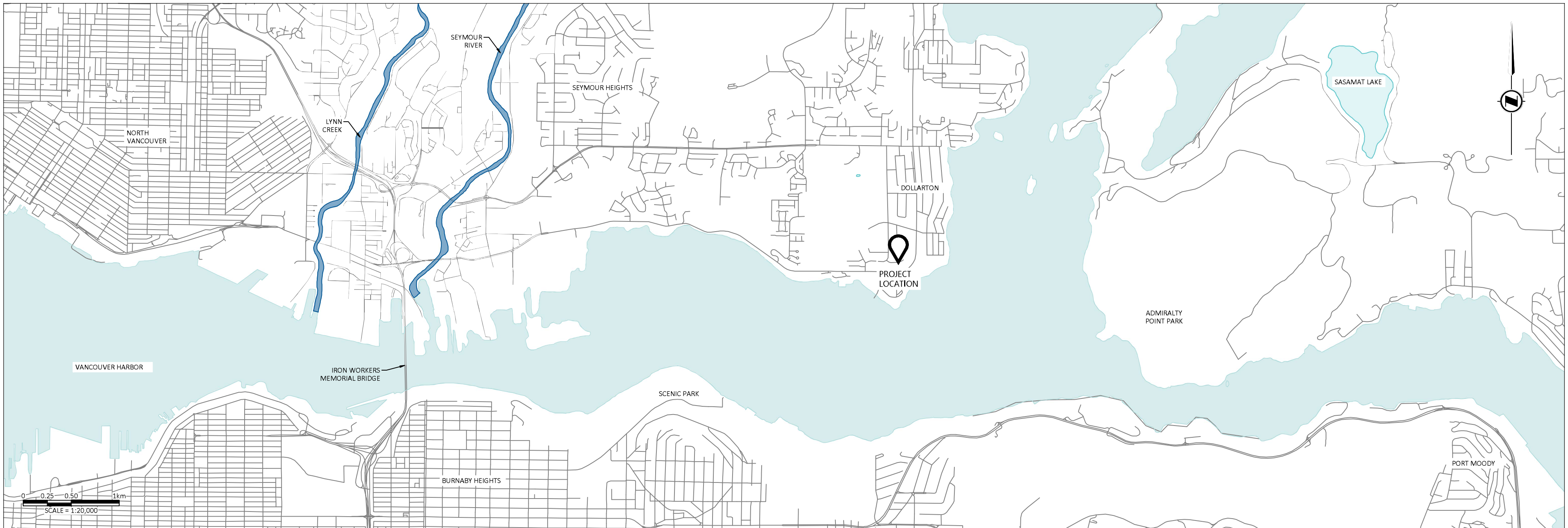
APPENDIX A

ISSUED FOR PERMIT REVISION 1 DRAWINGS



LINEWORK DATA SOURCE: HTTPS://CATALOGUE.DATA.GOV.BC.CA/DATASET

DISTRICT OF NORTH VANCOUVER

CATES PARK SHORELINE RESTORATION

RE-ISSUED FOR PERMITTING, MARCH 2025

DRAWING INDEX	
SHEET No.	SHEET DESCRIPTION
G-0-001	COVER SHEET
G-0-002	NOTES
G-0-003	KEY MAP & SITE OVERVIEW
G-0-004	SITE ACCESS
SITE 1 | WEST BEACH	
C-1-101	PLAN VIEW AND SECTIONS
SITE 2 | CENTRAL BEACH	
C-2-101	PLAN VIEW AND SECTIONS
SITE 3 | ROCHE POINT	
C-3-101	PLAN VIEW
C-3-301	SECTIONS
SITE 4 | EAST BEACH	
C-4-101	PLAN VIEW
C-4-102	PLAN VIEW
C-4-103	PLAN VIEW
C-4-301	SECTIONS
C-4-302	SECTIONS
SITE 5 | LITTLE CATES	
C-5-101	PLAN VIEW
C-5-301	SECTIONS

DISTRICT OF NORTH VANCOUVER

Tsleil-Waututh Nation
PEOPLE OF THE INLET

nhc

NHC PROJECT No. 3008311
REVISION No. 1
SHEET No.
G-0-001

NOTES

1. GENERAL NOTES
   1.1. A COPY OF THE LATEST REVISION OF THE DRAWING SET MUST BE REVIEWED BY THE CONTRACTOR, AND MUST BE PRESENT AT ALL TIMES ON SITE WHILE WORK IS PROCEEDING.
   1.2. WORK SHALL BE PERFORMED IN ACCORDANCE WITH ALL LOCAL, PROVINCIAL, AND FEDERAL REGULATIONS FOR THE PROJECT AREA.
   1.3. REFER TO CONTRACT DOCUMENTS FOR GENERAL NOTES, INCLUDING ENVIRONMENTAL, ARCHAEOLOGICAL, AND ANY OTHER REGULATORY AUTHORITY'S REQUIREMENTS.
   1.4. WORK LIMITS
      1.4.1. THE CONTRACTOR SHALL BE RESPONSIBLE FOR SITE AND TRAFFIC CONTROLS.
      1.4.2. WORK SITE EXTENTS ARE GIVEN ON THE DRAWINGS. THE CONTRACTOR SHALL ALERT THE OWNER'S REPRESENTATIVE ON-SITE OF ANY REQUIRED VARIANCE IN WORK LIMITS REQUIRED FOR EXECUTION OF THE WORK PRIOR TO UNDERTAKING WORK OUTSIDE OF SHOWN LIMITS
   1.5. DIMENSIONS
      1.5.1. ALL ELEVATIONS AND DIMENSIONS ARE IN METERS UNLESS NOTED OTHERWISE.
      1.5.2. COORDINATES ARE IN NAD83 (CSRS), UTM ZONE 10 NORTH.
      1.5.3. ALL ELEVATIONS ARE TO CGVD28. 0 m CGVD28 IS APPROXIMATELY 3.0 m ABOVE 0 m CHART DATUM (CD).
   1.6. DESIGN CRITERIA
      1.6.1. RELATIVE SEA LEVEL RISE (RSLR) FOR THE YEAR 2050 IS 0.6m.
      1.6.2. DESIGN WATER LEVELS (BASED ON CHS DATUM FROM VANCOUVER HARBOUR) ARE SHOWN IN TABLE 1.
   1.7. DESIGN INTENT
      1.7.1. THIS DESIGN IS MEANT TO MITIGATE EROSION OF THE BEACH USING A NATURE-BASED SOLUTION INCLUDING BEACH NOURISHMENT AND HEADLANDS DESIGN. AREAS USING BEACH NOURISHMENT, OR SOFT SHORE APPROACH ARE EXPECTED TO ADJUST FOLLOWING CONSTRUCTION. MONITORING AND ADAPTIVE MANAGEMENT ARE EXPECTED.
      1.7.2. THIS DESIGN IS TO PROTECT AGAINST SHORELINE EROSION, AND FUTURE EROSION DUE TO CLIMATE CHANGE, AND MITIGATE THE POTENTIAL FOR WAVE RUNUP TO DAMAGE NEARBY PARK RECREATIONAL ASSETS. THE DESIGN DOES NOT MITIGATE FLOOD RISK, AS THE BERM AT THE TOP OF BEACH IS PERMEABLE. THIS IS TO ALLOW SURFACE WATER TO DRAIN THROUGH THE BERM. AS IT IS PERMEABLE, IT IS NOT A DIKE, NOR DOES IT FUNCTION AS A DIKE.
   1.8. WORK AREA
      1.8.1. THE WORK AREA IS EXPOSED TO TIDES, WAVES, AND CURRENTS. IT IS THE RESPONSIBILITY OF THE CONTRACTOR TO REVIEW TIDE AND WEATHER FORECASTS AND PLAN THEIR WORK ACCORDINGLY TO MINIMIZE STAND-BY TIME AND DELAYS.
      1.8.2. WATER LEVELS ARE SHOWN IN TABLE 1. WEATHER SYSTEMS MAY CAUSE STORM SURGES THAT INCREASE WATER LEVELS ABOVE ASTRONOMICAL PREDICTIONS.
      1.8.3. AREAS OUTSIDE OF WORK SITE EXTENTS ARE NOT TO BE DISTURBED.
      1.8.4. IT IS THE RESPONSIBILITY OF THE CONTRACTOR TO LOCATE UTILITIES (IF ANY)

2. CONSTRUCTION
   2.1. SURVEY
      2.1.1. THE CONTRACTOR SHALL DEVELOP SURVEY PROCEDURES TO ENSURE THAT WORK IS UNDERTAKEN AS SPECIFIED ON THE DRAWINGS, AND THE REQUIRED ELEVATIONS AND SLOPES ARE ACHIEVED.
      2.1.2. PRE AND POST CONSTRUCTION TRANSECT SURVEYS SHALL BE COMPLETED AT 5 m INTERVALS ALONG THE ALIGNMENT FOR THE PROJECT WORK AREA. IF SURVEY'S ARE UNDERTAKEN BY A 3RD PARTY, THE CONTRACTOR SHALL ALLOW SITE ACCESS FOR SURVEYS AS REQUIRED.
      2.1.3. WORK POINTS SHALL BE STAKED PRIOR TO COMMENCEMENT OF WORK BY CONTRACTOR TO GIVE VISUAL LIMITS ON WORK AREAS.
   2.2. EXECUTION
      2.2.1. PRE AND POST CONSTRUCTION TRANSECT SURVEYS SHALL BE COMPLETED AT 5 m INTERVALS ALONG THE ALIGNMENT FOR THE PROJECT WORK AREA. EACH MATERIAL TYPE SHALL BE SURVEYED AT 5 m INTERVALS ALONG THE ALIGNMENT ONCE PLACEMENT IS COMPLETED.
      2.2.2. THE CONTRACTOR SHALL PLAN THE WORK SO AS TO LIMIT THE FOOTPRINT OF THE WORK SITE ON THE FORESHORE AS MUCH AS REASONABLY POSSIBLE.
      2.2.3. EXISTING BOULDER ARMORING ON THE FORESHORE SHALL BE BURIED BY BEACH NOURISHMENT AND DISTURBANCE TO THE EXISTING SHORELINE MINIMIZED AS MUCH AS POSSIBLE.
      2.2.4. SALVAGE BEACH LOGS (IF ANY) THAT ARE PRESENT IN THE WORK AREA FOR LATER REINSTATEMENT AT THE DIRECTION OF THE ENGINEER.
      2.2.5. EMBEDDED SALVAGE BEACH LOGS THAT CANNOT BE REMOVED WITHOUT EXCAVATION OF BEACH MATERIAL SHALL BE LEFT IN PLACE AND BURIED WITH BEACH MATERIAL.
   2.3. EQUIPMENT
      2.3.1. ALL EQUIPMENT ACCESSING THE BEACH MUST RUN BIODEGRADABLE HYDRAULIC FLUIDS. EQUIPMENT INCLUDES, BUT IS NOT LIMITED TO, EXCAVATORS, ROCK TRUCKS, BACKHOES, AND LOADERS.
      2.3.2. THE CONTRACTOR SHALL NOT RE-FUEL ANY EQUIPMENT WITHIN 15 METERS OF THE SHORELINE.
      2.3.3. SPILL TRAYS BUT BE LOCATED UNDERNEATH HEAVY EQUIPMENT WHILE NOT IN USE.
   2.4. SUBMITTALS
      2.4.1. THE CONTRACTOR SHALL SUBMIT A WORK PLAN TO THE CONTRACT ADMINISTRATOR AT LEAST TWO (2) WEEKS IN ADVANCE OF COMMENCING THE WORK. THE WORK PLAN SHALL SPECIFY: EQUIPMENT TO BE USED ON SITE, NAMES AND CONTACT INFORMATION OF SUPERVISING PERSONNEL, PLAN DESCRIBING HOW MATERIALS ARE TO BE HANDLED AND SORTED ON-SITE, MAP SHOWING HAUL ROUTES OF MATERIALS, AND SCHEDULE FOR THE WORK.
      2.4.2. THE CONTRACTOR SHALL SUBMIT COPIES OF WEIGHT SLIPS FOR MATERIAL BROUGHT TO SITE WITHIN 48 HOURS OF MATERIAL PLACEMENT TO OWNER'S REPRESENTATIVE.

3. MATERIALS
   3.1. SEE TABLE 2 TO TABLE 8 FOR MATERIAL SPECIFICATIONS
   3.2. MATERIALS QUANTITIES
      3.2.1. SEE TABLE 8 FOR MATERIAL QUANTITIES.
      3.2.2. TABULATED ESTIMATES OF VOLUME ARE CLEAN LINE ESTIMATES GENERATED FROM CIVIL 3D SOFTWARE (AUTODESK). ALLOWANCES FOR CLEARING, SETTLEMENT AND/OR LOSS ARE NOT INCLUDED. VARIATION IN ACTUAL MATERIAL QUANTITIES MAY OCCUR DUE TO SITE CONDITIONS AT TIME OF CONSTRUCTION.
      3.1.2. AREA AND MATERIAL VOLUMES AT ROCHE POINT EXCLUDE STAIRS AND SUPPORTING STRUCTURAL FILL. STAIRS AND SUPPORTING STRUCTURAL FILL TO BE DESIGNED BY OTHERS.
   3.2. ALL MATERIALS ARE TO BE NON-PLASTIC, WELL-GRADED, AND COMPOSED OF CLEAN, UN-COATED PARTICLES FREE FROM LUMPS OF CLAY OR OTHER DELETERIOUS MATERIALS.
   3.3. MATERIAL SHALL BE SCREENED TO MEET THE DESIRED GRADATION. MATERIAL SHALL BE STONE OF FLUVIAL OR GLACIAL ORIGIN. FRACTURED MATERIAL WILL NOT BE ACCEPTED.
   3.4. TYPE 5 IS TO BE BLOCKY IN SHAPE, ROUGHLY EQUAL DIMENSIONAL WITH LENGTH NOT MORE THAN 2.4 TIMES THE WIDTH OR THICKNESS AS MEASURED IN THE MIDDLE OF THE STONE.
   3.5. GRADATION FOR TYPE 1, TYPE 2, TYPE 3, TYPE 4 AND TYPE 5 MATERIALS SHALL BE IN ACCORDANCE WITH TABLES 3, 4, 5, 6 AND 7, OR AS APPROVED BY THE ENGINEER.
   3.6. ALL MATERIALS AND/OR ALTERNATIVE MATERIALS SHALL BE REVIEWED AND APPROVED BY THE ENGINEER PRIOR TO INSTALLATION.
   3.7. CONTRACTOR, OR QUARRY, SHALL PROVIDE A COPY OF TEST RESULTS FROM A LOCATION IN THE QUARRY NEAR TO THE SOURCE OF MATERIALS, NO LESS THAN FIVE (5) DAYS PRIOR TO DELIVERY OF MATERIALS. GRADATIONS FOR ALL MATERIALS SHALL BE INCLUDED IN TEST RESULTS.
   3.8. ONLY SUITABLE MATERIALS SHALL BE BROUGHT TO SITE. GRADATION CHECKS SHALL BE PERFORMED ON MATERIALS DEEMED UNSUITABLE BY THE ENGINEER AT THE COST OF THE CONTRACTOR. MATERIALS FAILING THE GRADATION SPECIFICATION CHECK SHALL BE REMOVED AT NO COST TO THE OWNER.
   3.9. IN THE CASE OF A DISPUTE REGARDING THE MATERIAL GRADATION (BY MASS), THE CONTRACTOR SHALL PROVIDE A MEANS TO WEIGHT INDIVIDUAL ROCKS AT SITE AT NO COST TO THE PROJECT TO VERIFY GRADATION

4. MATERIAL PLACEMENT
   4.1. TYPE 1 MGC1, TYPE 2 MSG2, TYPE 3 MSG3 AND TYPE 4 MGC2 MAY BE PLACED IN BULK AND SUBSEQUENTLY TRIMMED TO THE ELEVATIONS, THICKNESS, AND SLOPES AS INDICATED ON THE DRAWINGS
   4.2. TYPE 5 BOULDERS SHALL BE INDIVIDUALLY PLACED TO ENSURE GOOD INTER-LOCKING BETWEEN ADJACENT ROCKS.
   4.3. FINISHED HEADLANDS AND SLOPE PROTECTION STRUCTURE SHALL BE WELL-KEYED AND STABLE, WITH UNIFORM GRADATION OF MATERIAL SIZE THROUGHOUT STRUCTURES. REMOVE AND REPLACE ANY PORTIONS IN WHICH MATERIALS ARE SEGREGATED IN SIZE OR POORLY INTER-LOCKED.

5. ACCURACY
   5.1. INFORMATION SHOWN ON DRAWINGS IS RELATIVE TO EXISTING CONDITIONS AND IS PROVIDED AT THE BEST PRESENT KNOWLEDGE, BUT WITHOUT GUARANTEE OF ACCURACY. WHERE CONDITIONS CONFLICT WITH THE DRAWINGS, SUCH DISCREPANCIES SHALL BE REPORTED TO THE ENGINEER.

TABLE 1. DESIGN WATER LEVELS

DESCRIPTION	ABBREVIATION	ELEVATION (m, CGVD28)	ELEVATION (m, CD)
HIGHER HIGH WATER LARGE TIDE	HHWLT	2.0	5.0
HIGHER HIGH WATER MEAN TIDE	HHWMT	1.5	4.5
MEAN WATER LEVEL	MWL	0.1	3.1
LOWER LOW WATER MEAN TIDE	LLWMT	-1.8	1.2
LOWER LOW WATER LARGE TIDE	LLWLT	-2.9	0.1

TABLE 2. MATERIAL TYPES AND PRELIMINARY DESCRIPTION

MATERIAL TYPE	TARGET D50 (mm)	DESCRIPTION
TYPE 1. MIXED GRAVEL-COBBLE (MGC 1)	50	2-INCH MINUS COBBLE WITH COARSE TO MEDIUM GRAVEL BASE (ROUNDED)
TYPE 2. MIXED SAND-GRAVEL (MSG 2)	10	MEDIUM TO FINE PEBBLES (ROUNDED GRAVEL) WITH COARSE SAND BASE
TYPE 3. MIXED SAND-GRAVEL (MSG 3)	1.2	FINE (PEA) GRAVEL WITH MEDIUM SAND BASE
TYPE 4. MIXED GRAVEL-COBBLE (MGC2)	90	3.5 INCH MINUS COBBLE WITH VERY COARSE GRAVEL (ROUNDED)
TYPE 5. BOULDERS	500	GOOD QUALITY WIDELY GRADED ROCK

TABLE 3. TYPE 1 MIXED GRAVEL-COBBLE (MGC1) GRADATION

PERCENT PASSING (%)	AVERAGE DIAMETER (mm)
90	200
50	50
15	10

TABLE 4. TYPE 2 MIXED SAND-GRAVEL(MSG2) GRADATION

PERCENT PASSING (%)	AVERAGE DIAMETER (mm)
90	22
50	10
15	1

TABLE 5. TYPE 3 MIXED SAND-GRAVEL (MSG3) GRADATION

PERCENT PASSING (%)	AVERAGE DIAMETER (mm)
90	13
50	1.2
15	0.7

TABLE 6. TYPE 4 MIXED GRAVEL-COBBLE (MGC2) GRADATION

PERCENT PASSING (%)	AVERAGE DIAMETER (mm)
90	200
50	90
15	50

TABLE 7. TYPE 5 BOULDERS GRADATION

PERCENT PASSING (%)	AVERAGE DIAMETER (mm)	AVERAGE MASS (kg)
90	460	250
50	390	155
15	320	85

TABLE 8. MATERIALS AND QUANTITIES BY REACH

REACH	DESCRIPTION	VOLUME (m^3)
WEST BEACH	TYPE 1. MGC 1	2,430
	TYPE 2. MSG 2	1,770
	TYPE 5. BOULDERS	380
CENTRAL BEACH	TYPE 1. MGC 1	920
	TYPE 3. MSG 3	890
	TYPE 5. BOULDERS	250
ROCHE POINT	TYPE 2. MSG 2	5,710
EAST BEACH	TYPE 1. MGC 1	5,520
	TYPE 2. MSG 2	3,620
	TYPE 4. MGC 2	660
	TYPE 5. BOULDERS	820
LITTLE CATES	TYPE 1. MGC 1	1,680
	TYPE 3. MSG 3	800
	TYPE 5. BOULDERS	540

TABLE 9. DESIGN AREA BY REACH

REACH	AREA (Ha)	AREA (m^2)
WEST BEACH	0.41	4,130
CENTRAL BEACH	0.19	1,860
ROCHE POINT	0.68	6,760
EAST BEACH	1.23	12,324
LITTLE CATES	0.44	4,430

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1	RE-ISSUED FOR PERMITTING	2025-03-31	P. OSBORNE	R. CLARK	P. OSBORNE
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CATES PARK SHORELINE RESTORATION

NOTES

NHC PROJECT No.
3008311

COORD SYS. AND DATUM
HORIZ: UTM NAD83 ZONE 10
VERT: CGVD28

SHEET No.
G-0-002

GENERAL NOTES:
1. IMAGE SOURCE:
   1.1. SPITFIRE DRONES (2023-08-30)
   1.2. ESRI OPEN SOURCE AERIAL IMAGERY (DATE UNKNOWN, RECEIVED 2024-03-20)

KEY MAP & SITE OVERVIEW
SCALE 1:1,500

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1	RE-ISSUED FOR PERMITTING	2025-03-31	P. OSBORNE	R. CLARK	P. OSBORNE
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V7H 2V6

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KEY MAP & SITE OVERVIEW

NHC PROJECT No.
3008311

COORD SYS. AND DATUM
HORIZ: UTM NAD83 ZONE 10
VERT: CGVD28

SHEET No.
G-0-003

SITE ACCESS
SCALE 1:2,000

GENERAL NOTES:
1. IMAGE SOURCE:
   1.1. SPITFIRE DRONES (2023-08-30)
   1.2. ESRI OPEN SOURCE AERIAL IMAGERY (DATE UNKNOWN, RECEIVED 2024-03-20)

LEGEND:
- SITE ACCESS AND LAYDOWN
- DESIGN FOOTPRINT
- SENSITIVE HABITAT AREAS

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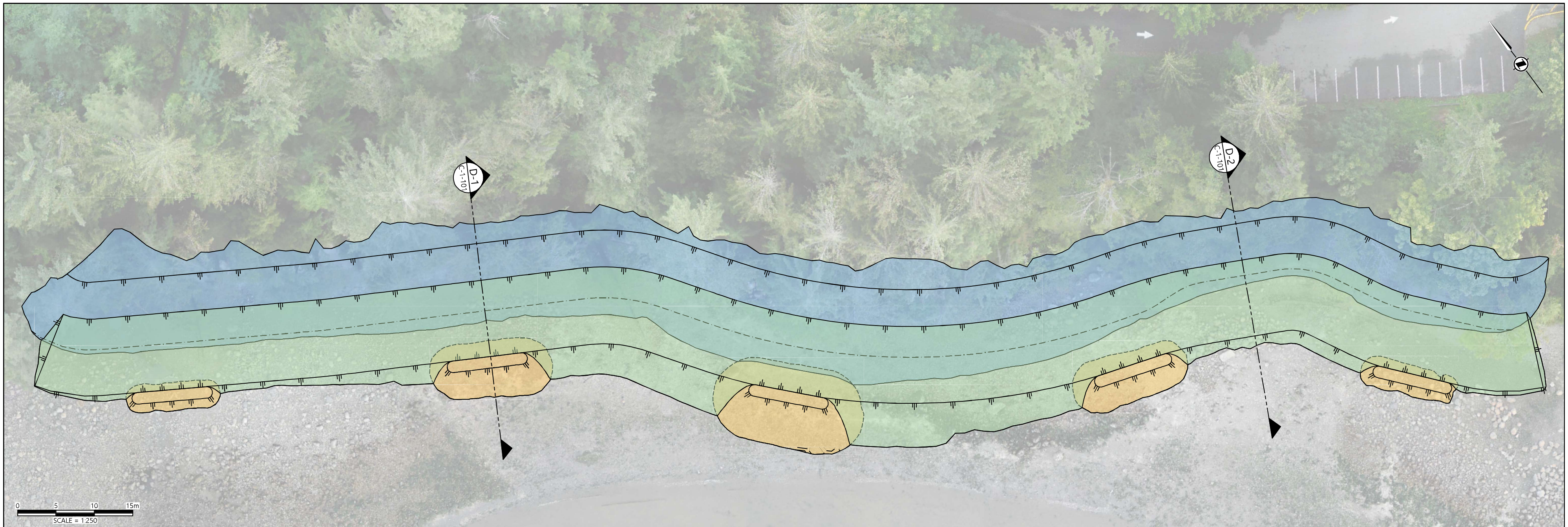
SITE ACCESS

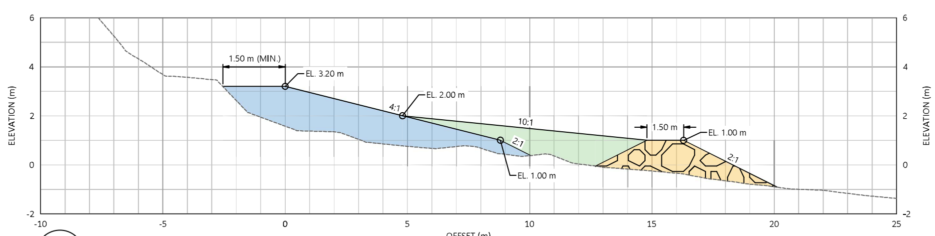
NHC PROJECT No. 3008311

COORD SYS. AND DATUM
HORIZ: UTM NAD83 ZONE 10
VERT: CGVD28

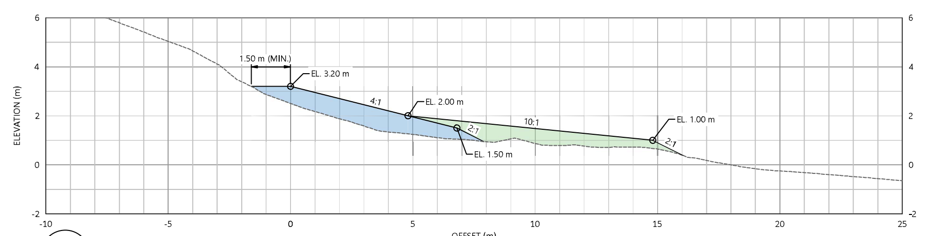
SHEET No.
G-0-004



PLAN VIEW | WEST BEACH
SCALE 1:250



D-1 C-1-101 SECTION | WEST BEACH
SCALE 1:100 | 1H:1V



D-2 C-1-101 SECTION | WEST BEACH
SCALE 1:100 | 1H:1V

LEGEND:

- DESIGN LINEWORK
- GRADE BREAK
- TOP OF SLOPE
- EXISTING GRADE
- TYPE 1. MGC 1 (MIXED COBBLE-GRAVEL)
- TYPE 2. MSG 2 (MIXED SAND-GRAVEL)
- TYPE 5. BOULDERS

GENERAL NOTES:
1. IMAGE SOURCE: SPITFIRE DRONES (2023-08-30)
2. COORDINATE SYSTEM:
   - 2.1. PROJECTION: UTM ZONE 10
   - 2.2. HORIZONTAL DATUM: NAD83(CSRS) 4.0.0 BC.1.MVRD
   - 2.3. VERTICAL DATUM: CGVD28GVRD2018
   - 2.4. GEOID: GVRD00

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REV	DESCRIPTION	DATE	DESIGNER	DRAWN BY	APPROVED
1	RE-ISSUED FOR PERMITTING	2025-03-31	P. OSBORNE	R. CLARK	P. OSBORNE
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NORTH VANCOUVER, B.C.
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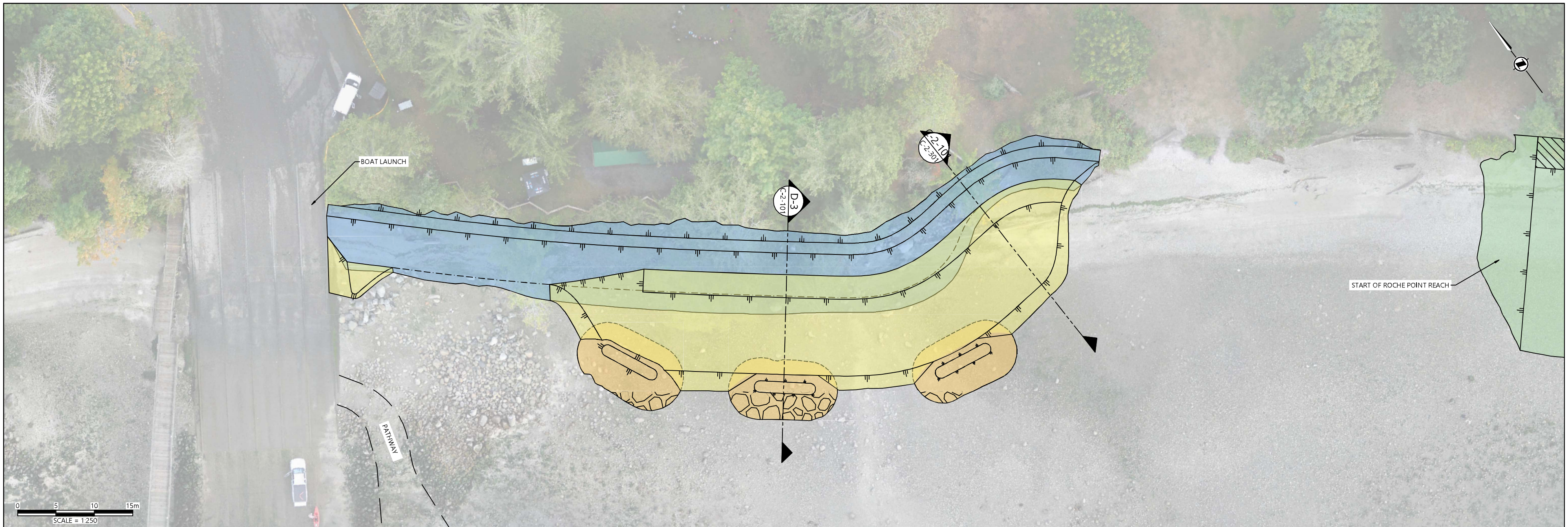
SITE 1 | WEST BEACH
PLAN VIEW

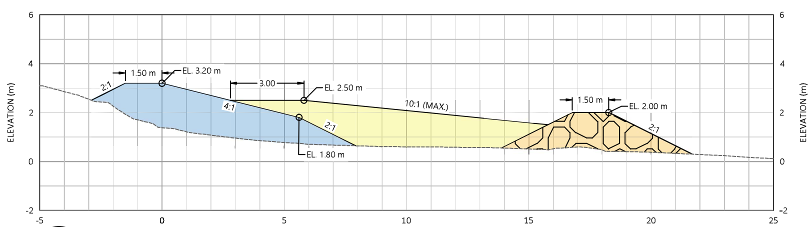
NHC PROJECT No.
3008311

COORD SYS. AND DATUM
HORIZ: UTM NAD83 ZONE 10
VERT: CGVD28

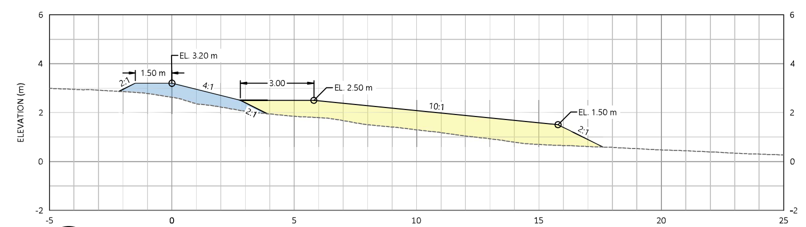
SHEET No.
C-1-101



PLAN VIEW | CENTRAL BEACH
SCALE 1:250



D-3 C-2-101 SECTION | CENTRAL BEACH
SCALE 1:100 | 1H:1V



D-4 C-2-101 SECTION | CENTRAL BEACH
SCALE 1:100 | 1H:1V

GENERAL NOTES:
1. IMAGE SOURCE: SPITFIRE DRONES (2023-08-30)
2. COORDINATE SYSTEM:
 2.1. PROJECTION: UTM ZONE 10
 2.2. HORIZONTAL DATUM: NAD83(CSRS) 4.0.0 BC.1.MVRD
 2.3. VERTICAL DATUM: CGVD28GVRD2018
 2.4. GEOID: GVRD00

NOT FOR CONSTRUCTION

LEGEND:

- DESIGN LINEWORK
- GRADE BREAK
- TOP OF SLOPE
- EXISTING GRADE
- TYPE 1. MGC 1 (MIXED COBBLE-GRAVEL)
- TYPE 3. MSG 3 (MIXED SAND-GRAVEL)
- TYPE 5. BOULDERS

DRAWING REVISION SCHEDULE

REV	DESCRIPTION	DATE	DESIGNER	DRAWN BY	APPROVED
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SITE 2 | CENTRAL BEACH
PLAN VIEW AND TYPICAL SECTIONS

NHC PROJECT No. 3008311
COORD SYS. AND DATUM
HORIZ: UTM NAD83 ZONE 10
VERT: CGVD28

SHEET No. C-2-101

PLAN VIEW | ROCHE POINT

SCALE 1:250

GENERAL NOTES:
1. IMAGE SOURCE: SPITFIRE DRONES (2023-08-30)
2. COORDINATE SYSTEM:
   - 2.1. PROJECTION: UTM ZONE 10
   - 2.2. HORIZONTAL DATUM: NAD83(CSRS) 4.0.0 BC.1.MVRD
   - 2.3. VERTICAL DATUM: CGVD28GVRD2018
   - 2.4. GEOID: GVRD00

NOT FOR CONSTRUCTION

LEGEND:
- DESIGN LINEWORK
- GRADE BREAK
- TOP OF SLOPE
- TYPE 2: MSG 2 (MIXED SAND-GRAVEL)

DRAWING REVISION SCHEDULE

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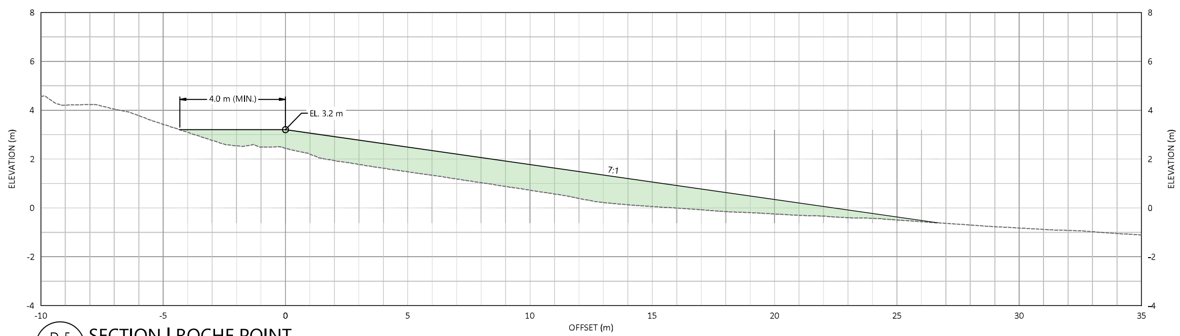
SITE 3 | ROCHE POINT
PLAN VIEW

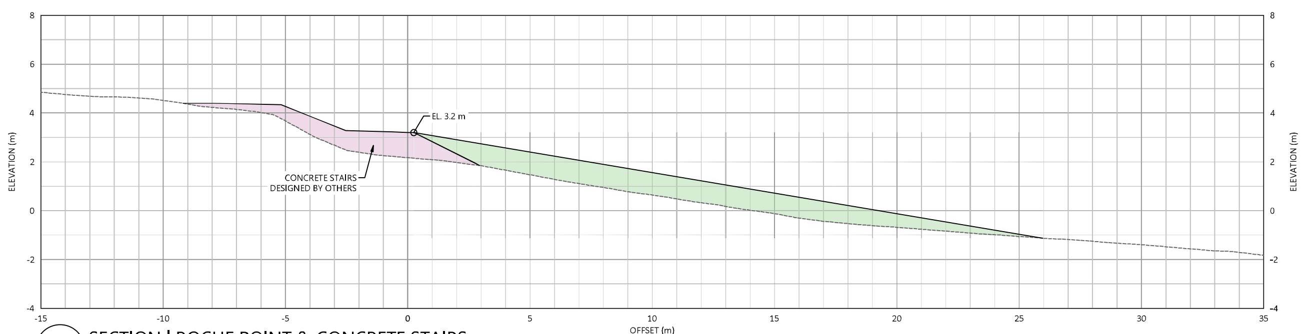
NHC PROJECT No.
3008311

COORD SYS. AND DATUM
HORIZ: UTM NAD83 ZONE 10
VERT: CGVD28

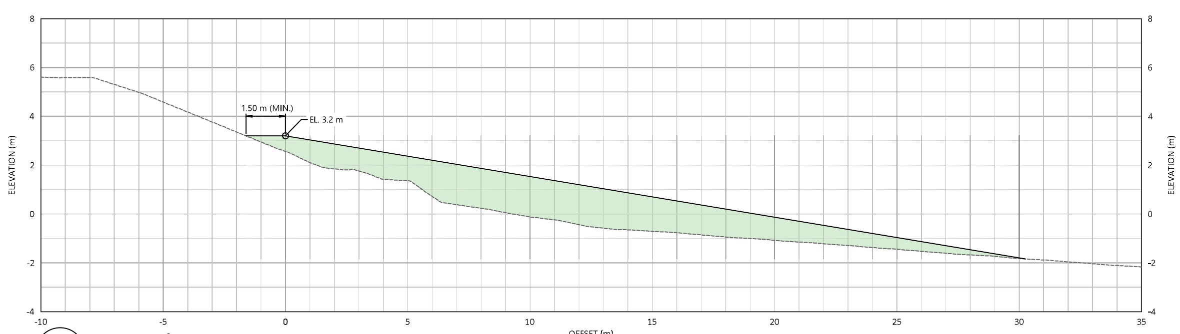
SHEET No.
C-3-101



D-5 C-3-101 SECTION | ROCHE POINT
SCALE 1:100 | 1H:1V



D-6 C-3-101 SECTION | ROCHE POINT & CONCRETE STAIRS
SCALE 1:100 | 1H:1V



D-7 C-3-101 SECTION | ROCHE POINT
SCALE 1:100 | 1H:1V

NOT FOR CONSTRUCTION

LEGEND:

- EXISTING GRADE
- DESIGN GRADE
- DESIGNED BY OTHERS
- TYPE 2. MSG 2 (MIXED SAND-GRAVEL)

DRAWING REVISION SCHEDULE

REV	DESCRIPTION	DATE	DESIGNER	DRAWN BY	APPROVED
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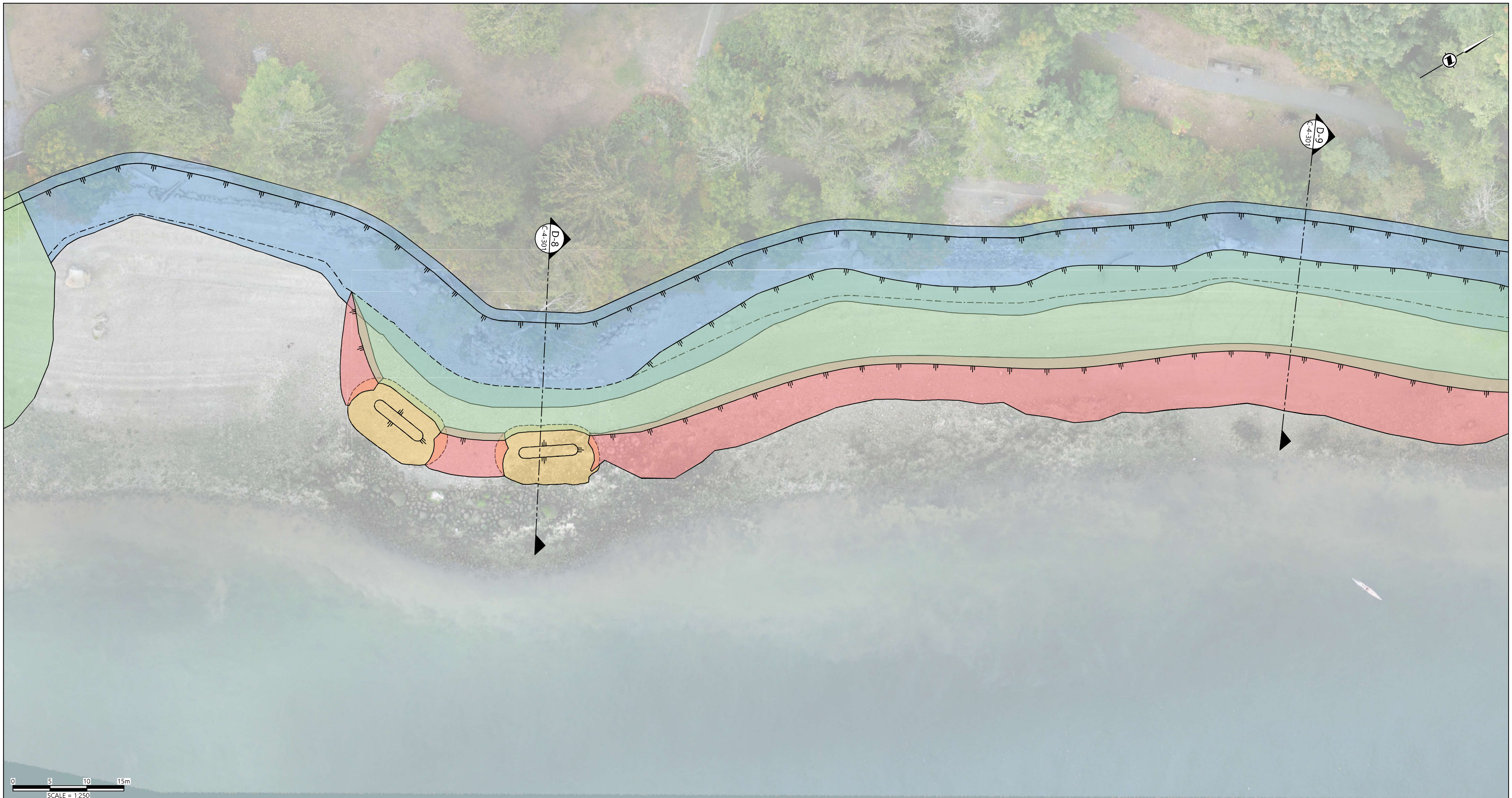
SITE 3 | ROCHE POINT
TYPICAL SECTIONS

NHC PROJECT No. 3008311

COORD SYS. AND DATUM
HORIZ: UTM NAD83 ZONE 10
VERT: CGVD28

SHEET No.
C-3-301



PLAN VIEW | EAST BEACH
SCALE 1:250

LEGEND:

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GRADE BREAK	TYPE 2. MSG 2 (MIXED SAND-GRAVEL)
TOP OF SLOPE	TYPE 4. COBBLE
	TYPE 5. BOULDERS

GENERAL NOTES:
1. IMAGE SOURCE: SPITFIRE DRONES (2023-08-30)
2. COORDINATE SYSTEM:
   - 2.1. PROJECTION: UTM ZONE 10
   - 2.2. HORIZONTAL DATUM: NAD83(CSRS) 4.0.0 BC.1.MVRD
   - 2.3. VERTICAL DATUM: CGVD28GVRD2018
   - 2.4. GEOID: GVRD00

NOT FOR CONSTRUCTION

DRAWING REVISION SCHEDULE

REV	DESCRIPTION	DATE	DESIGNER	DRAWN BY	APPROVED
1	RE-ISSUED FOR PERMITTING	2025-03-31	P. OSBORNE	R. CLARK	P. OSBORNE
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PEOPLE OF THE INLET

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NORTH VANCOUVER, B.C.
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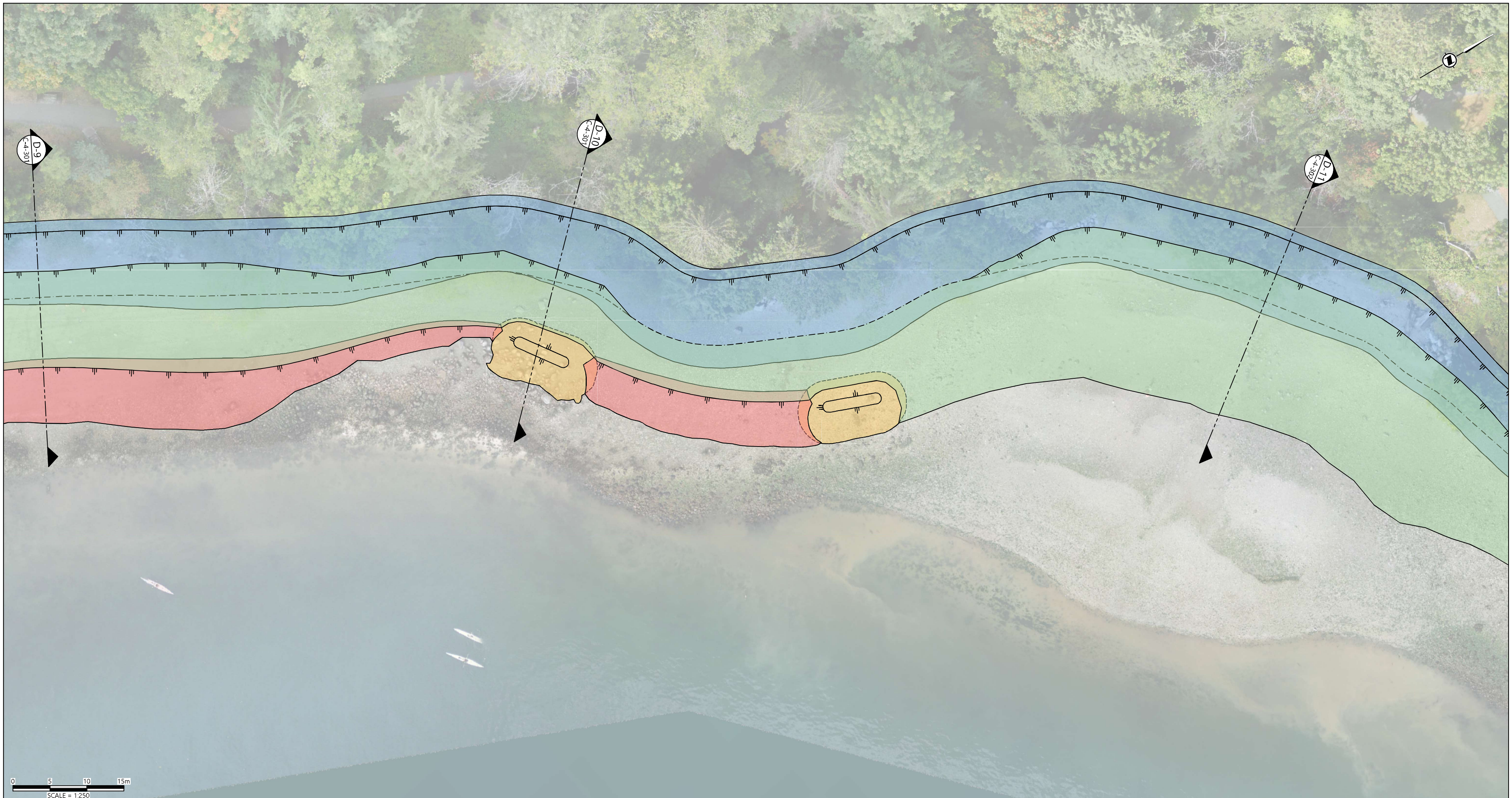
SITE 4 | EAST BEACH
PLAN VIEW

NHC PROJECT No.
3008311

COORD SYS. AND DATUM
HORIZ: UTM NAD83 ZONE 10
VERT: CGVD28

SHEET No.
C-4-101



PLAN VIEW | EAST BEACH
SCALE 1:250

LEGEND:

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(green)	TYPE 2. MSG 2 (MIXED SAND-GRAVEL)
(red)	TYPE 4. COBBLE
(yellow)	TYPE 5. BOULDERS

GENERAL NOTES:
1. IMAGE SOURCE: SPITFIRE DRONES (2023-08-30)
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   2.2. HORIZONTAL DATUM: NAD83(CSRS) 4.0.0 BC.1.MVRD
   2.3. VERTICAL DATUM: CGVD28GVRD2018
   2.4. GEOID: GVRD00

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SITE 4 | EAST BEACH
PLAN VIEW

NHC PROJECT No.
3008311

COORD SYS. AND DATUM
HORIZ: UTM NAD83 ZONE 10
VERT: CGVD28

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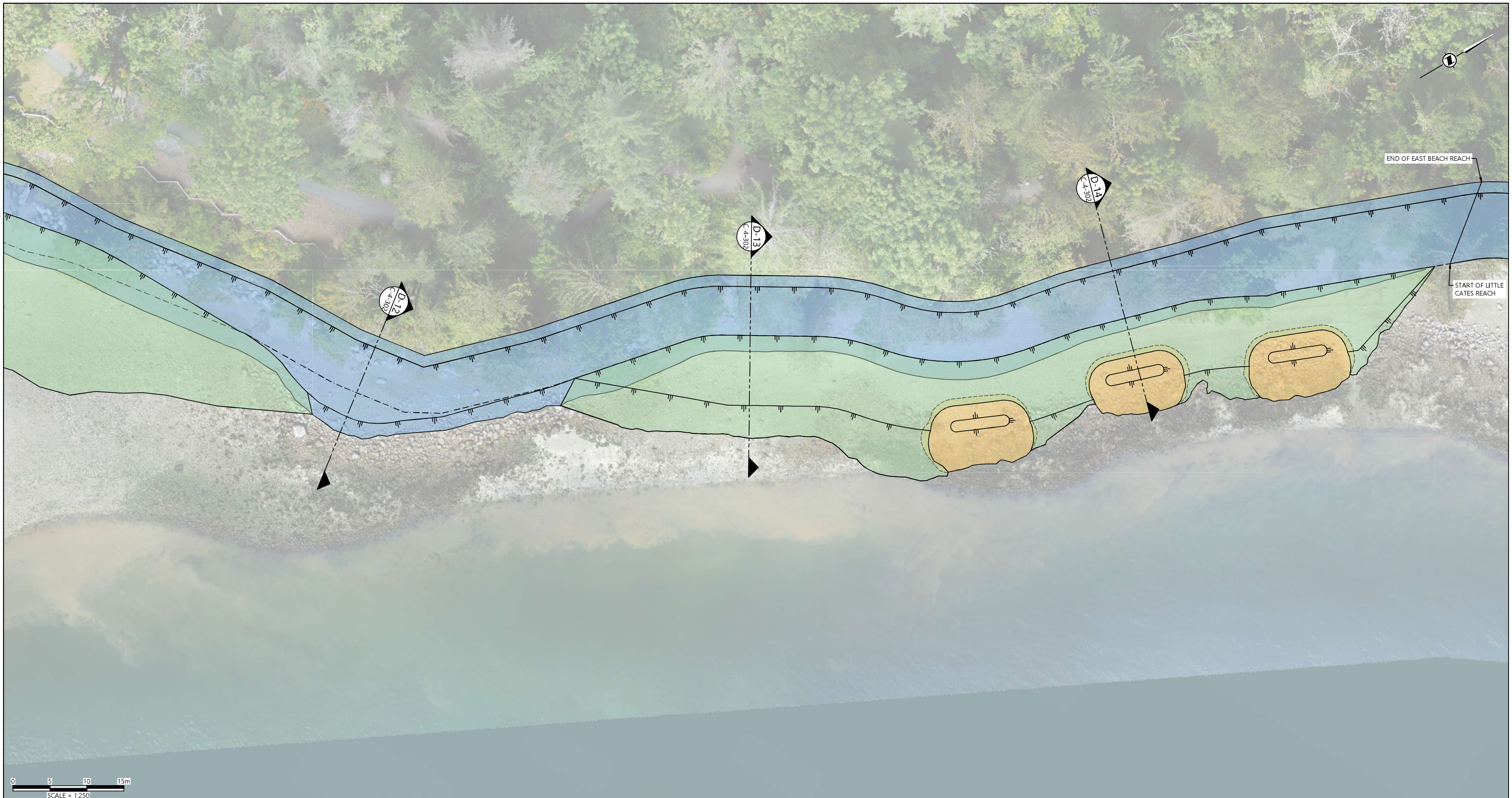

PLAN VIEW | EAST BEACH
SCALE 1:250

GENERAL NOTES:
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2. COORDINATE SYSTEM:
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   2.3. VERTICAL DATUM: CGVD28GVRD2018
   2.4. GEOID: GVRD00

LEGEND:

DESIGN LINEWORK	TYPE 1. MGC 1 (MIXED COBBLE-GRAVEL)
GRADE BREAK	TYPE 2. MSG 2 (MIXED SAND-GRAVEL)
TOP OF SLOPE	TYPE 4. COBBLE
	TYPE 5. BOULDERS

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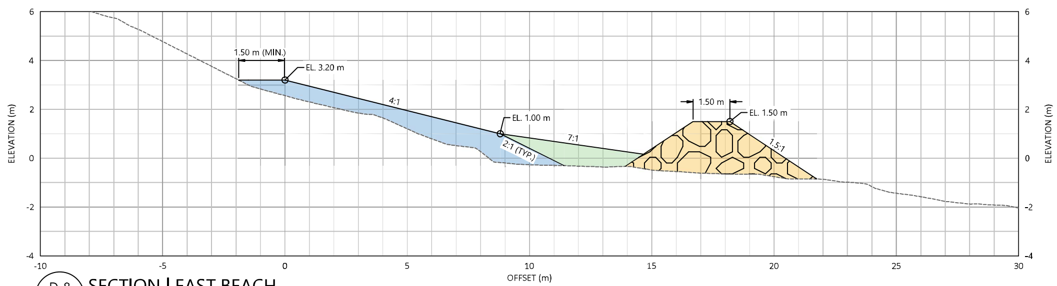
SITE 4 | EAST BEACH
PLAN VIEW

NHC PROJECT No.
3008311

COORD SYS. AND DATUM
HORIZ: UTM NAD83 ZONE 10
VERT: CGVD28

SHEET No.
C-4-103



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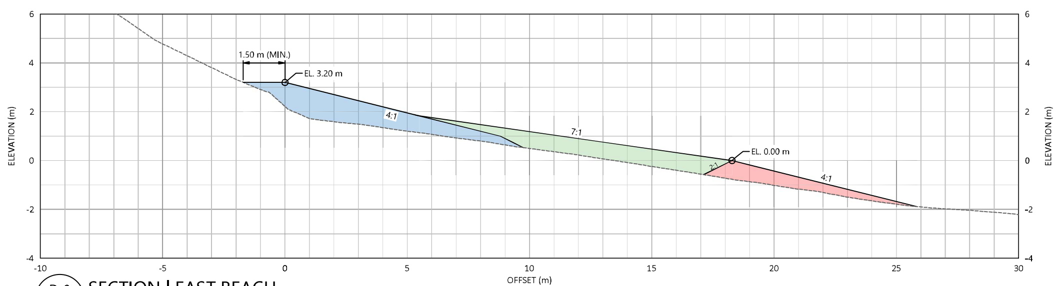

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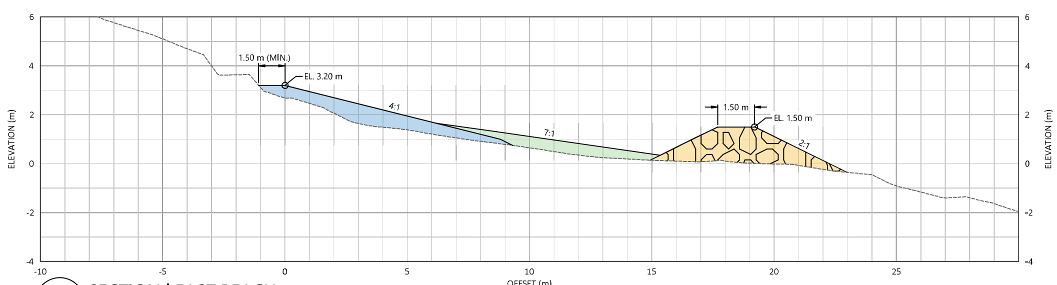

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DESIGN GRADE
TYPE 1. MGC 1 (MIXED COBBLE-GRAVEL)
TYPE 2. MSG 2 (MIXED SAND-GRAVEL)
TYPE 4. COBBLE
TYPE 5. BOULDERS

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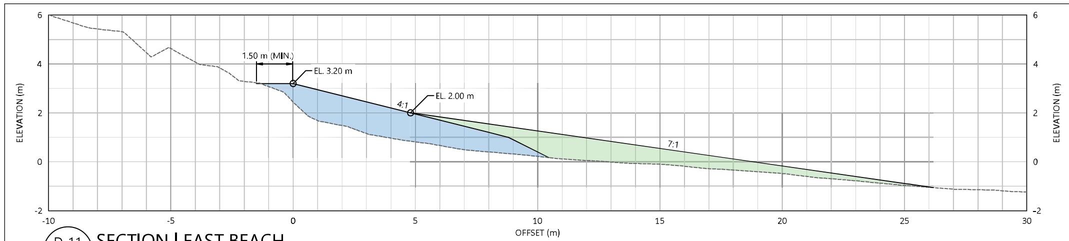
SITE 4 | EAST BEACH
TYPICAL SECTIONS

NHC PROJECT No. 3008311

COORD SYS. AND DATUM
HORIZ: UTM NAD83 ZONE 10
VERT: CGVD28

SHEET No.
C-4-301



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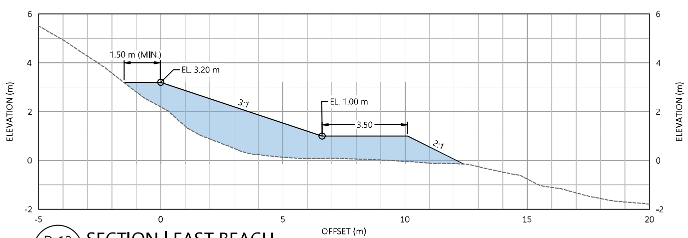

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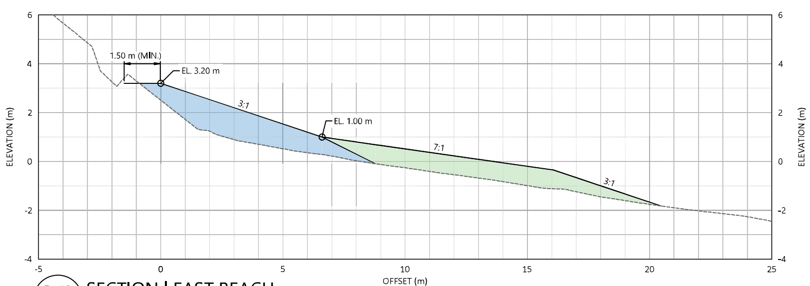

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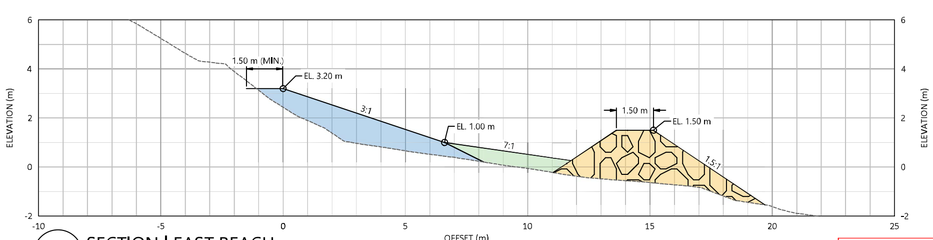

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NOT FOR CONSTRUCTION

LEGEND:

EXISTING GRADE
DESIGN GRADE
TYPE 1. MGC 1 (MIXED COBBLE-GRAVEL)
TYPE 2. MSG 2 (MIXED SAND-GRAVEL)
TYPE 4. COBBLE
TYPE 5. BOULDERS

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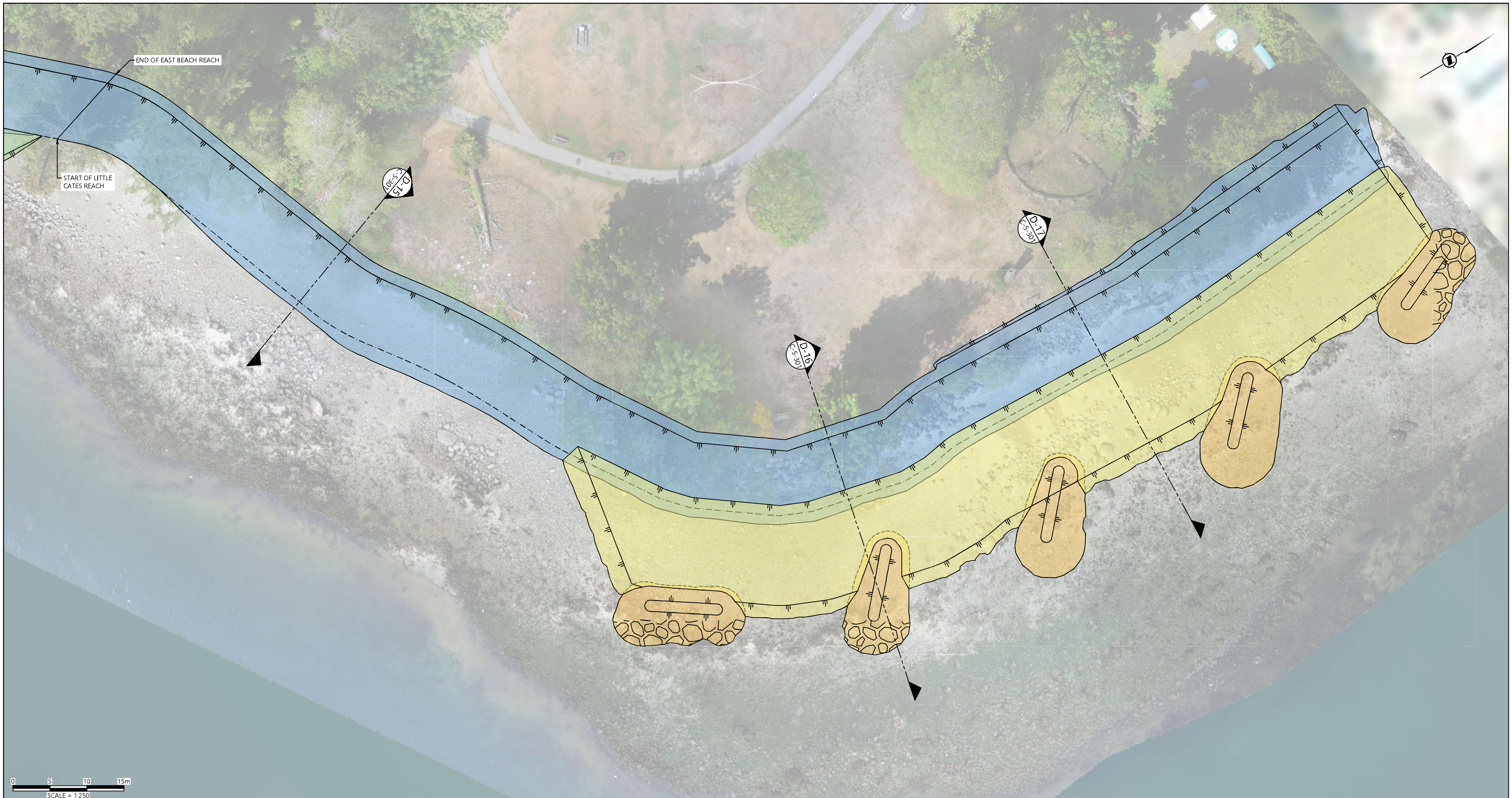
SITE 4 | EAST BEACH
TYPICAL SECTIONS

NHC PROJECT No.
3008311

COORD SYS. AND DATUM
HORIZ: UTM NAD83 ZONE 10
VERT: CGVD28

SHEET No.
C-4-302



PLAN VIEW | LITTLE CATES
SCALE 1:250

LEGEND:

DESIGN LINEWORK	TYPE 1. MGC 1 (MIXED COBBLE-GRAVEL)
GRADE BREAK	TYPE 3. MSG 3 (MIXED SAND-GRAVEL)
TOP OF SLOPE	TYPE 5. BOULDERS

GENERAL NOTES:
1. IMAGE SOURCE: SPITFIRE DRONES (2023-08-30)
2. COORDINATE SYSTEM:
   - 2.1. PROJECTION: UTM ZONE 10
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   - 2.4. GEOID: GVRD00

NOT FOR CONSTRUCTION

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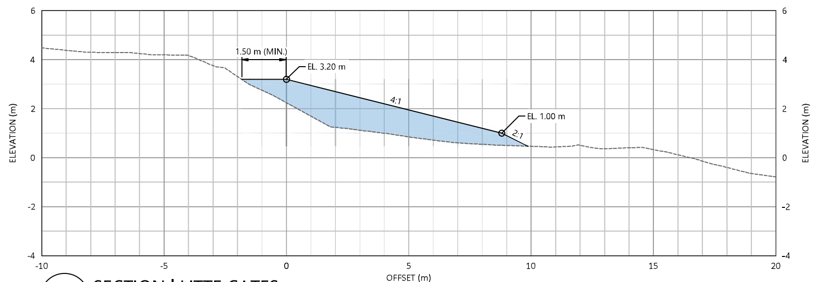
SITE 5 | LITTLE CATES
PLAN VIEW

NHC PROJECT No.
3008311

COORD SYS. AND DATUM
HORIZ: UTM NAD83 ZONE 10
VERT: CGVD28

SHEET No.
C-5-101



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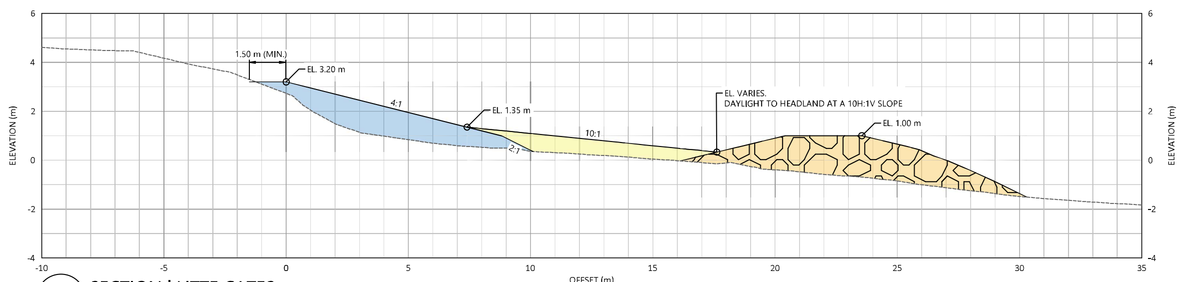

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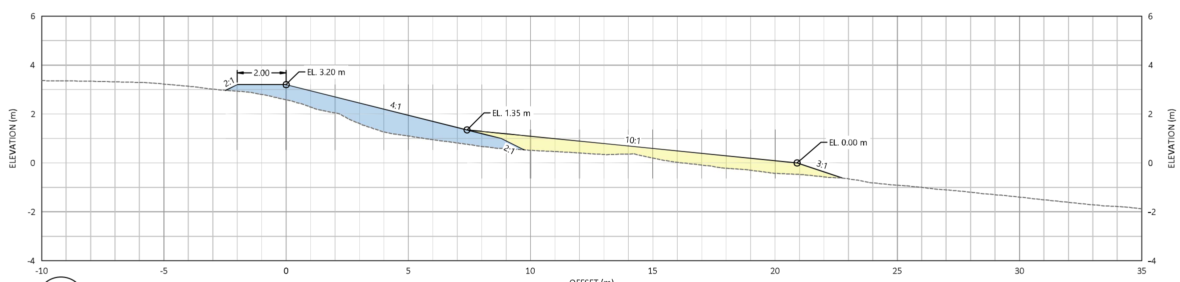

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TYPE 3. MSG 3 (MIXED SAND-GRAVEL)
TYPE 5. BOULDERS

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3178 ALDER COURT
NORTH VANCOUVER, B.C.
V7H 2V6

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SITE 5 | LITTLE CATES
TYPICAL SECTIONS

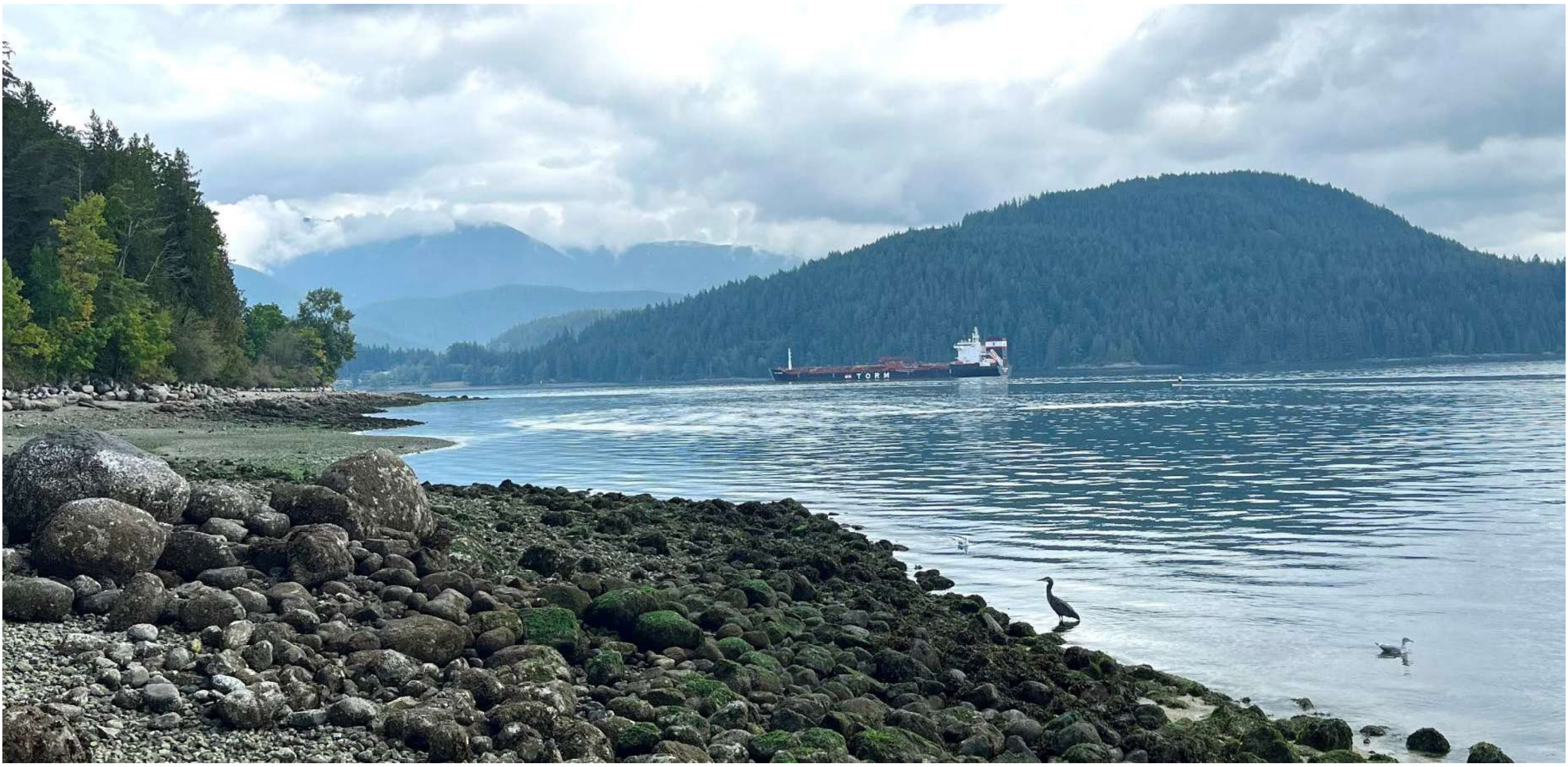
NHC PROJECT No.
3008311

COORD SYS. AND DATUM
HORIZ: UTM NAD83 ZONE 10
VERT: CGVD28

SHEET No.
C-5-301

APPENDIX B

COASTAL PROCESSES ASSESSMENT (NHC, 2023)



Cates Park/Whey-Ah-Wichen Shoreline Restoration Plan
Coastal Processes Report

Prepared by:

Northwest Hydraulic Consultants Ltd.
30 Gostick Place
North Vancouver, BC V7M 3G3
Tel: (604) 980-6011
www.nhcweb.com

NHC Project Contact:
Neville Berard, MASc, PEng
Coastal Engineer

Prepared for:

District of North Vancouver
355 West Queens Road
North Vancouver, BC
V7N 4N5

December 20, 2023
Final Report, Rev. R1

NHC Reference 3008311

Document Tracking

Date	Revision No.	Reviewer	Issued for
October 23, 2023	0	Neville Berard, Phil Osborne	Client Review
December 20, 2023	1	Neville Berard, Phil Osborne	Use

nhc

Report prepared by:

Kate Lappan, EIT
Coastal Engineer

Pauline Martens, MSc, AAg
Coastal Geomorphologist

Report reviewed by:

PROFESSIONAL
PROVINCE OF
N. A. BERARD
47849
BRITISH COLUMBIA
ENGINEER

Dec 20, 2023

Neville Berard, MASc, PEng
Coastal Engineer

Phil Osborne, PhD, PGeo
Coastal Geomorphologist

EGBC Permit to Practice Number: 1003221

DISCLAIMER

This report has been prepared by Northwest Hydraulic Consultants Ltd. for the benefit of District of North Vancouver for specific application to the Cates Park/Whey-Ah-Wichen Shoreline Restoration Plan. The information and data contained herein represent Northwest Hydraulic Consultants Ltd. best professional judgment in light of the knowledge and information available to Northwest Hydraulic Consultants Ltd. at the time of preparation and was prepared in accordance with generally accepted engineering and geoscience practices.

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TABLE OF CONTENTS

APPENDICES

LIST OF TABLES IN TEXT

LIST OF FIGURES IN TEXT

ABBREVIATIONS

Acronym / Abbreviation	Definition
AEP	Annual exceedance probability
AIS	Automated identification system
BC MOE	British Columbia Ministry of Environment
CD	Chart Datum
CGVD2013	Canadian Geodetic Vertical Datum of 2013
CGVD28	Canadian Geodetic Vertical Datum of 1928
CHS	Canadian Hydrographic Service
DEM	Digital elevation model
DNV	District of North Vancouver
DWL	Design water level
ECCC	Environment and Climate Change Canada
EST	Empirical simulation technique
EVA	Extreme value analysis
GPS	Global positioning system
IPCC	Intergovernmental panel on climate change
H	Wave height
H_{max}	Maximum wave height
H_s	Significant wave height
HHWLT	Higher high water, large tide
HHWMT	Higher high water, mean tide
KWL	Kerr Wood Leidal
LEES	LEES + Associates Consulting Ltd.
LiDAR	Light Detection and Ranging
LLWLT	Lower low water, large tide
LLWMT	Lower low water, mean tide
LNHE	Laboratoire National d'Hydraulique et Environnement
MWL	Mean water level

Acronym / Abbreviation	Definition
NHC	Northwest Hydraulic Consultants Ltd.
NONNA	Canadian Hydrographic Service Non-Navigational (NONNA) Bathymetric Data
NRCan	Natural Resources Canada
PST	Pacific standard time
RSLR	Relative sea level rise
SLR	Sea level rise
SWAN	Simulating WAves Nearshore
T	Wave period
T_p	Peak wave period
WaW	Whey-Ah-Wichen

1 INTRODUCTION

The District of North Vancouver (DNV) retained Hatfield, Northwest Hydraulic Consultants (NHC) and LEES + Associates Consulting Ltd. (LEES) to provide a Shoreline Restoration Plan for the Whey-ah-Wichen or Cates Park (WaW) shoreline that enhances resilience to climate change using nature-based solutions, preserves the historical significance and enhances səlilwətaɬ (Tsleil-Waututh) Nation (Tsleil-Waututh) cultural use of the site, and integrates visitor usage and education (the Project).

The WaW shoreline has been eroding. This process has been accelerated by visitors to the park, increased vessel traffic, changes to sediment supply and the impacts of climate change. The DNV and Tsleil-Waututh co-manage the park and are developing a long-term strategy to restore the shoreline and enhance its resilience to climate change, while preserving the cultural and historical significance of the park.

This report provides a review of previous coastal geomorphology and engineering work at the site, establishes baseline coastal processes, and provides design basis information required for restoration concepts for the shoreline. An overview map of the WaW shoreline can be seen in Figure 1.1.

Figure 1.1 Overview map of WaW project site with the shoreline broken into three reaches and areas of interest shown in white.

1.1 Project Datum

Elevations (including water levels) are referenced to CGVD2013 (Canadian Geodetic Vertical Datum of 2013) unless otherwise stated for the purpose of this project. Based on Benchmark M08C9006 at Vancouver Harbour (Fisheries and Oceans Canada, 2008), CGVD2013 can be converted to either Chart Datum (CD) or Canadian Geodetic Vertical Datum of 1928 (CGVD28) using the following formula:

$$Elev_{CGVD28} = Elev_{CD} - 3.0\ m$$

$$Elev_{CGVD28} = Elev_{CGVD2013} - 0.119\ m$$

2 PREVIOUS STUDIES

Coastal processes studies have been conducted in and around WaW over at least the two decades. These include, but are not limited to, a beach nourishment study designed by Golder Associates Ltd. (Golder) in 2013, a follow up site assessment report by Golder in 2019, a wave climate study performed by Kerr Wood Leidal (KWL) in conjunction with MarineLabs in 2021, a sediment transport pathways thesis written by Carlijn Meijers in 2021, and several concept documents written by and for Tsleil-Waututh to inform future shoreline adaption strategies in the years 2006, 2017 and 2022. These studies will be described in the sections below.

2.1 Golder Beach Nourishment

Golder was retained in May 2013 to analyze the wave climate around WaW and develop beach protection measures (Golder, 2013). Golder reviewed historic air photos to assess changes in coastline morphology and performed site assessments. It was estimated that the erosion rate at Roche Point over the 6- years prior to 2013 was approximately 0.06 m/year.

To establish design metocean conditions, a 14-year record of hourly data from the Vancouver Harbour station was used to estimate extreme wind speeds for the southeasterly and westerly directions (with fetches of 4.3 km and 6.4 km, respectively) at selected return periods. A wave hindcast was performed using only the westerly direction (longer fetch), using empirical equations. Golder predicted that a 200-year wind generated wave, with windspeed of 13.33 m/s, has a significant wave height[1] (H_s) of 0.61 and a peak wave period[2] (T_p) of 2.86 s.

Three shoreline protection concepts were developed with a recommendation to choose a beach nourishment design approach, where sand and gravel are imported to protect the existing headland from erosion. This design is shown in Figure 2.1. This design also recommended locations for future nourishment after addressing the areas of immediate concern. Construction of the nourishment project

[1] Significant wave height (H_s) is typically used to describe wave fields and is approximately equal to the average of the highest 1/3 of the waves.

[2] Peak wave period (T_p) is defined as the time between successive wave crests. It refers to the wave period which has the most wave energy in a distribution or spectrum.

was completed in 2014 and Golder carried out a site visit on April 10, 2019 to review the condition of the restored beach in WaW (Golder, 2019). Erosion at the restored beach and at the adjacent sandy beach to the west was documented, along with observations of other areas experiencing erosion that should be assessed in the future. The placed material (beach nourishment) was identified to have been redistributed west from the point to the central beach through longshore drift. This was expected as part of the design and supported the development of an upper intertidal dune grass habitat. Noted erosion in 2019 was due to a combination of pedestrian foot traffic and storm waves. Overland discharge was also observed from the parking areas due to uncontrolled drainage pathways. It was indicated that this may affect coastal erosion due to water discharge over exposed, erodible soils. It was recommended that a comprehensive erosion management plan be developed for the park, with an evaluation of the priority areas of erosion needing management.

Figure 2.1 Beach nourishment placement and additional erosion at WaW (Golder, 2019)

2.2 Wave Climate Study

Work completed by MarineLabs (2021) which is summarized by KWL (2021) analyzed the wave climate at two sites selected in collaboration with Tsleil-Waututh in 2021. The goal was to record waves to assess the impact of wind generated waves and passing vessels wake.

MarineLabs deployed two wave buoys from August 2019 to September 2020 at the locations shown in Figure 2.2; Buoy 1 was located west of WaW offshore of the Tsleil-Waututh lands in approximately 24 m depth and Buoy 2 was offshore of the east beach in approximately 21 m depth.

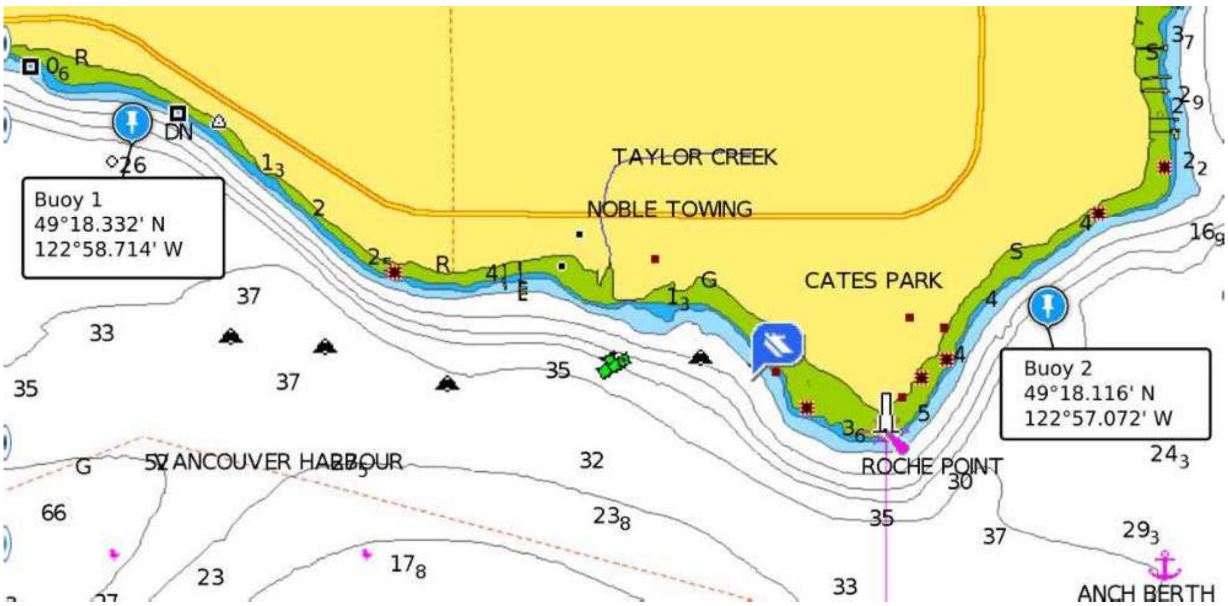

Figure 2.2 Location of the two buoys (MarineLabs, 2021).

MarineLabs performed post-processing to separate vessel wake from wind generated wave measurements. Automated Identification System (AIS) data was obtained from MarineTraffic, an online vessel tracking data provider, to study vessel behavior and compile statistics. In addition to the AIS data, periodic visual observations of vessel transits past the buoys were made and used to verify the AIS data and capture a representative subset of vessel wake wave events caused by non-AIS tracked vessels. The manual vessel data MarineLabs collected was used to analyze the success of the separation algorithm for wind generated waves from wake events; a success rate of 79% was achieved with most errors due to missed wake events.

Wave power was selected as the key attribute for the data due to several referenced studies indicating that wave power was a driver in shoreline erosion; however KWL (2021) noted that wave power levels which cause erosion are site specific and not known for the Tsleil-Waututh locations. MarineLabs showed that at Buoy 1, high wave power events (200 W/m) were more likely caused by wind and at Buoy 2, they were more likely caused by vessels. It was suggested that vessels travelling north through Indian Arm travel closer to Buoy 2 and this could be resulting in the larger portion of wave power attributed to vessel wake at that location.

Wakes from vessels with non-AIS data were recorded most frequently (63% of observed wakes at Buoy 1 and 85% at Buoy 2). These were mostly attributed to pleasure craft. Tugs produced the most commonly identifiable wakes in the record with 20% of observed vessel wakes at Buoy 1 and 9% at Buoy 2. Vessel traffic is tripled in the summer relative to the winter.

The analysis concluded that larger wave events are governed by wind-generated waves especially at WaW; however, the lower power levels (interpreted as lower wave heights) are significantly increased by vessel wake, especially during the summer season. In summarizing the work completed, KWL (2021) concluded that additional monitoring of both waves and the shoreline erosion was needed in addition to morphodynamic modelling of the shoreline.

Parametric (e.g., hourly significant wave height, peak period, and peak wave direction) timeseries were provided by MarineLabs but did not include the separation of wind generated waves from vessel wakes. The use of this data is discussed in Section 5.

2.3 Sediment Transport Pathways in Burrard Inlet

To help understand the mechanisms behind the ongoing erosion along Tsleil-Waututh shorelines, Meijers (2021) set-up and calibrated a Delft3D FM model to better understand the processes in the inlet. The work concluded:

- Flows through Burrard Inlet is accelerated at constricted locations (such as First and Second Narrows) while the wider basins allow eddies to form near the shoreline. The model results also implied that these eddies act as sediment sinks.
- The impact of wind and waves on sediment transport is limited. This was considering a maximum H_s of 0.70 m. To assess wind generated waves the site, Meijers (2021) used the wind record from Marine Labs (2021) and correlated it to Point Atkinson. A factor of 1.792 was used to down sample Point Atkinson winds for use at WaW. The largest scenarios run for wind generates waves were 8.7 m/s (from 15.6 m/s at Point Atkinson) for both the East and the West as well as an extreme West wind of 24.2 m/s (not modified from Point Atkinson).
- Sediment sources to WaW are mostly likely a combination of sediment from Lynn Creek and the Seymour River; however, it is not clear how much sediment is arriving at the site. Seymour River also has a dam which reduces possible sediment load from that source.

These results are summarized on Figure 2.3 where eroding shorelines at both WaW and the Tsleil-Waututh Reserve are shown along with the eddies and suspected sediment transport directions. At WaW sediment transport is shown to travel south from the east beach and east from the central beach both terminating at Roche Point. From the point, sediment is transported offshore by an eddy driven by tidal currents and lost to the nearshore system.

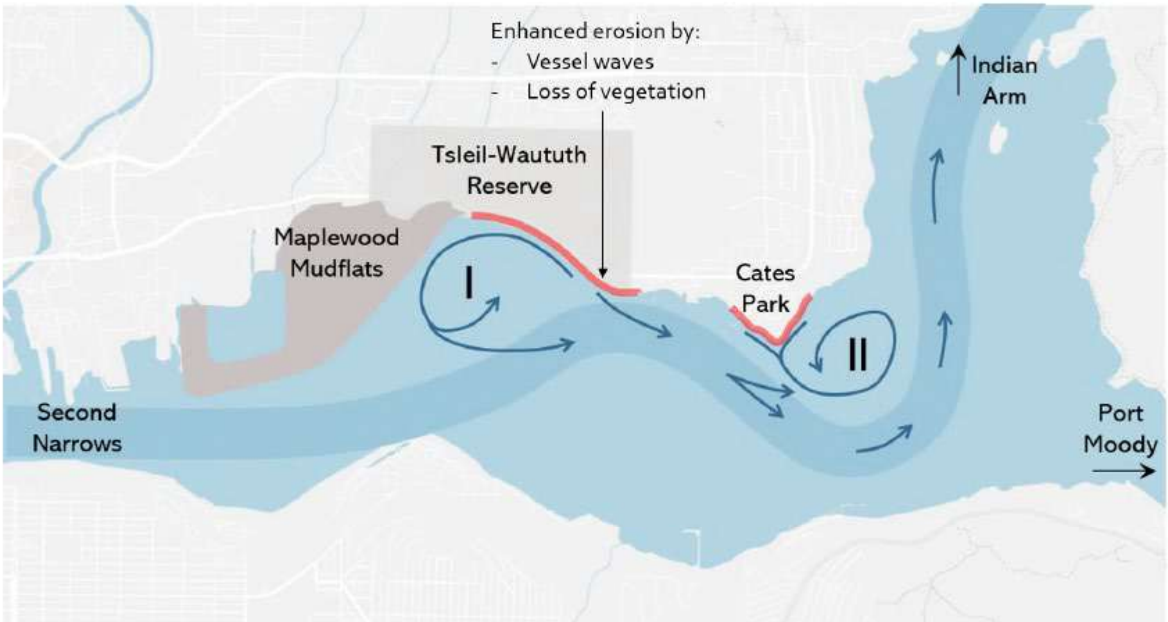

Figure 2.3 Map showing the withdrawal of sediment from eroding shorelines and the two identified eddies (I and II) that impact Tsleil-Waututh lands (Meijers, 2021).

The thesis also referenced work being undertaken by KWL to understand sediment transport mechanisms at the site; however, it wasn't clear if this was the wave climate study described above in Section 2.2 or if additional work done was previously completed on this topic.

3 BACKGROUND INFORMATION AND DATA COLLECTION

Where possible, NHC collected data from public sources and previous studies (see Section 2.0). This was supplemented with a new topographic survey collected by a drone equipped with LiDAR, an updated site orthophoto, and a site inspection performed by the team.

3.1 Publicly Available Data

Public data sources of elevations were used. These included:

1. Bathymetric data from the Canadian Hydrographic Service (CHS, 2022). For this project 10 m resolution bathymetric data from the CHS Non-Navigational (NONNA) Bathymetric Data portal, was used.
2. Topographic Data from the GeoBC Data Portal. Specifically the LiDAR data which was collected between June 20, 2016 and September, 12, 2016 (Government of British Columbia, 2016).

3.2 Site Survey

NHC conducted a physical site survey of the shoreline and beach on August 30, 2023. The field assessment was performed by a Geomorphologist and Junior Coastal Engineer from NHC. The field assessment included observations and photos of areas of shoreline erosion, sediment types and an interpretive assessment of coastal geomorphic processes and sediment transport indicators. The site assessment and the description below were performed starting at the western end of WaW (west beach) and walking east across the central beach and before turning north to walk the east beach (see Figure 1.1 for nomenclature).

The backshore of the west beach of WaW, west of the boat launch and adjacent to the western edge of the parking lot, is undercut. Several cedar trees in this area have exposed roots and are potentially at risk of falling due to erosion (Figure 3.1) The inter-tidal foreshore in this area is mostly unconsolidated cobble and boulders.

Figure 3.1 Two examples of exposed tree roots due to erosion, west of the boat launch.

Closer to the boat launch and along the western end of the central beach, logs and vegetation were present with no visible signs of erosion.

The foreshore directly seaward of the picnic tables is covered with large boulders, with little to no fine sediments present and evidence of backshore (bluff) erosion (Figure 3.2). Tree roots were exposed, and a scarp was present. Pedestrian foot traffic may also contribute to this erosion.

Figure 3.2 Erosion at the picnic tables (facing west).

Minimal erosion was observed on the central beach from the picnic tables to Roche Point. A sandy beach was present, with logs, grasses, and shrubs on the foreshore. Evidence of erosion in the form of a scarp was observed at Roche Point, most likely from high wave energy combined with high water levels and pedestrian traffic from the back beach to the foreshore. Images of the point taken from the west and east are displayed in Figure 3.3.

Figure 3.3 Erosion at Roche Point facing east (left) and facing west (right).

Figure 3.4 shows additional placed boulders and degradation of the upper beach in the area directly northeast of the point on the east beach. It appears that some of these boulders have been placed for previous bluff protection from wave attack and have since been dislodged.

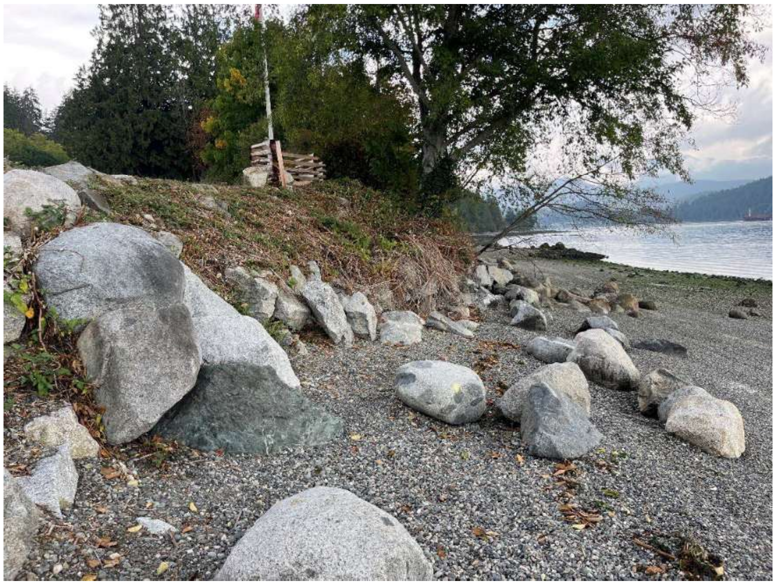

Figure 3.4 Erosion directly northeast of Roche Point.

Northeast from Roche Point along the entirety of the east beach of WaW, areas of possible and observed evidence of erosion were visible, including the undercutting of soil in multiple locations. Evidence of erosion was often visible behind large boulders and near trees, exposing the roots. In many areas shrubs were growing over rocks making it difficult to distinguish the amount of erosion, if any, landward. Examples of erosion on the west beach are shown in Figure 3.5 and Figure 3.6. Erosion was also visible at the base of multiple stairways leading down to the beach.

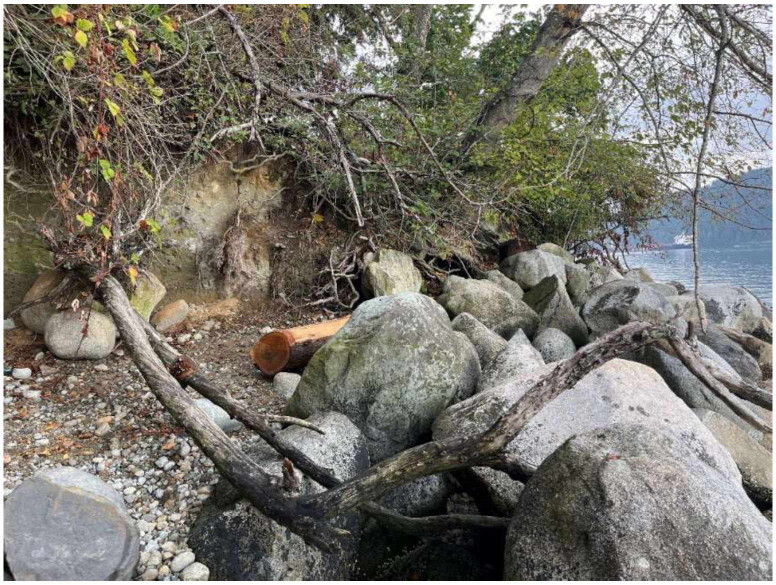

Figure 3.5 Bluff erosion with evidence of previous armouring along the west beach of WaW.

Figure 3.6 Exposed tree roots along the west beach of WAW.

3.3 Drone Survey

The site survey included a Light Detection and Ranging (LiDAR) and imaging drone survey carried out by Spitfire Drone Survey Ltd. (Spitfire) on August 30, 2023, to collect updated orthoimagery of the site and topographic data of areas above water. The survey was performed at a low water level of around 0.5 m CD (-2.5 m CGVD2013) to collect information across as much of the inter-tidal beach as possible. Elevations of the beach and intertidal area were collected along with orthographic imagery of the site. The collected data has a ground sampling distance of 2.5 cm and orthomosaic imagery with a resolution of 2 cm. The data from the topographic survey was processed for use in digital elevation model (DEM) development and used to assess topographic change and areas of beach erosion and accretion.

3.4 Modifications to the Shoreline

In addition to the information provided above, additional shoreline modifications were observed during the site observations. These include:

- Boulder rock armouring along large portions of the upper beach (particularly the east beach) that appears to have been installed as a form of erosion protection. Per Tsleil-Waututh (2022) this was installed in the 1980's to early 1990's.
- To the west of the project site in front of the Cate's Landing development, boulder clusters exist to provide additional habitat as part of that shoreline work that was completed in the 2010's.

No detailed information on timing or technical details for either of these works was available and reviewed by the project team.

4 COASTAL PROCESSES AND GEOMORPHIC ASSESSMENT

The geomorphology assessment is based on the site surveys, the change in beach topography (i.e., bed level changes) between 2016 and 2023 and the characterization of the different sediment types on the beach. This information is used to assess the coastal processes including sediment transport directions and patterns.

4.1 Interpretive Geomorphology

Much of the foreshore in WaW is backed by low bluffs and erosion scarps, from < 1 m to > 3 m in height. Although mixed sand and gravel sediment is present over much of the upper inter-tidal foreshore, there are substantial areas that have either a thin veneer or are void of unconsolidated sediment. The latter areas are characterized by outcrops of consolidated sediment of glacial origin (e.g., Vachon outwash terrace deposits, Bednarski, 2014). The bluffs and scarps show signs of active erosion and are formed in midden (e.g., shell material, artefacts, sand, gravel, and organic detritus), and densely consolidated and less consolidated sediments composed of sand, gravel, cobble, and boulder. Bluffs near Roche Point above the east beach show signs of groundwater flow in the form of sapping and piping which also likely contribute to bluff slope failures; see also Golder (2019). Bluff erosion is interpreted to be a primary source of sediment to the upper foreshore. Ongoing erosion combined with progressive reduction in sediment supply due to backshore protection armouring have gradually reduced sediment cover of the foreshore to a thin veneer of unconsolidated sediment over till, or till exposure. Conversation with long-time residents (beach walkers) in the area during the site assessment indicated that they had observed progressive thinning of beach sediments and increasing exposure of consolidated till over a period of decades. Attempts to protect the toe of bluffs from coastal processes erosion with boulder placements have been only partially successful as evidenced by continued recession of the bluff face shoreward of the boulders in many places.

The east beach becomes increasingly sediment starved with distance north from Roche Point. There is a distinct break in slope on the mid foreshore which is also marked by a significant coarsening of sediment. This gives the upper foreshore the appearance and geometry of a perched beach (Figure 4.1).

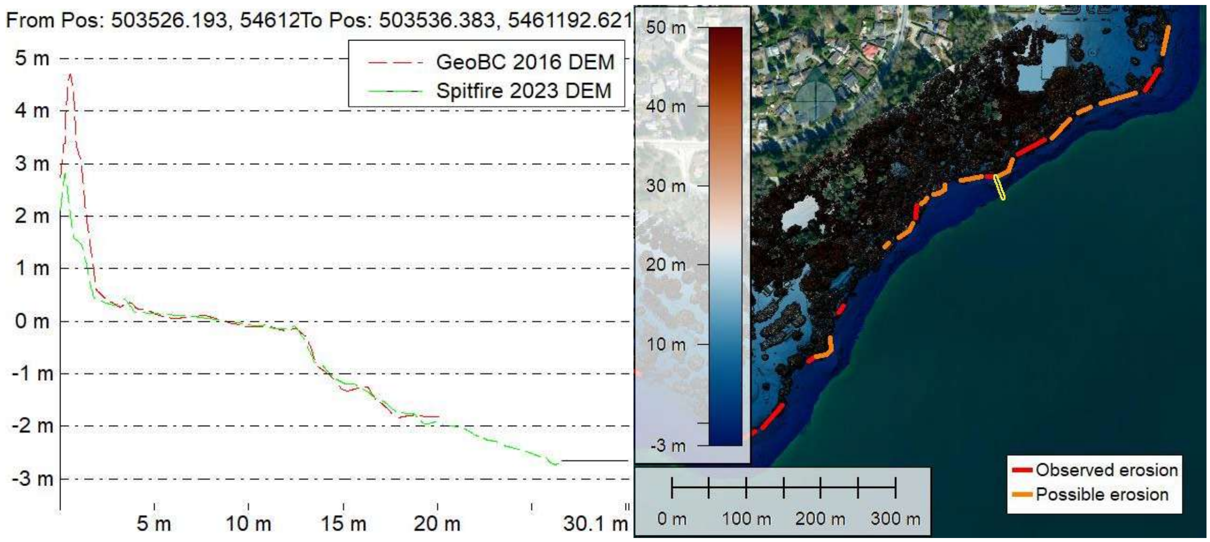

Figure 4.1 Representative cross-section of the elevation profile at the east beach.

The central beach is currently less sediment starved than the east beach. This is likely a byproduct of the fact that the central beach was supplied with sediment in the 2014 beach nourishment project and as a result, longshore transport has distributed this material. The profile of the central beach, east beach and at Roche Point are similar to the section presented in Figure 4.2. The beach in this area is generally more in equilibrium although it is currently deflating.

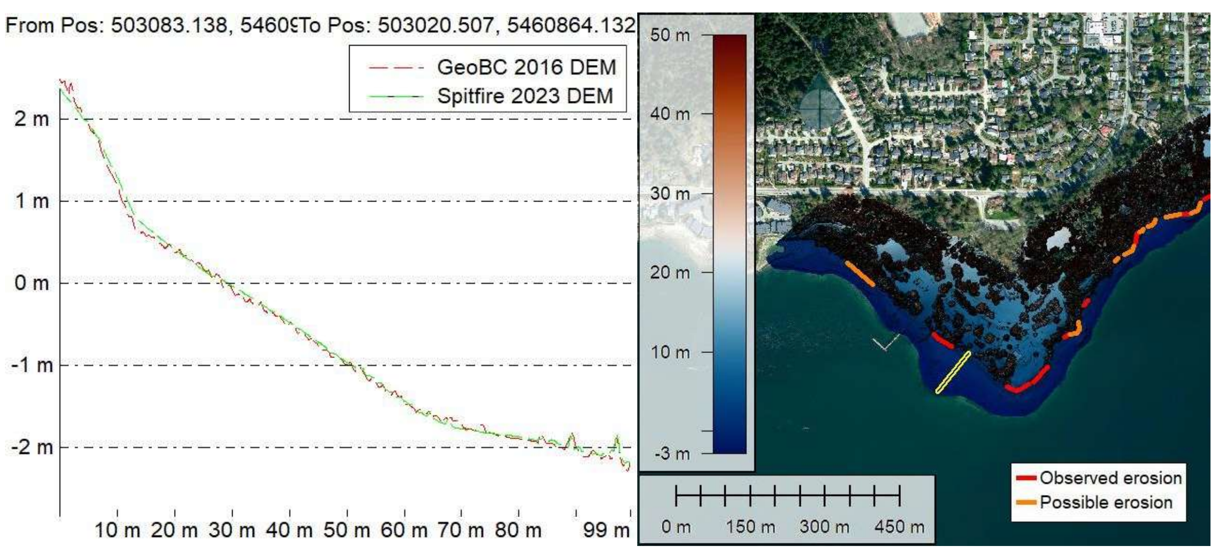

Figure 4.2 Representative cross-section of the elevation profile at the central beach.

The central beach becomes increasingly sediment starved with distance west of the point – e.g. area in front of the picnic shelter (Golder, 2019) and the area west of the boat ramp which is relatively devoid of finer and unconsolidated (mobile) sediment and is mainly composed of large cobble and boulders.

4.2 Recent Coastal Change Assessment

The change in beach morphology and shoreline extent between 2016 and 2023 was to understand present processes influencing the site for design purposes. It is well documented by sources such as Tsleil-Waututh (2022) and Meijers (2021) that significant changes in both the shape and processes of the WaW shoreline have changed since the 1700's; and previous work by Golder (2013) had reviewed the air photo record between 1949 and 2013. The purpose of the present scope was to understand changes in the present day environment.

This was done using topographic difference maps comparing the 2016 LiDAR (collected between 2016/06/20 and 2016/09/12) from the Crown Registry and Geographic Base Branch (Government of British Columbia, 2016) to the LiDAR survey performed by Spitfire. The change in bed level indicates areas of erosion and deposition, as well as general transport directions and sink and source relations. Note that this assessment was not possible at locations of significant overhanging vegetation where the LiDAR surveys could not penetrate. The latter includes most of the backshore bluffs which show substantial evidence of erosion as noted above. In such areas erosion indicators were observed and recorded by ground-based photos (see Section 4.1). The latter areas are indicated as *observed erosion* in Figure 4.3. Some areas of the site had impenetrable vegetation and direct observations/photography were impossible. Several of these locations (also indicated in Figure 4.3) were interpreted as *possible erosion* based on the upper foreshore condition and adjacent exposures.

The WaW intertidal area shows a limited amount of change over the 7-year interval between LiDAR surveys (Figure 4.3). The primary area of beach erosion (bed level lowering) and shoreline recession is indicated by *A1* on Figure 4.3 (up to 1.7 m) and is located at Roche Point. The area has experienced long term erosion, which was targeted with the 2014 beach nourishment. This point is located at a natural change in shoreline direction and is exposed to tidal current, wind and wave action from the west, east and north. The area is also non-vegetated, making it more prone to erosion and undercutting. There is accretion to the west (central beach) and east (east beach) of this area which suggests that the erosion of the end of the point is driven mainly by alongshore transport to the east and west (away from the point) respectively. This contradicts the findings of Meijers (2021) that materials through this reach is transported directly offshore.

The alternating areas of erosion and accretion along the central beach at *A2* on Figure 4.3 are a continuation of the longshore transport from the point. The sediment is interpreted as it is transported along the beach in a wave-like pattern. This sediment likely originated from Roche Point and from the sand placement (e.g., Figure 2.1). This observation is consistent with those reported by Golder (2019) during the monitoring site visit. At the same time there is observed erosion along the shoreline to the west of this area (*A2* on Figure 4.3). The accretion east of this section could originate from these eroding bluffs.

The areas indicated by *B* (three total) on Figure 4.3 show the main locations of bed level change on the beach. *B1* on the west beach has experienced a small amount of lowering associated with recent changes made to the beach and the placement of boulder clusters. The two areas on the east beach, *B2* and *B3*, both show erosion on the lower beach and accretion on the upper beach. *B2* has experienced up to 0.5 m of erosion and up to 0.7 m accretion. *B3* shows up to 0.3 m of erosion and up to 0.3 m accretion. Based on the patterns of erosion and accretion, these changes represent localized shifts in sediment where the sediment is moved in an onshore direction. This pattern does not appear to be seasonal, as both elevation surveys were collected in the summer (GeoBC LiDAR collected between June 20, 2016, and September 12, 2016, and Spitfire drone survey collected on August 30, 2023).

The high intertidal shoreline area is obscured by vegetation in the LiDAR derived surfaces. This constrains quantifying areas of shoreline erosion. Sections of observed and possible shoreline erosion have been added to the map based on site observations and ground-based photography during the site survey on August 30, 2023. The high magnitudes of change on the topographic change map near the shoreline and backshore are the result of changes in vegetation and not beach elevations. The northern end of the east beach (approximately 500 m of shoreline) of WaW was observed or is suspected to have shoreline erosion of the upper beach (*C* on Figure 4.3). In total, there is an approximate length of 250 m where shoreline erosion was observed and an approximate length of 370 m where there is potential for future shoreline erosion or where shoreline erosion is possible based on observed indicators. Other key locations of upper beach erosion included Roche Point, in front of the picnic shelters and a small section of the west beach.

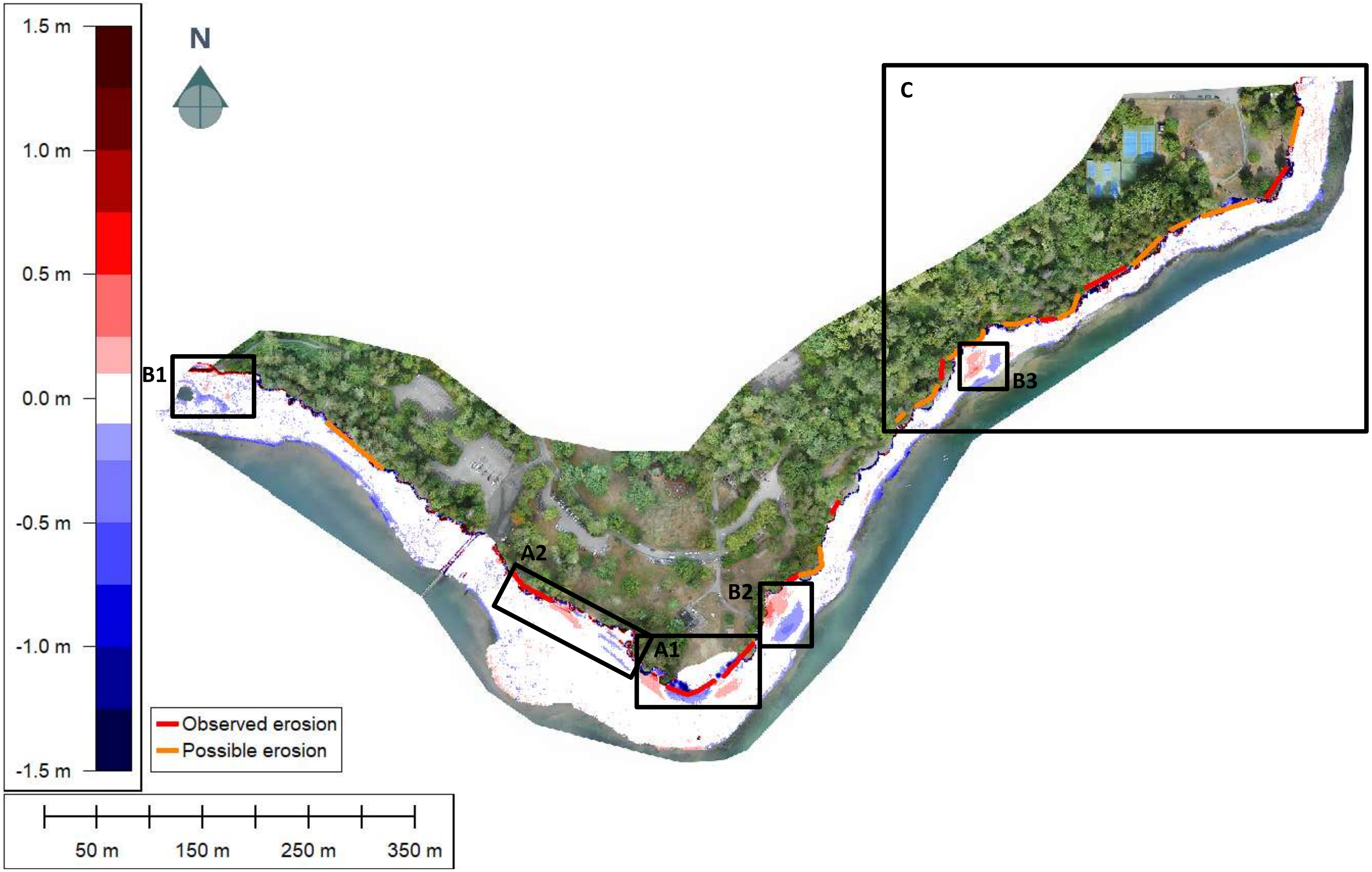

Figure 4.3 Bed Level change between 2016 and 2023 and shoreline sections experiencing observed and possible erosion. Areas of erosion shown as negative. Box details refer to areas of interest described in Section 4.2.

4.3 Sediment Characterization

This section presents a surface sediment map based on the interpretation of the 2023 LiDAR survey and orthoimagery and field observations made during the site survey. The distribution of sediment and sedimentary features provides an indication of sediment transport directions and source and sink relations. Sediment characteristics also inform which areas might be more prone to erosion and which areas are generally stable. Sediment indicators are a key consideration in the conceptual design process for nature-based solutions.

WaW predominately consists of a sand or sand and gravel upper beach and a gravel and boulder, gravel, or cobble and boulder lower beach (Figure 4.4). At the upper beach the sediment is generally finer and coarsens with distance from the shoreline. This cross-shore sorting pattern is common and is the result of waves, tides, and the downslope effect of gravity.

Most of the backshore is backed by low bluffs (1 - 3 m), apart from the midden deposits at Roche Point. A large part of the backshore and the midden area shows signs of active erosion and have developed vertical scarps. The bluff sediment consists of densely consolidated and less consolidated sediments composed of sand, gravel, cobble, and boulders. These bluffs act as long term source for beach sediment. There are several sections along the shoreline where boulders have been placed. The boulders armour the toe of the bluffs and were intended to reduce bluff erosion and recession but may also have contributed to beach erosion by increasing velocities in localized areas and reducing sediment supply from the bluffs. Figure 4.3 shows that the topographic change on the beach over the last 7 years has been limited. This indicates that beach erosion (differentiated from bluff recession) might be a lesser concern. This conclusion is reasonable, as there is little erodible loose sediment left on the beach and most of the east and west beach now consists of non-erodible resistant till or resistant cobble and boulder armour. However, the bluff scarps continue to slowly erode during periods of extreme high water combined with waves, however further beach lowering is limited by the lack of available unconsolidated sediment on the beach surface.

As mentioned in section 4.1, shoreline erosion was also observed at the location of *A* on Figure 4.4. There are two sections of shoreline armoured with boulders in this area. The orthoimagery shows that the boulder coverage in these sections is discontinuous and that boulders have been displaced downslope (consistent with on site observations). The cross-shore width of the sand deposit in between these two boulder sections is higher than along the rest of the upper beach. This same area also shows accretion (up to 0.2 m in Figure 4.3). This indicates that sand eroded from the shoreline remains on the upper beach in the short term but is likely removed over the long term (given the limited amount of accretion observed on the beach).

The sediment on the either side of the boat ramp (*B* on Figure 4.4) has coarsened and consists of cobble and boulder, gravel and boulder and gravel and cobble. Shoreline erosion was observed along the southwestern shoreline within *B* on Figure 4.4. Possible erosion occurring along the shoreline of area *C*. There are three coarse sediment bars on the upper beach within this area consisting of boulders.

The surface sediments in the area indicated by *D1* and *D2* on Figure 4.4 are coarser than most other areas at WaW. Especially the northern extent of *D2* where most of the upper beach is covered with gravel and cobble. The surface sediment has formed into an armour lag deposit due to the erosion of finer material. Sections of the shoreline along *E* on Figure 4.4 are protected by boulder placements, but there is still potential for bluff erosion in this area. The upper and lower beach area within *F* on Figure 4.4 is covered with sand. The extent of the sand deposit indicate that this area is a minor sediment sink.

Figure 4.4 Sediment characterization for WaW Park. Box details refer to areas of interest described in Section 4.3.

5 METOCEAN CONDITIONS

Coastal processes that include sediment transport, beach and bluff erosion and accretion are driven by a combination of metocean conditions that include water level variations, waves, and currents. WaW is in a unique location in Burrard Inlet where it is exposed to winds from the west, east, and north. Wind-generated waves are responsible for the largest wave in Burrard Inlet, however vessel generated waves (wakes) contribute to the wave climate. As there is no long-term wave measurement data recorded at the site, a wind and wave analysis was performed to determine the incident wave climate and to develop design conditions for shoreline restoration. Currents at the site may be driven by both winds and tides. Water level variations at the site due to tides and storm surge affect the exposure of the beach and bluffs to wave and current action.

5.1 Water Levels

Water level variations at WaW relevant to the design of shore restoration are forced by a combination of local astronomical tides, storm surge and sea level rise (SLR). These processes are described in the following sections.

5.1.1 Astronomical Tide Range

Tides at the project site are mixed semi-diurnal with an annual mean tide range of 3.3 m and a large tidal range of 4.9 m. Table 5.1 presents the tidal elevations for Vancouver Harbour (Station ID 7735) (Fisheries and Oceans Canada, 2022).

Table 5.1 Tidal levels at Vancouver Harbour.

Description	Acronym	Elevation	Elevation
		(m, CD)	(m, CGVD28)
Higher High Water, Large Tide	HHWLT	5.0	2.0
Higher High Water, Mean Tide	HHWMT	4.5	1.5
Mean Water Level	MWL	3.1	0.1
Lower Low Water, Mean Tide	LLWMT	1.2	-1.8
Lower Low Water, Large Tide	LLWLT	0.1	-2.9

5.1.2 Storm Surge

Storm surge is the rise in water level due to atmospheric effects (such as wind stress and reduced atmospheric pressure) above the normal tidal level. Storm systems (which produce storm surge) and tidal levels are largely independent events in Burrard Inlet and the Strait of Georgia.

NHC previously estimated the joint probability of storm surge and tides for Point Atkinson by applying the Empirical Simulation Technique (EST) on the long term tidal record (NHC and Triton, 2006). The EST method is recommended by the Coastal Hydraulics Laboratory (from the US Army Corps of Engineers) and the US Federal Emergency Management Agency for frequency related studies. The analysis determined total water levels for various annual exceedance probabilities (AEP) which are shown in Table 5.2.

Table 5.2 Point Atkinson statistics based on total water level.

AEP (%)	Elevation (m CGVD28)
10	2.4
2.0	2.6
1.0	2.7
0.5	2.8

Because there is a negligible difference in tidal datums between Point Atkinson and Vancouver Harbour, these water levels are adopted for use at the project site.

5.1.3 Sea Level Rise

Global climate change is expected to result in increased sea levels from melting of global ice and increased ocean volume due to rising water temperature. The BC Provincial Climate Change Adaption Guidelines by the BC Ministry of Environment (BC MOE, 2011c) recommends that SLR associated with global climate change will result in a base water level increase of 1 m above that seen in the year 2000 by the year 2100 (or 10 mm / year) (Figure 5.1). The recommended rate of SLR for planning and design in BC was based on a 2008 study by DFO (Thomson et al., 2008) and British Columbia MOE (Bornhold, 2008). The authors of those works acknowledge the design SLR for BC is greater than the global mean SLR projected by the Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report (AR6) for the year 2100 (roughly 20 cm greater than their highest projection for Surrey) (IPCC, 2022). Other studies have investigated the potential effect of a collapse of the Antarctic ice sheet and have shown that such an event would result in higher levels of SLR (e.g. Hansen et al., 2016).

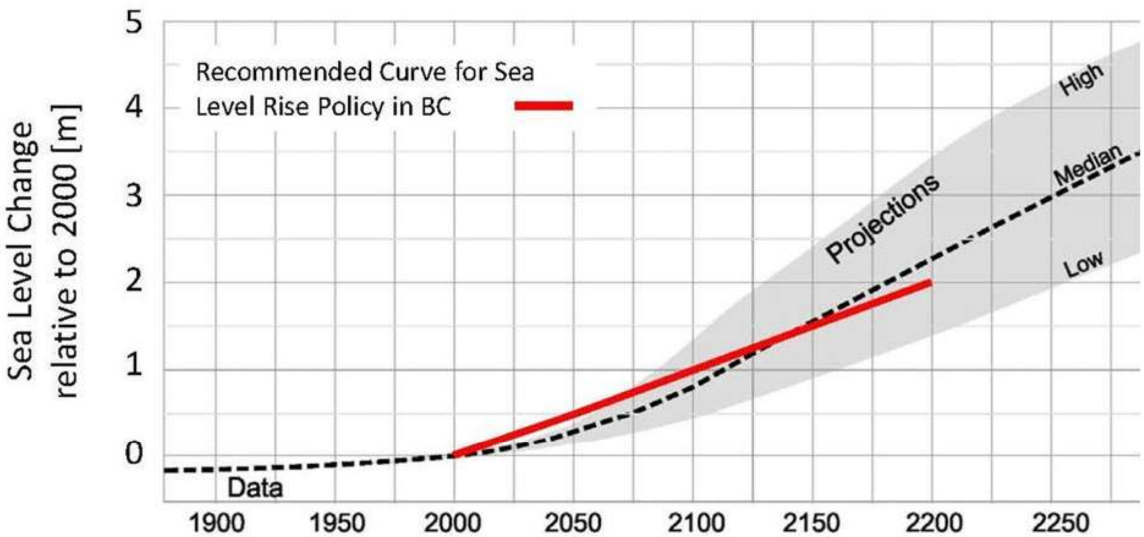

Figure 5.1 Recommended SLR recommended for planning and design in BC (BC MOE, 2011c).

In addition to global SLR, isostatic rebound, tectonic uplift, and/or sediment consolidation may influence the local relative SLR. The Canadian Geodetic Survey of Natural Resources Canada (NRCan) has created a national-scale crustal velocity model, using an updated vertical grid which incorporates global positioning system (GPS) observations with the crustal uplift predictions from glacial isostatic adjustment and elastic rebound models (Robin et al., 2020). NRCan has created an application which allows users to download the updated velocity grid, enter coordinates of the designated site, and the application outputs the vertical crustal velocity for that area. Several locations along the length of the shoreline at WaW were checked and all returned a subsidence value of 1.1 mm/year (ground lowering).

The calculation of the relative sea level rise (RSLR) is based upon the global SLR allowance of 10 mm/year minus the local uplift. In calculating RSLR values to use for this project, present, near future and distant future values were considered as shown in Table 5.3.

Table 5.3 RSLR scenarios.

Condition	SLR Scenario (m)	Subsidence Total (m)	RSLR (m)
Present	0	N/A	0
Near Future (assumed year 2050)	0.5	0.055	0.56
Distant Future (assumed year 2100)	1.0	0.11	1.11

5.1.4 Design Water Level Summary

The design water level (DWL) for the project site includes the combined effect of astronomical, non-astronomical effects and RSLR. It is important to understand the potential DWLs for various AEPs when designing modifications to the shoreline, to understand which level of storms certain types of modifications may be able to withstand. The design water levels for WaW are summarized in Table 5.4.

Table 5.4 DWL for WaW.

AEP (%)	Present Day	Near Future (assumed year 2050)	Distant Future (assumed year 2100)
10	2.4	3.0	3.5
2.0	2.6	3.2	3.7
1.0	2.7	3.3	3.8
0.5	2.8	3.4	3.9

5.2 Wind

The largest waves that the site will experience are wind-generated waves. WaW is exposed to winds from the east and west, aligning with the orientation of the inlet, as well as winds from the north that are funneled down Indian Arm. Although WaW is also exposed to winds from the south, the fetch[3] is small compared to other directions and therefore will not govern.

There are no known anemometers within Burrard Inlet with suitable wind data (long term records) for analysis directly offshore of the project site. However, Environment and Climate Change Canada (ECCC) operates several wind stations in the surrounding area that can be used to help characterize the wind climate at the site. Two wind stations were analyzed to establish the design winds: Point Atkinson and Pam Rocks (locations shown in Figure 5.2). Point Atkinson provides a good representation of storms from the east and from the west storms; however, it is sheltered from north winds due to local topography. Pam Rocks is in Howe Sound and, although farther from the site, it records northerly outflow winds that are funneled south from Squamish in a similar way to expected conditions in Indian Arm. It is assumed that these north winds will be larger in magnitude than those arriving at WaW, providing a conservative northerly design wind speed.

[3] Fetch refers to the distance over which winds blow to generate waves.

Figure 5.2 Pam Rocks and Point Atkinson wind stations. Image from GoogleEarth™.

The local wind climate can be visualized using a wind rose (a graphic presentation of winds for specified areas) utilizing arrows at the cardinal and inter-cardinal compass points to show the direction from which the winds blow and the magnitude and frequency for a given period. The wind rose showing the direction and magnitude of the winds from Point Atkinson wind station from 1996 to 2022 is shown in Figure 5.3 and for Pam Rocks from 1994 to 2021 in Figure 5.4.

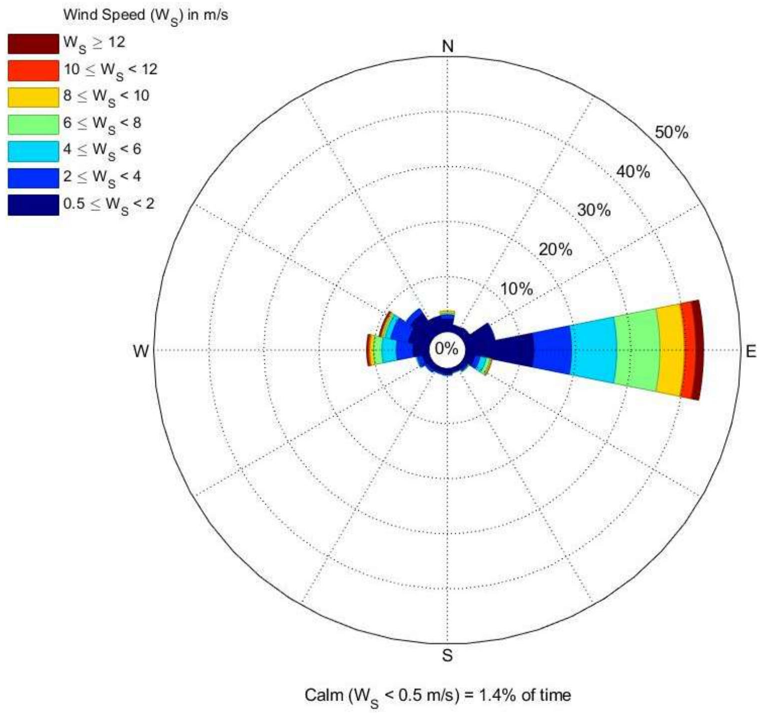

Figure 5.3 Point Atkinson wind rose from 1996 to 2022.

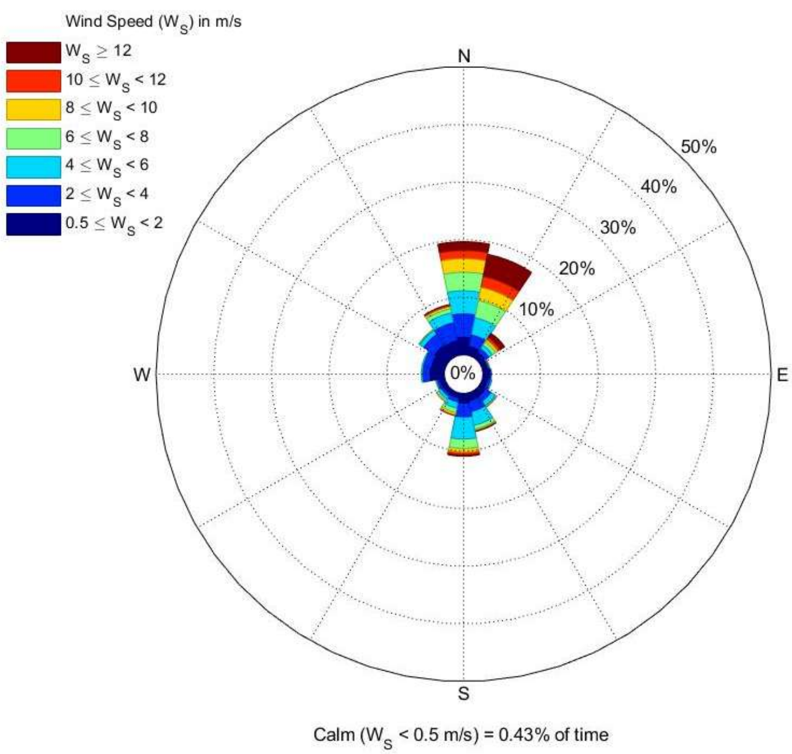

Figure 5.4 Pam Rocks wind rose from 1994 to 2021.

The Point Atkinson wind rose shows that wind is experienced most frequently from the east and secondly from the west. An extreme value analysis (EVA) was conducted on the Point Atkinson data to obtain the east and west design wind speeds for various AEPs. The Pam Rocks wind rose shows the most frequent and highest magnitude winds are experienced from the north; a second EVA was conducted to obtain north design wind speeds. The design wind speeds are summarized in Table 5.5. The northerly speeds taken from the Pam Rocks wind station have the highest magnitude of the three directions considered. No over-land to over-water corrections to wind speeds were performed as the anemometers at both locations are immediately adjacent to a body of water and judged to be in representative of winds over the water.

Table 5.5 Design wind speeds for WaW.

AEP (%)	Easterly Design Speeds (Point Atkinson)		Westerly Design Speeds (Point Atkinson)		Northerly Design Speeds (Pam Rocks)	
	(m/s)	(km/hr)	(m/s)	(km/hr)	(m/s)	(km/hr)
20	20.4	73	20.6	74	26.9	97
10	20.9	75	21.8	78	28.1	101
2	22.0	79	24.5	88	30.8	111
1	22.5	81	25.7	93	31.9	115
0.5	22.9	82	26.8	97	33.0	119

MarineLabs (2021) provided NHC with hourly metocean data from their 2019-2020 data collection program (see Section 2.2). Wind data collected at each of the buoys was analyzed and compared to Point Atkinson and Pam Rocks to check if there was agreement between the datasets. The time series of wind speed and direction from Point Atkinson from August 2019 to October 2020 was plotted (see Appendix A). The top storm in this time frame was recorded on January 15, 2020, with a peak windspeed of 19.2 m/s. In comparison to the design wind speeds derived from Point Atkinson, this value is lower than a 20% AEP storm and around a 50% AEP event.

The time series of wind speed and direction for each buoy are also included in Appendix A. Recorded windspeeds were primarily under 5 m/s and no large storm events were captured during the deployment. Wind roses were plotted for each buoy and further display the high occurrence of low velocity storm events. The wind rose for Buoy 1 (Figure 5.5) displays the highest windspeeds from the west which is expected considering the geographic location of the buoy and how it is sheltered from the east by Roche Point. Buoy 1 records lower windspeeds from the southeast which can be attributed to easterly storms being steered around Roche Point to the location of the buoy. The wind rose for Buoy 2 (Figure 5.6) displays the highest wind speeds from the northeast which are expected due to winds funneling down the Indian Arm and being steered towards WaW. The buoy also experiences moderately high winds from the W, which can be attributed to westerly storms being steered around Roche Point towards the buoy.

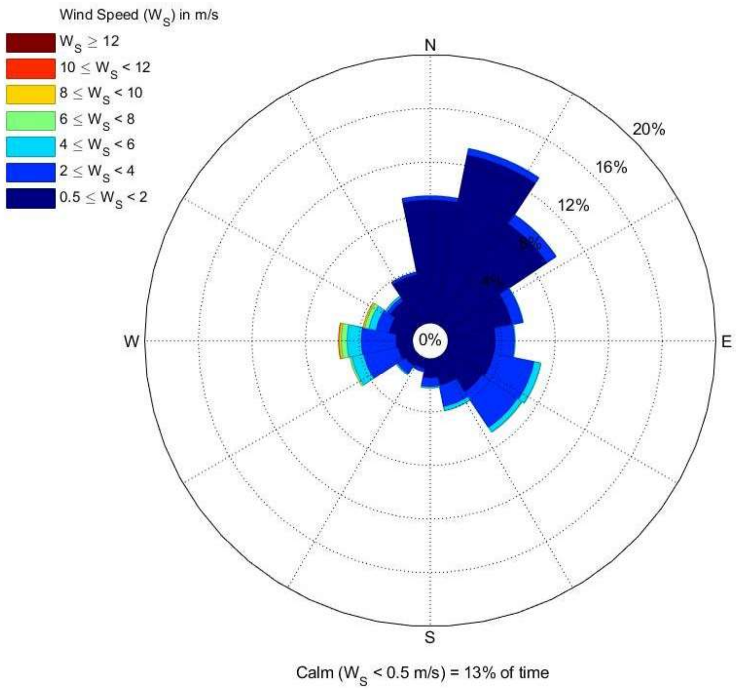

Figure 5.5 Wind rose of MarineLabs Buoy 1 from deployment during August 2019 – September 2020.

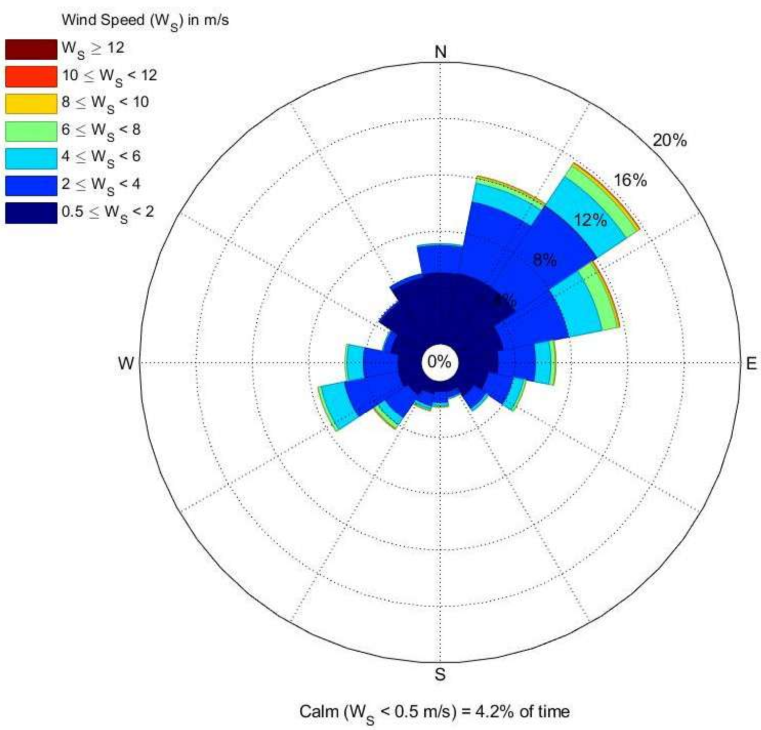

Figure 5.6 Wind rose of MarineLabs Buoy 2 from deployment during August 2019 – September 2020.

Results indicated that peaks in wind speed aligned during large storm events were experienced, however both ECCC datasets (Point Atkinson and Pam Rocks) had larger magnitude winds which are expected to be more representative of the conditions over water that generate waves reaching Tsleil-Waututh shorelines.

5.3 Waves

The wave climate at WaW is comprised of both wind generated and vessel generated (wake) waves. While work by Meijers (2021) concluded that wind-generated waves were not critical to sediment transport patterns at the site, it is important not to ignore these waves as they can be drivers of episodic change, especially at high water levels. These waves can cause back bluff erosion, drive sediment delivery to the site and quickly modify beach profiles.

Data from the MarineLabs (2021) wave climate study (see Section 2.2) was a useful measure of the combined waves arriving to the project region. Compass rose distributions of H_s by direction for Buoy 1 and Buoy 2 are presented in Figure 5.7 and Figure 5.8, respectively.

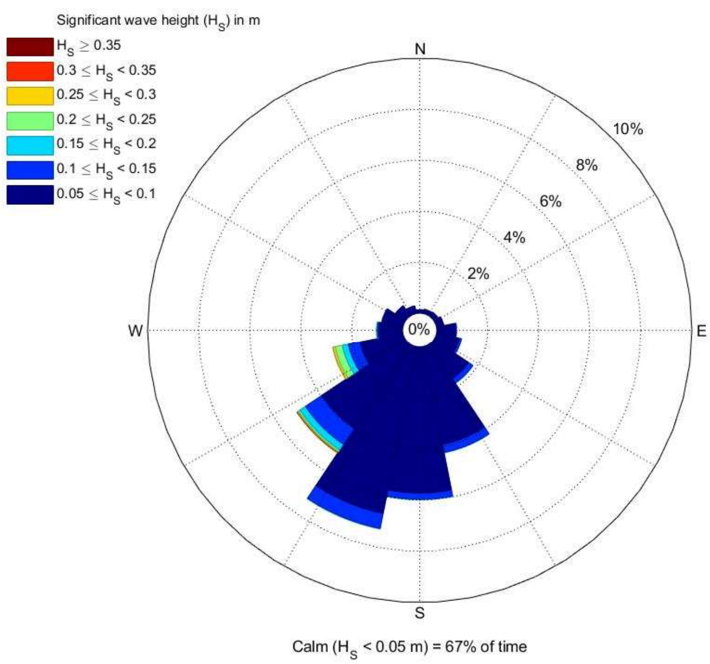

Figure 5.7 Compass rose distribution of significant wave height by direction measured at Buoy 1 (MarineLabs, August 2019 to September 2020)

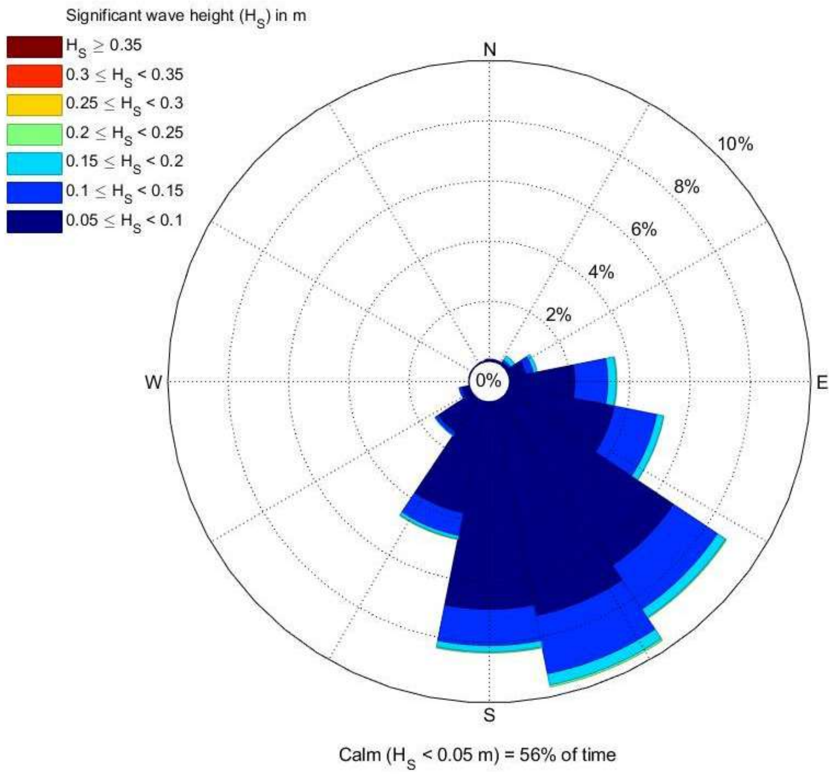

Figure 5.8 Compass rose distribution of significant wave height by direction measured at Buoy 2 (MarineLabs, October 2019 to September 2020)

Waves at Buoy 1 are primarily from the southwest which can be attributed to easterly winds creating in Burrard Inlet, which constrict through Second Narrows, and then refract towards the shoreline where Burrard Inlet widens, east of Maplewood Flats. As Buoy 1 is sheltered from the north and east, no waves were recorded from these directions. Waves at Buoy 2 are primarily experienced from the east/southeast, and secondarily from the northeast. These can be attributed to typical easterly storms and to winds funneling down the Indian Arm creating waves that diffract around the northeastern point of WaW.

To understand the effects of each wave type, numerical modelling of the wind-generated waves was performed, and vessel wake waves were assessed using previous studies in the inlet and measurements at the site.

5.3.1 Wind Generated Waves

A nearshore wave model (Simulating Waves Nearshore or SWAN) of the Burrard Inlet was developed to model wave generation and propagation from deep water into coastal areas and shorelines. The model extents for the Vancouver Harbour model are shown in Figure 5.9. SWAN incorporates physical processes such as wave propagation, wave generation by wind, white-capping, shoaling, wave breaking, bottom friction, sub-sea obstacles, wave setup and wave-wave interactions in its computations (Booij et al., 2004). SWAN version 41.20 was used for this study. The Burrard Inlet model domain measures 22.8 km east-west and 5.1 km north-south, with each grid cell measuring 50 m by 50 m.

Figure 5.9 SWAN grid model domain for Burrard Inlet.

A second SWAN model encompassing the entirety of the Indian Arm and the site was developed to assess the impact of waves from the north arriving at WaW. The model extents are shown in Figure 5.10 and measure 8.1 km by 22.8 km with 50 m grid cells.

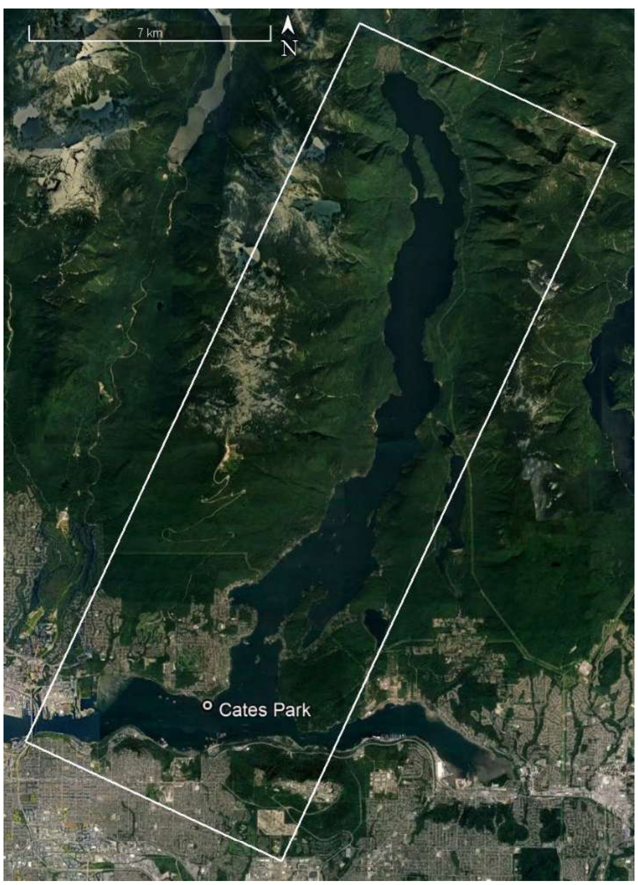

Figure 5.10 SWAN grid model domain for Indian Arm.

5.3.1.1 Model Calibration

Data from the August 2019 to September 2021 MarineLabs (2021) dataset for both buoys was reviewed for wind generated storm events that could be used for model calibration. The recorded largest H_s was 0.26 m and less than 5 events had H_s greater than 0.20 m.

The data from Buoy 1 was primarily used to calibrate the SWAN model for western events and the data from Buoy 2 was used to calibrate the SWAN model results for the easterly and northerly events. This is due to the geographic location of the buoys: Buoy 1 is largely sheltered from easterly storms and Buoy 2 is sheltered from westerly storms both by Roche Point.

The hourly data was sorted by the largest H_s so that the top storm for each direction of interest (N, E, and W) could be analyzed. These values were then compared to hourly ECCC wind data recorded at either the Point Atkinson (for E and W events) or Pam Rocks (N events) wind stations. After analysis of the hourly Point Atkinson data, no suitable easterly storms were found that corresponded to the highest waves recorded at Buoy 2. The peak westerly and northerly ECCC windspeeds were used as inputs to the corresponding SWAN models to simulate the same wind conditions that were expected to have caused the recorded waves. The MarineLabs storm selected for each direction is presented in Table 5.6 while the corresponding peak wind events from ECCC data are in Table 5.7. Times are shown in Pacific Standard Time (PST).

Table 5.6 MarineLabs metocean data at Buoy 2.

Direction	Buoy	Report Timestamp (UTC)	Local Time (PST)	H_s (m)	T_p (s)	Wind Direction (deg)
W	1	1/11/2020 23:00	1/11/2020 15:00	0.26	2.3	225
N	2	8/17/2020 0:00	8/16/2020 17:00	0.21	2.8	40

Table 5.7 ECCC peak wind data.

Direction	ECCC Wind Station	Local Time (PST) of Peak Wind Speed	Wind Speed (km/h)	Wind Speed (m/s)	Wind Direction (deg)
W	Point Atkinson	1/11/2020 13:00	57.0	15.8	290
N	Pam Rocks	8/16/2020 7:00[1]	43.0	11.9	330

1. Time of storm varies due to geographic location of wind station.

The results of the calibration runs comparing H_s and T_p are presented in Table 5.8.

Table 5.8 Calibration results.

Parameter	N		W	
	SWAN	MarineLabs Buoy 2	SWAN	MarineLabs Buoy 1
H_s (m)	0.20	0.21	0.51	0.26
T_p (s)	2.29	2.81	2.76	2.28

The results show that the SWAN model using Pam Rocks wind data and encompassing the Indian Arm for northern runs predicts wave results that are in good agreement with the recorded wave data. The SWAN model using Point Atkinson winds for W wind significantly overpredicts H_s values compared to Buoy 1; therefore, it can be assumed that the SWAN model will provide conservative results. This could be due to the wind inputs being used (unfactored from Point Atkinson) or lack of energy loss due to refraction in the SWAN model. The SWAN model results will not have any correction factors applied when used for design bases.

The sensitivity of wind direction on the wave results was then analyzed for both SWAN models. The E and W 100-year return period windspeeds were applied from the southeast (SE) and southwest (SW), respectively. Results indicated that changing the wind directions had no significant impact on results, and pure easterly and westerly wind directions were kept as the design directions. The north windspeed was applied to a northeast (NE) direction and results predicted larger waves. This can be expected due to the NE alignment of Indian Arm, providing a larger fetch to the site. Thus, the NE wind direction was chosen for further modelling.

5.3.1.2 Model Runs

The 20%, 5% and 1 % AEP design wind speeds for each direction (W, E and NE) were used as input to the respective SWAN models. Model results for the 1% AEP wind-generated waves are presented in the following section, where H_s is shown by colour shading and peak wave direction is shown by vectors.

A plot of the 1% AEP NE waves generated within the Indian Arm can be seen in Figure 5.11 and a zoomed-in view near WaW can be seen in Figure 5.12. The results show that northerly winds generate large H_s near the north-east corner of WaW, and the east beach is relatively sheltered from the larger waves by the corner of land. A limitation of SWAN modeling is that diffraction of waves- the bending of waves around an obstacle – is not well represented as mentioned during calibration; therefore, higher waves than presented below may reach the northern portion of the east beach.

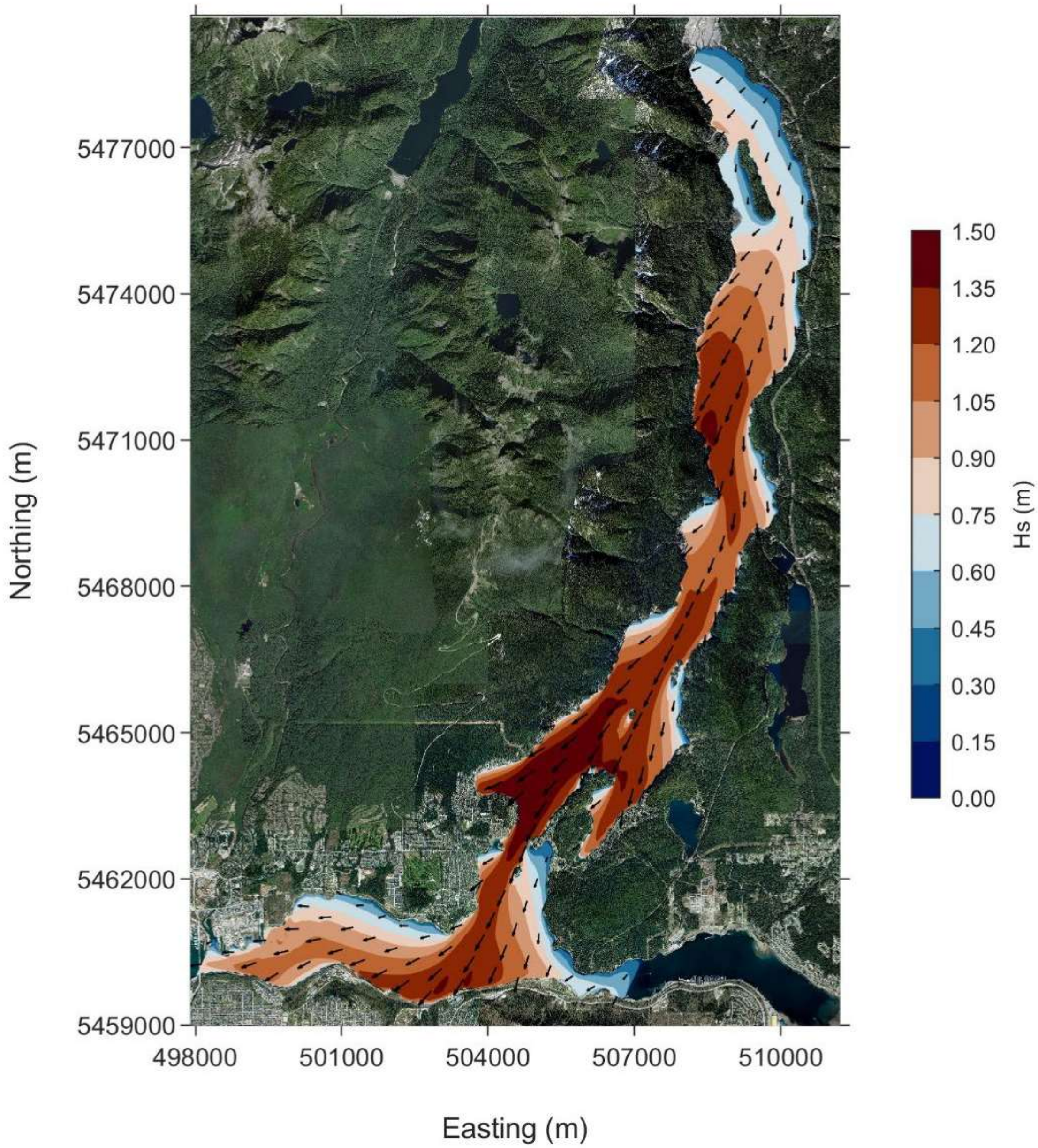

Figure 5.11 Significant wave heights and directions predicted by the SWAN model for a 1% AEP storm event from the northeast.

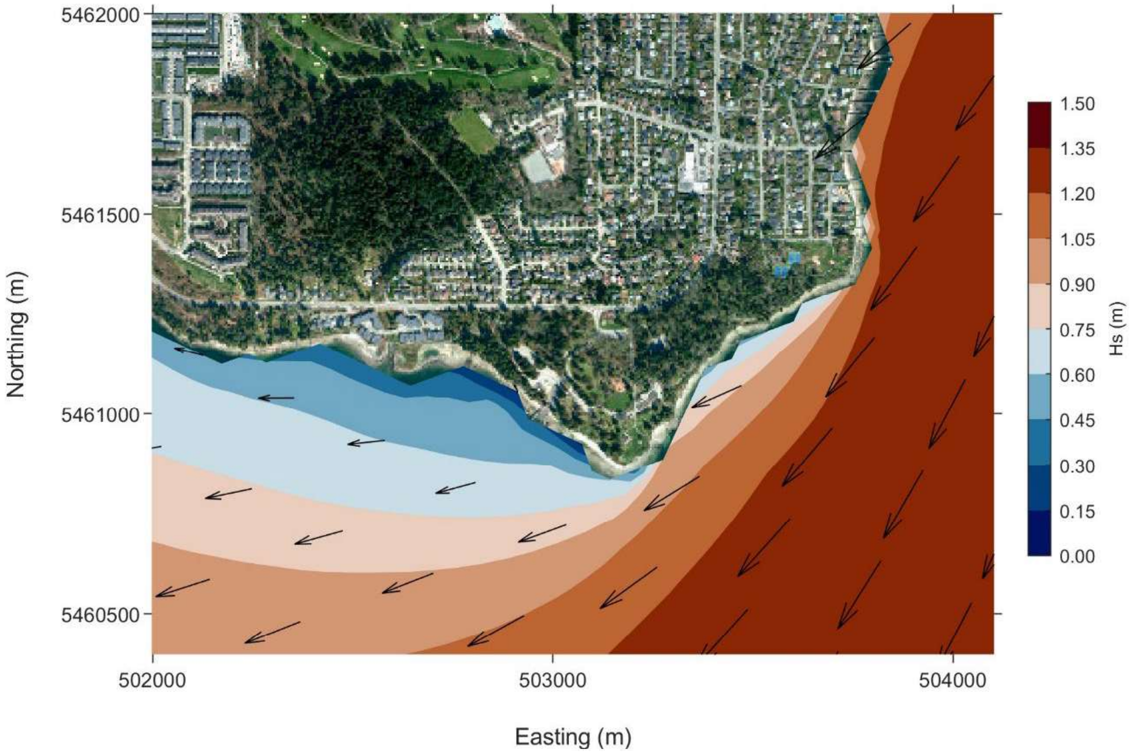

Figure 5.12 Close-up view of the significant wave heights and directions predicted by the SWAN model for a 1% AEP storm event from the northeast at WaW.

The 1% AEP westerly and easterly SWAN runs are shown in Figure 5.13 and the zoomed-in views near WaW for both directions can be seen in Figure 5.14. The results show that westerly storms create high H_s values at the west beach, central beach, and at Roche Point. The easterly storms create moderate H_s values at east beach; however, the northeasterly waves dominate for design conditions. It can be noted again for both the easterly and westerly storms that diffraction is not well represented by SWAN, and that wave values are likely higher where waves would bend around Roche Point.

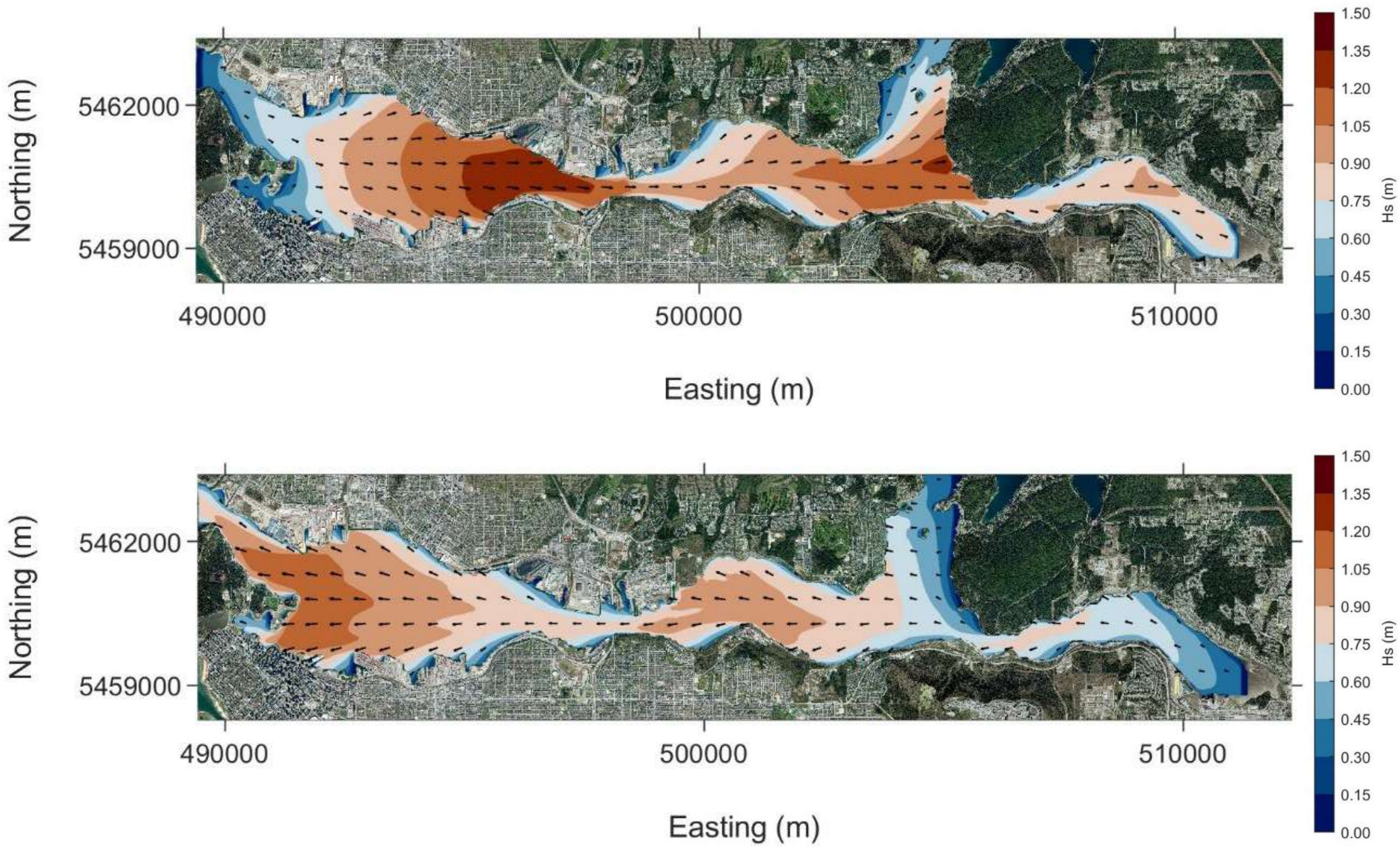

Figure 5.13 Significant wave heights and directions predicted by the SWAN model for 1% AEP storm events from the west (top) and east (bottom).

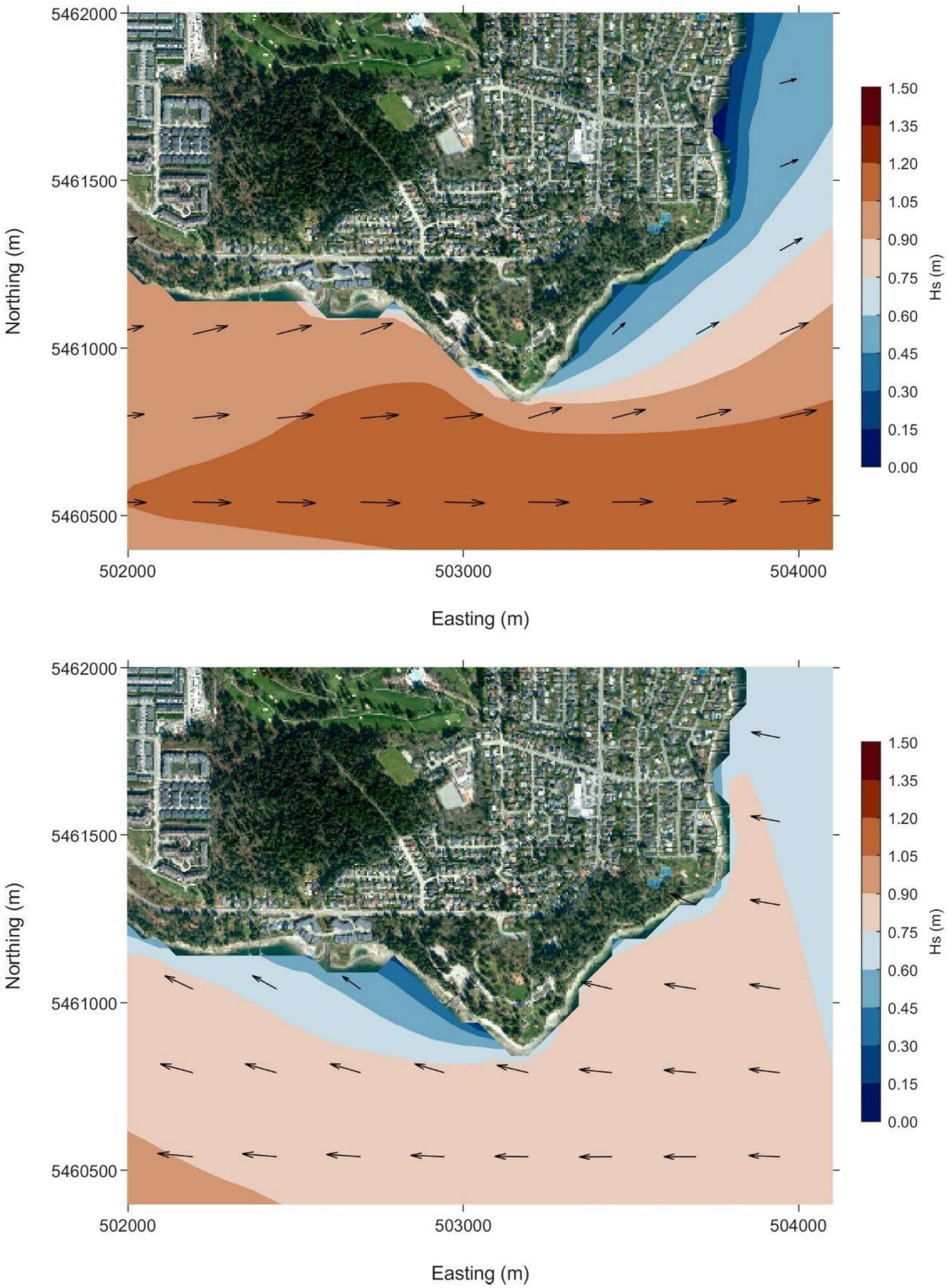

Figure 5.14 Close up of significant wave heights and directions predicted by the SWAN model for 1% AEP storm events from the west (top) and east (bottom) at WaW.

A total of nine output points were included in the SWAN models to monitor wave model output parameters in the offshore near WaW. Figure 5.15 displays seven points along WaW (P1-P7) and two additional points corresponding to the locations of the MarineLabs buoys (B1 and B2).

Figure 5.15 SWAN model output locations.

The full wave characteristics at each output point, as well as the depths, from each SWAN model run can be seen in Appendix B. A summary of these outputs is included below in Table 5.9. It is important to note that these wave conditions are for water depths between 10 – 15 m and the waves would be subject to shoaling and refraction processes, likely reducing the heights further as they came through the nearshore.

The results indicate that both the west and central beach are dominated by waves from the west, with a maximum H_s of 1.1 m and a corresponding T_p of 3.3 s. The east beach WaW is dominated by waves from the NE, with a maximum H_s of 1.3 m and a corresponding T_p of 4.4 s. Therefore, the design conditions are dependent on the westerly and northeasterly winds.

Table 5.9 Consolidated numerical modelling design conditions for wind-generated waves.

Beach(s)	AEP (%)	H_s (m)	T_p (s)	Storm Direction
West, Central	20	0.9	3.3	W
	5	1.0	3.7	W
	1	1.1	3.7	W
East	20	1.1	4.0	NE
	5	1.2	4.0	NE
	1	1.3	4.4	NE

5.3.2 Vessel Generated Wake

The work completed by MarineLabs (2021) as described in Section 2.2 clearly showed that vessel wake resulted in a larger percentage of the energy at Buoy 2 (offshore of WaW east beach) as opposed to Buoy 1 (in front of Tsleil-Waututh reserve). What the information provided to the design team does not include is the estimates of wave height for these vessels derived from the MarineLabs separation algorithm.

From the MarineLabs dataset, pleasure craft are observed to be having the largest impact by frequency at WaW (from datasets at both Buoy 1 and Buoy 2). This is based upon the large percentage of vessels without AIS which are typically smaller pleasure craft style vessel. Recreational vessels between 15 – 25 ft have been shown to generate a maximum wave height of 0.6 m (Maynord, 2005). Tugboats were the second largest vessel type whose wake was recorded. The estimated maximum wave height from a harbour tug vessel is 0.8 m with a period of 3.2 s (Port of Vancouver, 2022). The third most observed vessel type was referred to as a passenger craft vessel. This can be used to refer to passenger ferries, tourist vessels, transit vessels (such as the SeaBus) and even pilot boats. As this is such a wide range of vessels, it is difficult to determine a typical maximum vessel wake. Finally, while rarely observed by the buoys, maximum conditions for cargo ships and tankers were also available from the Port of Vancouver (2022). Expected maximum wave heights (H) and wave period (T) by vessel type are summarized in Table 5.10. At both Buoy 1 and Buoy 2, the highest power levels were created by non-AIS vessels (likely pleasure craft) followed by pleasure craft (with AIS) and then tugs at Buoy 2.

Table 5.10 Summary of maximum expected vessel generated wakes by vessel type.

Vessel Type	H (m)	T (s)	Notes
Pleasure Craft	0.6	N/A	For vessels less than 25ft.
Tug	0.8	3.2	From Port of Vancouver (2022)
Cargo/Tanker	0.2	3.2	

The parametric data provided by MarineLabs was reviewed for the maximum wave height (H_{max}). A typical relationship between H_s and H_{max} in wind generated seas is 1.9 (Kamphuis, 2010); this means that if measured H_s is 1 m, the expected H_{max} over the same time period is 1.9 m. In the 1-year dataset at Buoy 2, H_{max} exceeded 0.6 m 44 times. When comparing these numbers to the corresponding H_s from the same period, the correlation was a minimum of 2.9 to a maximum of 14.9. This indicates that these events are all likely vessel wake measurements and not typical of wind generated seas. Of these 44 waves the distribution is shown in Table 5.11. A single wave event with H_{max} greater than 1 m (1.00124 m) was recorded, and most of the events were less than 0.8 m. Note that at Buoy 1 the largest H_{max} recorded was 0.79 m and only 5 total events greater than 0.6 m were recorded.

Table 5.11 Number of occurrences of maximum wave height greater than 0.6 m recorded at Buoy 1 and Buoy 2.

H_{max} (m)	Buoy 2	Buoy 1
> 1.0	1	-
0.9 – 1.0	-	-

H_{max} (m)	Buoy 2	Buoy 1
0.8 – 0.9	2	-
0.7 – 0.8	15	2
0.6 – 0.7	26	3
TOTAL	**44**	**5**

From these results the maximum values presented in Table 5.10 are reasonable for design; however, the measurement of a single 1 m wave at Buoy 2 indicates that the 0.8 m may apply to tug vessels operating under typical conditions but there may be situations where this is periodically exceeded.

5.4 Currents

A previously developed TELEMAC model of Burrard Inlet was used to assess the impacts of currents at WaW. The TELEMAC SYSTEM is a suite of finite element computer programs developed by the Laboratoire National d'Hydraulique et Environnement (LNHE), a department of Electricité de France's Research and Development Division.

The TELEMAC model mesh used for the study is shown in Figure 5.16. The Tidal boundary was applied to the western extent in English Bay. The 3D model grid contains approximately 19,800 nodes, 37,600 elements and 11 levels in the vertical dimension. The element lengths vary from approximately 200 m in the Strait of Georgia to about 2 m in the Second Narrows. The model mesh length near WaW is 100 m.

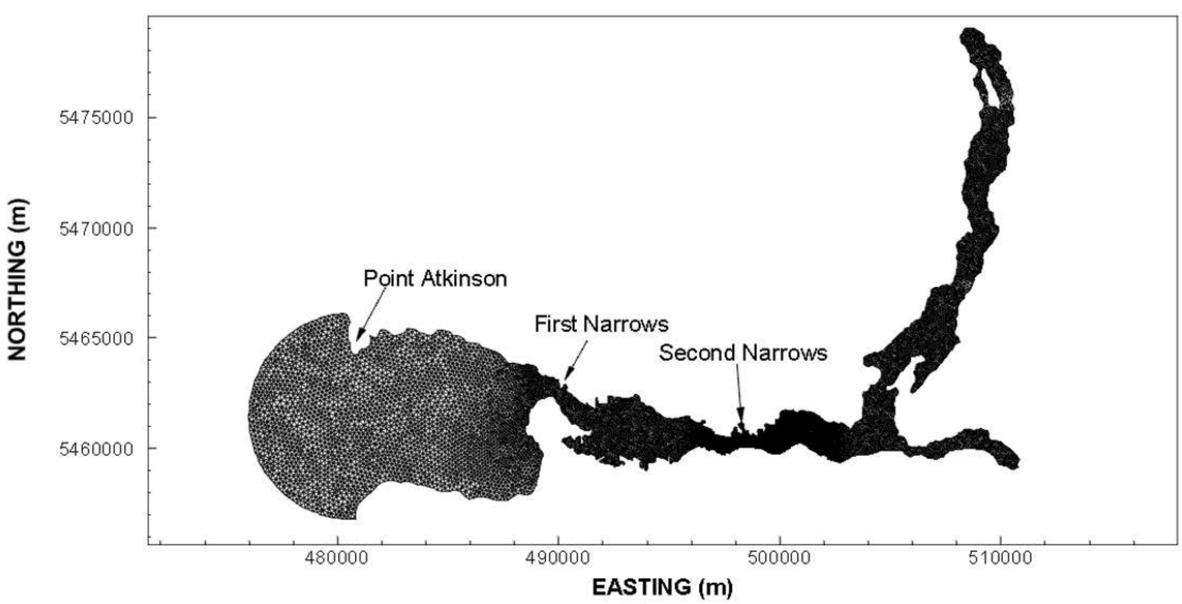

Figure 5.16 TELEMAC model domain.

Tidal fluctuations in the Strait of Georgia are driven by forcing and resonance with the tide cycles of the Pacific Ocean, which are predominantly mixed semidiurnal, having two highs and two lows of unequal height in a lunar day. Due to its larger tidal range, tidal currents are much higher at spring tide than at neap tide. To establish design scenarios, a hydraulic model simulation was conducted utilizing the 2022 king tide[4] period between December 21st and 29th, 2022. Tides from November 1, 2022, to January 1, 2023, are shown in Figure 5.17 to highlight the slight differences between tidal cycles.

Due to the deep water and non-shallow areas of the inlets (Strait of Georgia and Vancouver Harbour), there is not an expectation for there to be significant changes in tidal magnitude with sea level rise.

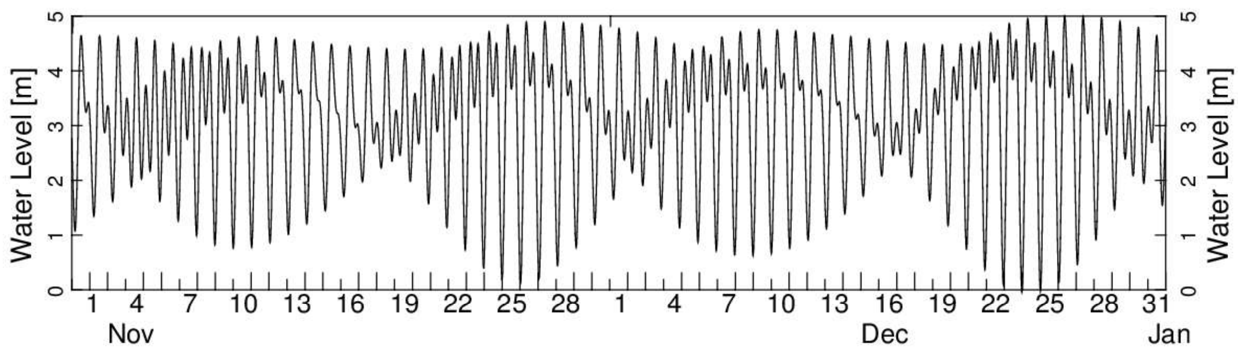

Figure 5.17 Predicted tides (Elevation in CD) at Point Atkinson from November 1st to December 31st, 2022 (times in PST).

Figure 5.18 and Figure 5.19 show the depth-averaged surface current velocities during the flood tide at 5 am on December 25, 2022 (PST), and the depth-averaged surface current velocities during the ebb tide at 10 pm on December 24, 2022 (PST) respectively. These times coincide with the peak velocities that occur during the simulation. The colour map indicates the surface current speed, and the vectors represent current direction and magnitude. The analysis found that the tidal current velocities are higher during the flood tide than during the ebb tide at WaW. Maximum modelled surface velocity near the project site is 0.36 m/s with the strongest velocities located in a jet slightly offshore of WaW. These conclusions are in general agreement with those of Meijers (2021) who also found higher velocities in this region of Burrard Inlet during the flood tide.

[4] A king tide is an especially high spring tide.

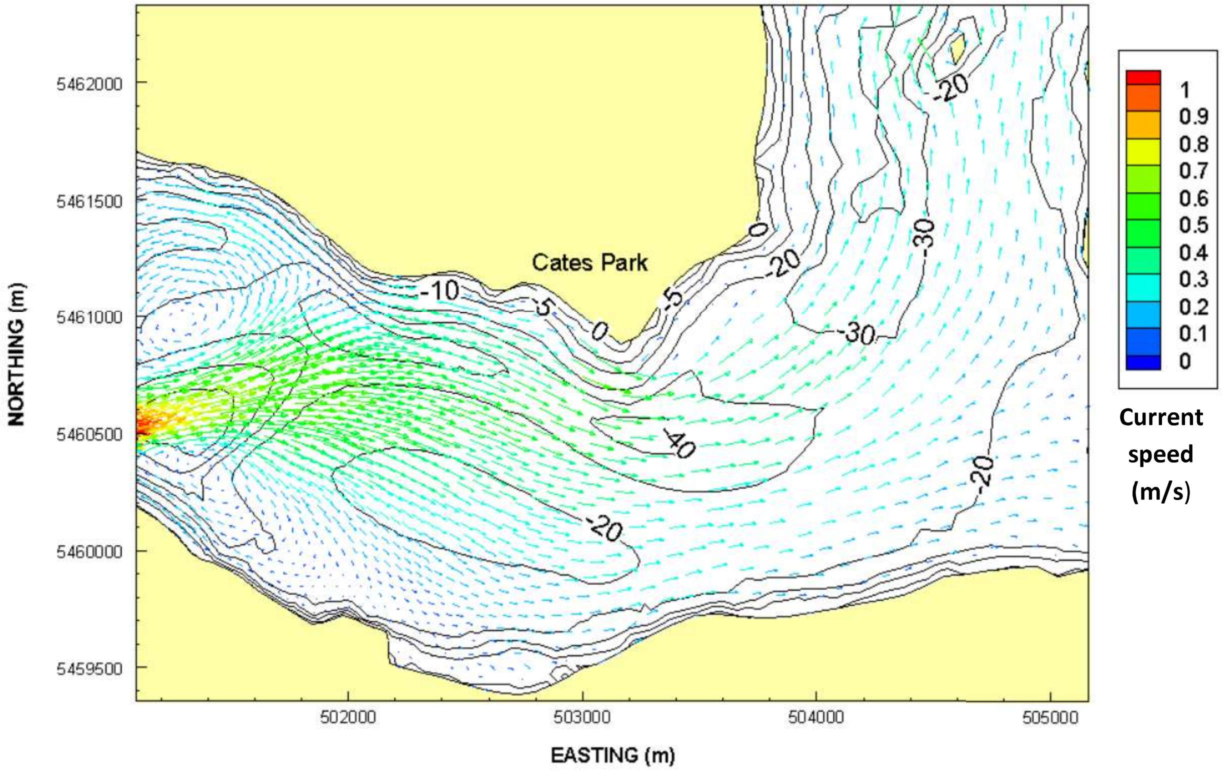

Figure 5.18 Modeled current velocities and circulation near WaW, showing peak velocities during the flood tide at 5am on December 25, 2022.

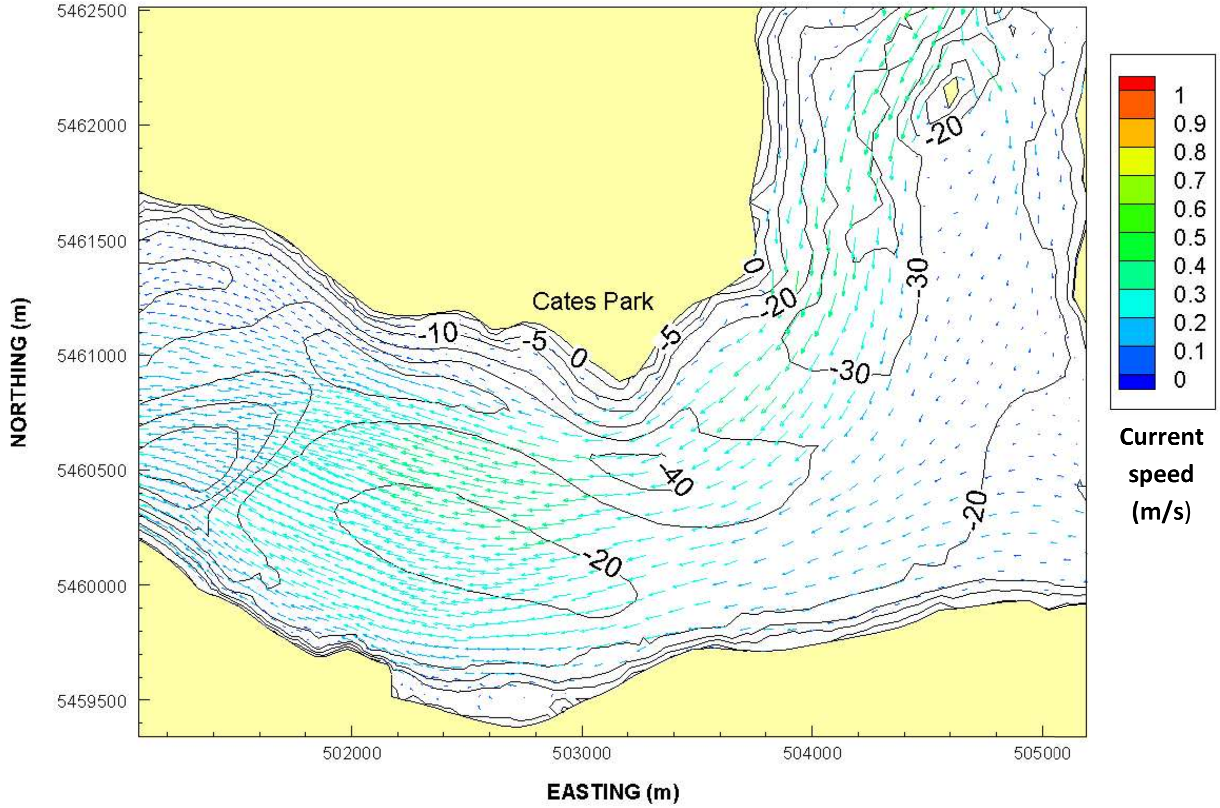

Figure 5.19 Modeled current velocities and circulation near WaW showing peak velocities during the ebb tide at 10pm on December 24, 2022.

6 SUMMARY

Whey-Ah-Wichen (Cates Park) is located uniquely within Burrard Inlet at the confluence of multidirectional tidal currents, winds from the west, east and north and is exposed to a busy vessel corridor contributing vessel generated waves (wakes) to the wave climate. Currents at the site may be driven by both winds and tides. Water level variations at the site due to tides and storm surge (as much as 0.4 to 0.8 m above high tide levels) affect the exposure of the beach and bluffs to wave and current action. The site is also subject to long term relative sea level rise with up to 0.56 m of relative rise expected by 2050 and greater than 1 m by 2100.

The site has a history of erosion of the backshore bluffs that has likely been exacerbated by high public use and interruptions to sediment delivery from both within and outside of the park. Modifications of the shoreline are present and include previous nourishment projects as well as attempts at slowing erosional processes using large boulders. Generally, the full system shows signs of sediment starvation and lack of sediment input. In total, there is an approximate length of 250 m where shoreline erosion was observed and an approximate length of 370 m where there is potential for future shoreline erosion or where shoreline erosion is possible based on observed indicators.

Previous studies of WaW were reviewed and supplemented with a site visit, geomorphological assessment and a coastal processes analysis. The key findings were broken down per segment (see Figure 1.1) and include:

- **West Beach.** This segment has limited sediment available which is clear by the coarse sediment found on the surface throughout the area. Beach lowering was identified at the western end which is likely associated with recent changes (addition of boulder clusters). Evidence of erosion of the back beach was observed. Adjacent to the boat launch is also particularly coarse material and starved of finer sediments. Sediment transport is expected to occur primarily from west to east. The west beach is the least exposed to vessel wake and experiences wind-generated waves from storms approaching from the west and the east. The area is sheltered from waves from the north.
- **Central Beach.** The section is the least sediment starved of the three beaches, likely due to the nourishment completed in 2014. Significant areas of backshore erosion were noted at the picnic shelter and at Roche Point. Similar to the west beach, the beach adjacent to the boat launch had coarser materials noted that the rest of the stretch. Material eroding from Roche Point appears to be depositing directly to the west and migrating along the central beach. Primary wave exposure is due to wind generated waves from the west and east and also vessel wake. The area is sheltered from waves from the north.
- **East Beach.** This segment is characterized by significant amounts of back beach erosion which has had boulders placed in front as a form of protection. The entire east beach is sediment starved and, in some locations, completely devoid of mobile sediment where consolidated till is exposed. The exception to this is a centrally located pocket beach where sandy and shelly sediment is present on the inter-tidal foreshore. The boulder placements along this reach have further reduced sediments available to the system. Bluffs near Roche Point above the east beach also show signs of groundwater flow in the form of sapping and piping which also likely contribute to bluff slope failures This section is the most exposed to vessel wakes with significant pleasure craft and tug vessels having a further impact on the shoreline. Governing waves are likely driven by northerly outflow winds from Indian Arm; however, storms also approach from the east. The East Beach is sheltered from waves arriving from the west

The key conclusions are that the system has a sediment deficit. This is likely due to many factors outside of WaW but is being worsened by the protection of the sediment bluffs within the park. For future success a sediment source will either need to be imported and maintained, or an equilibrium with the material available onsite will need to be established.

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APPENDIX A

TIMESERIES OF SELECTED WIND DATASETS

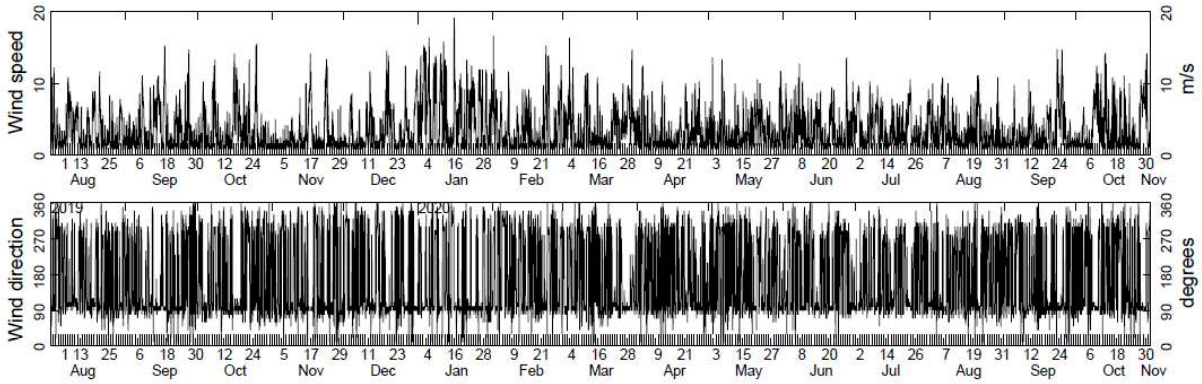


Figure A. 1 Point Atkinson wind data timeseries plot.

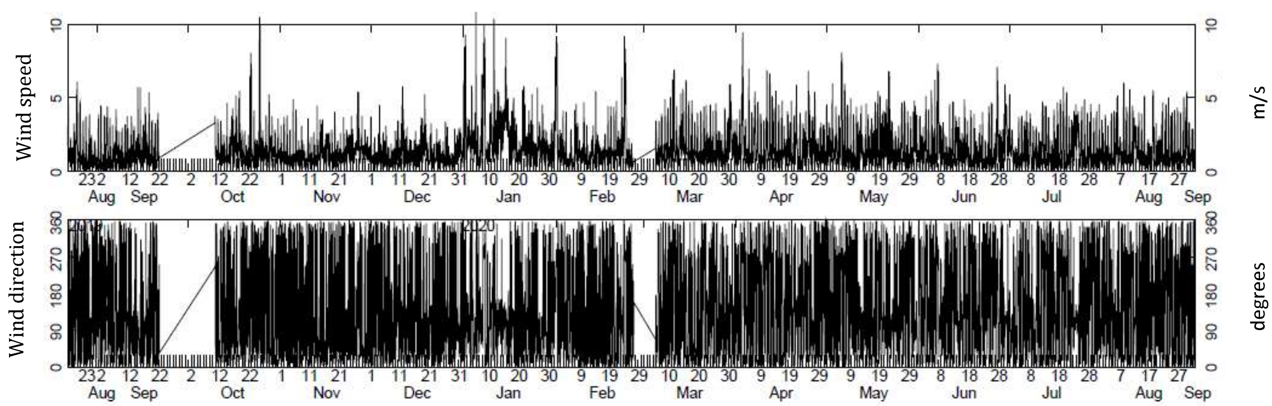


Figure A. 2 MarineLabs Buoy 1 (offshore of TWN Reserve) wind data timeseries plot

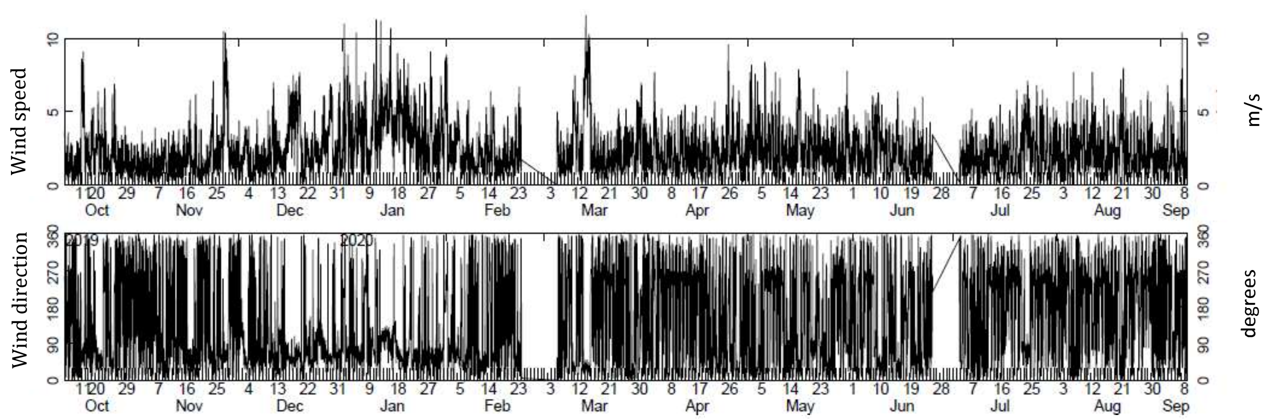


Figure A. 3 MarineLabs Buoy 2 (offshore of east beach) timeseries plot

APPENDIX B

DETAILED NUMERICAL MODELLING RESULTS

Table B. 1 Numerical model SWAN output parameters offshore of the project site at various locations for model runs from three directions (northeast, east and west). Parameters shown below include significant wave height (H_s), peak wave period (T_p) and peak wave direction (Dir).

Direction	AEP (%)	Point	B1	P7	P1	P2	P3	P4	B2	P5	P6
		Depth (m)	26.3	10.8	12.8	12.1	13.4	16.8	23.7	17.1	11.5
NE	1	H_s (m)	0.5	0.5	0.6	0.7	1.0	1.0	1.1	1.2	1.3
		T_p (s)	1.9	1.7	1.7	3.0	3.3	3.3	3.7	4.4	4.4
		Dir (deg)	77	78	75	74	64	62	55	50	38
	5	H_s (m)	0.5	0.5	0.5	0.7	0.9	0.9	1.0	1.1	1.2
		T_p (s)	1.7	1.7	1.7	3.0	3.3	3.3	3.3	4.0	4.0
		Dir (deg)	74	74	73	73	64	62	55	49	38
	20	H_s (m)	0.5	0.4	0.5	0.6	0.9	0.9	0.9	1.0	1.1
		T_p (s)	1.7	1.7	1.7	3.0	3.3	3.3	3.3	4.0	4.0
		Dir (deg)	72	80	75	73	64	61	54	48	37
E	1	H_s (m)	0.7	0.5	0.6	0.8	0.8	0.8	0.8	0.8	0.8
		T_p (s)	3.3	3.0	3.0	3.0	3.0	3.0	3.0	3.0	2.8
		Dir (deg)	128	129	125	108	97	100	101	104	100
	5	H_s (m)	0.6	0.5	0.5	0.7	0.8	0.8	0.8	0.7	0.7
		T_p (s)	3.3	3.0	3.0	3.0	3.0	3.0	3.0	2.8	2.8
		Dir (deg)	128	128	125	107	97	100	100	104	100
	20	H_s (m)	0.6	0.5	0.5	0.7	0.8	0.8	0.7	0.7	0.7
		T_p (s)	3.0	3.0	3.0	3.0	3.0	3.0	2.8	2.8	2.8
		Dir (deg)	128	128	125	107	97	100	100	104	99
W	1	H_s (m)	0.9	1.0	1.1	1.1	1.1	0.7	0.7	0.6	0.6
		T_p (s)	3.3	3.7	3.7	3.7	3.7	3.7	3.7	3.7	2.8
		Dir (deg)	243	251	259	263	262	236	236	230	238
	5	H_s (m)	0.8	0.9	1.0	1.0	1.0	0.6	0.6	0.5	0.5
		T_p (s)	3.3	3.3	3.3	3.7	3.7	3.7	3.3	3.3	2.5
		Dir (deg)	243	252	259	263	263	236	236	230	225
	20	H_s (m)	0.8	0.8	0.9	0.9	0.9	0.5	0.5	0.5	0.4
		T_p (s)	3.0	3.3	3.3	3.3	3.3	3.3	3.3	3.3	2.3
		Dir (deg)	244	252	259	264	263	237	236	230	223

APPENDIX C

SURFACE SEDIMENT IMAGES

2023 PSD Images

Photo 1 Surface sediment image for sample 2023-1.

Photo 2 Surface sediment image for sample 2023-2.

Photo 3 Surface sediment image for sample 2023-3.

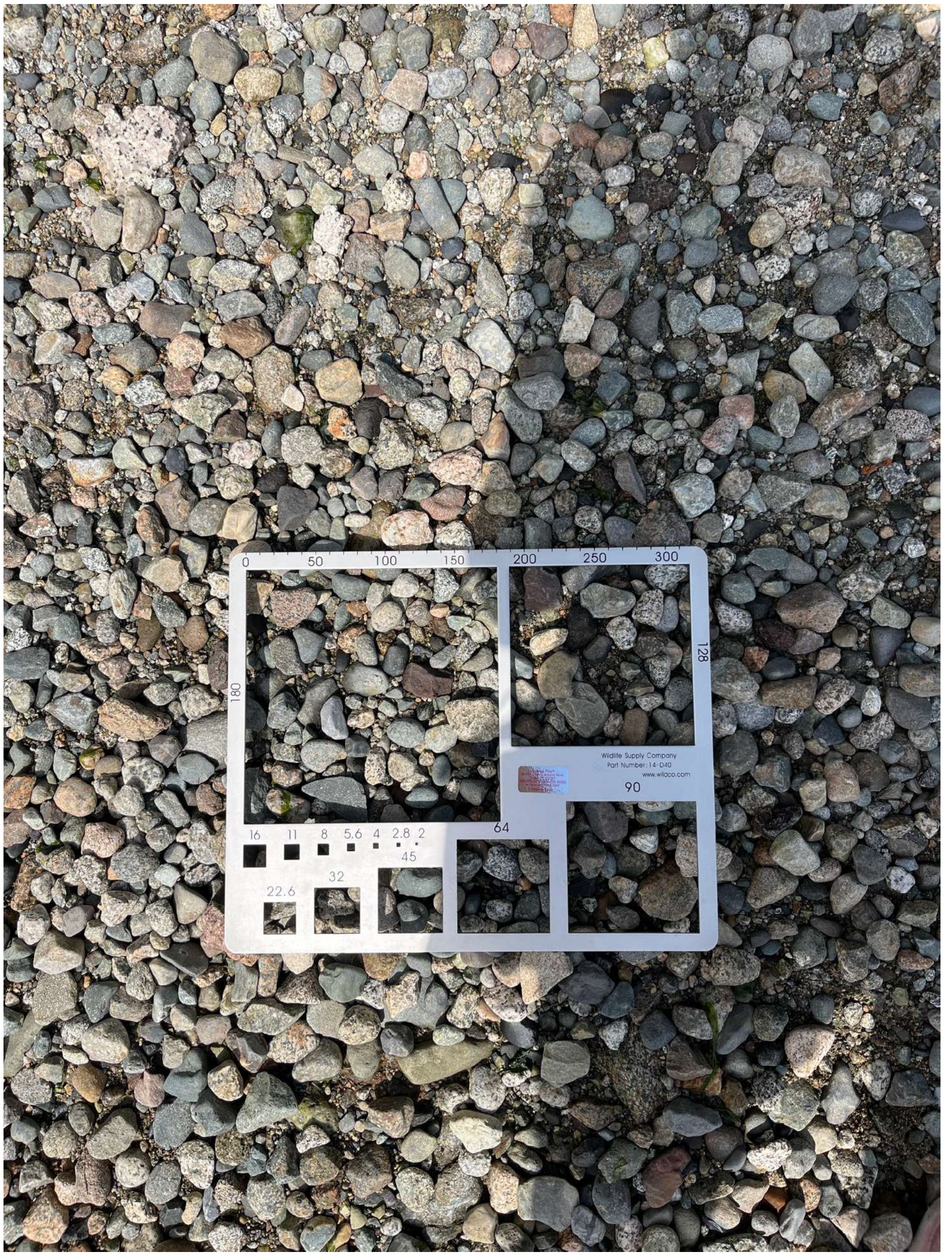


Photo 4 Surface sediment image for sample 2023-4.

2024 PSD Images

Photo 5 Surface sediment image for sample 2024-1.

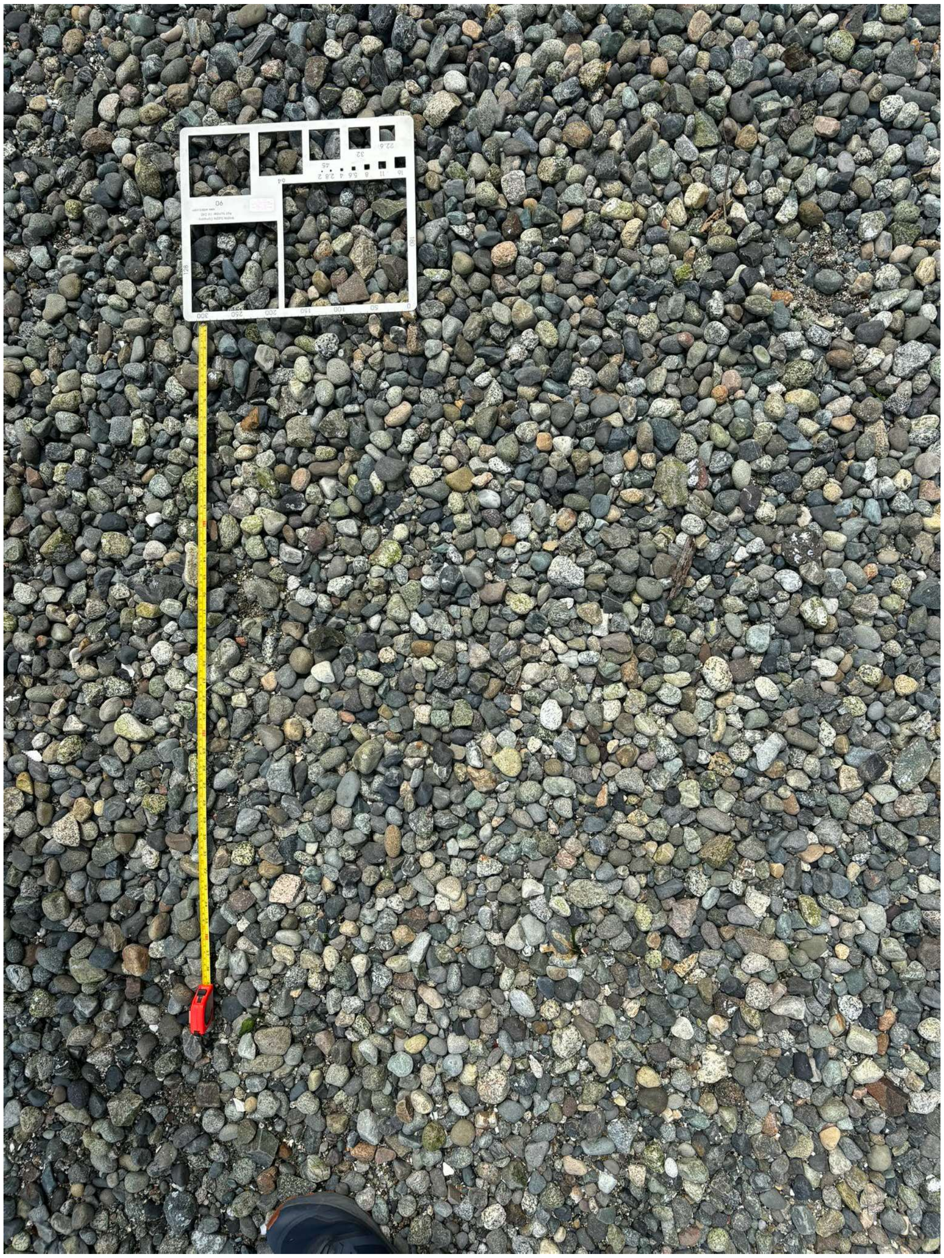


Photo 6 Surface sediment image for sample 2024-2.

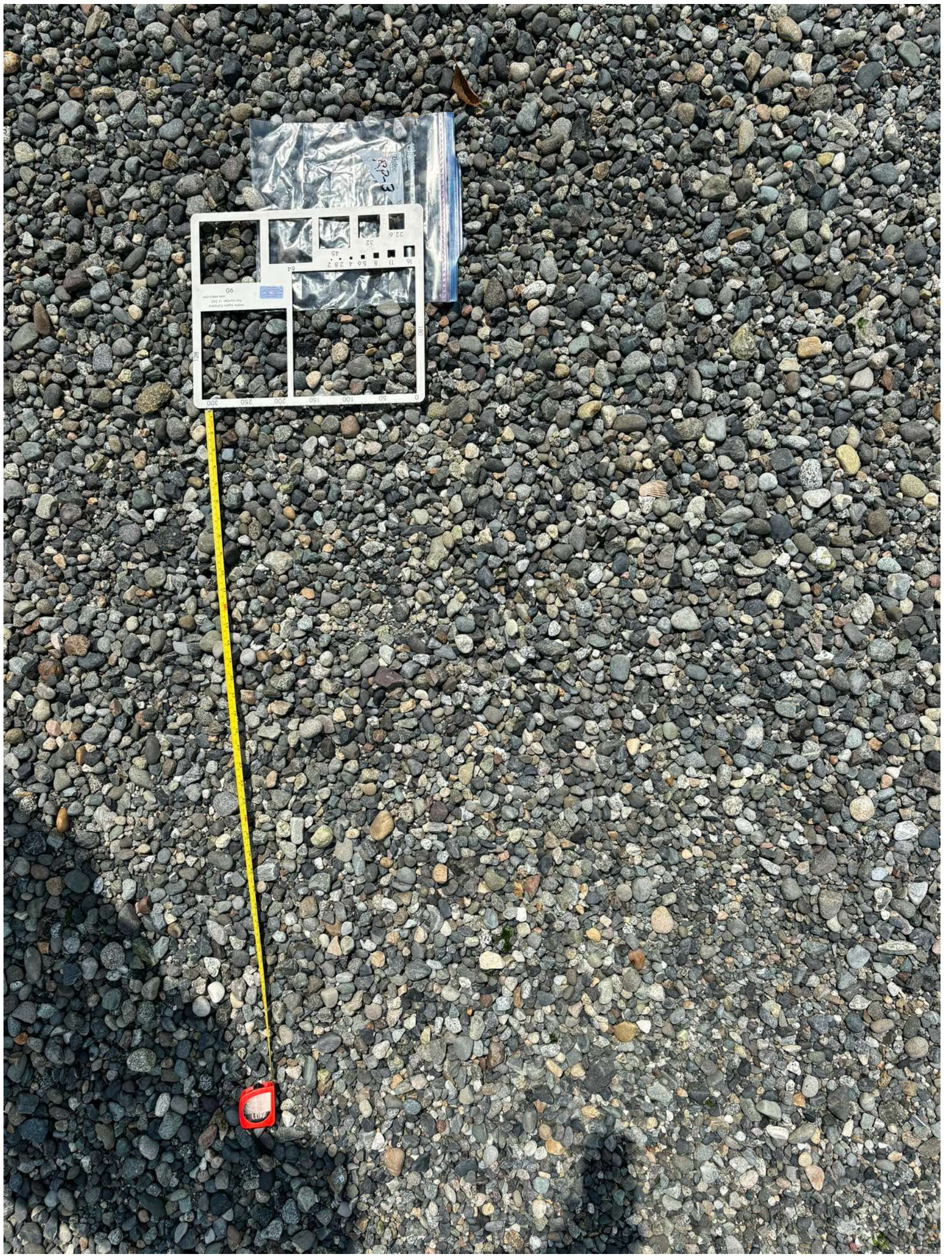


Photo 7 Surface sediment image for sample 2024-3.

Photo 8 Surface sediment image for sample 2024-4.

APPENDIX D

XBEACH MODEL RESULTS

XBeach 2D Surfbeat Model Results

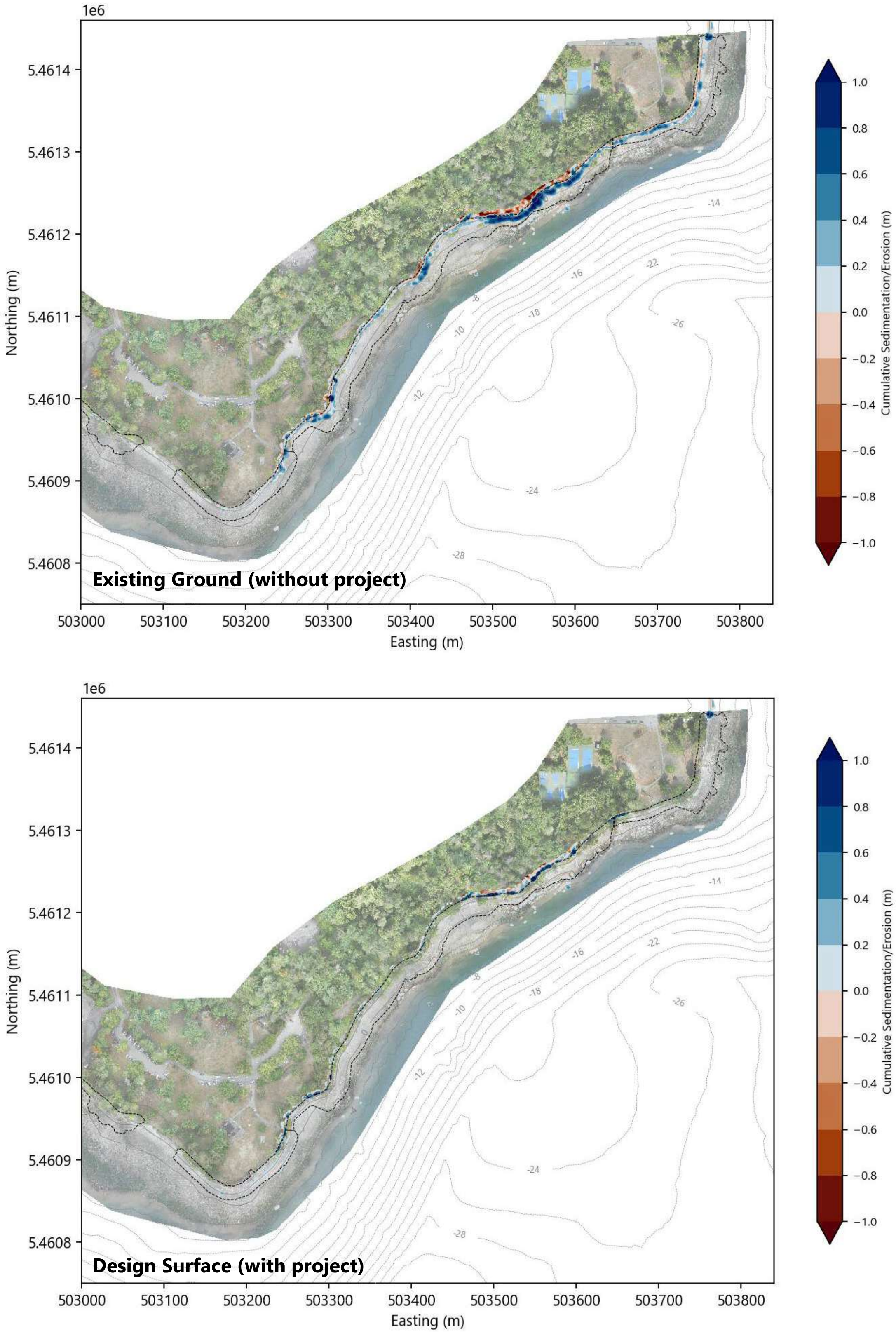


Figure 1 **Cumulative sedimentation/erosion during 5% AEP NE wind event occurring during a 10% AEP water level event with the existing beach (top) and the design surface (bottom) with sediment type MSG2. The black dashed line shows the project design footprint.**

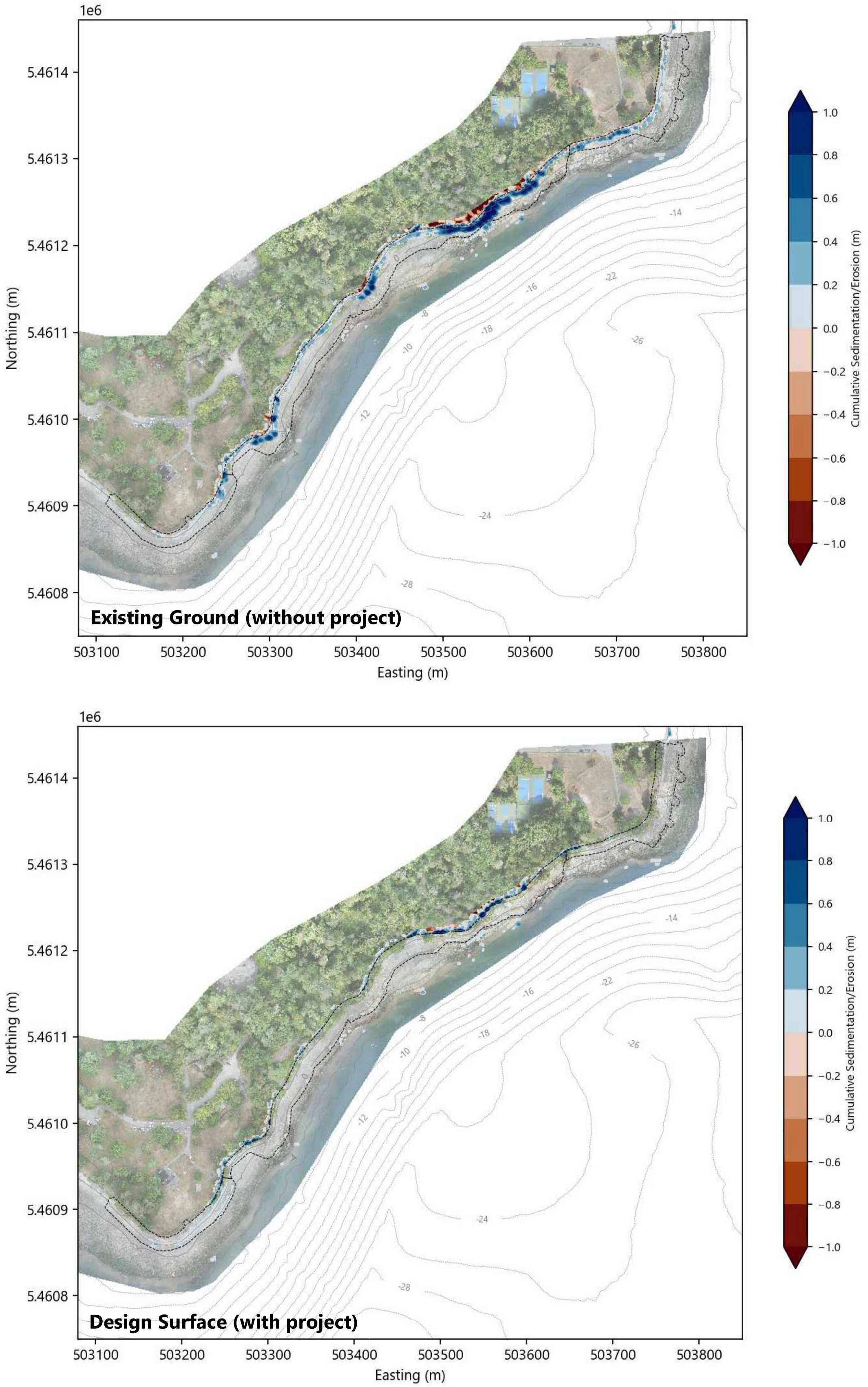


Figure 2 **Cumulative sedimentation/erosion during 5% AEP E wind event occurring during a 10% AEP water level event with the existing beach (top) and the design surface (bottom) with sediment type MSG2. The black dashed line shows the project design footprint.**

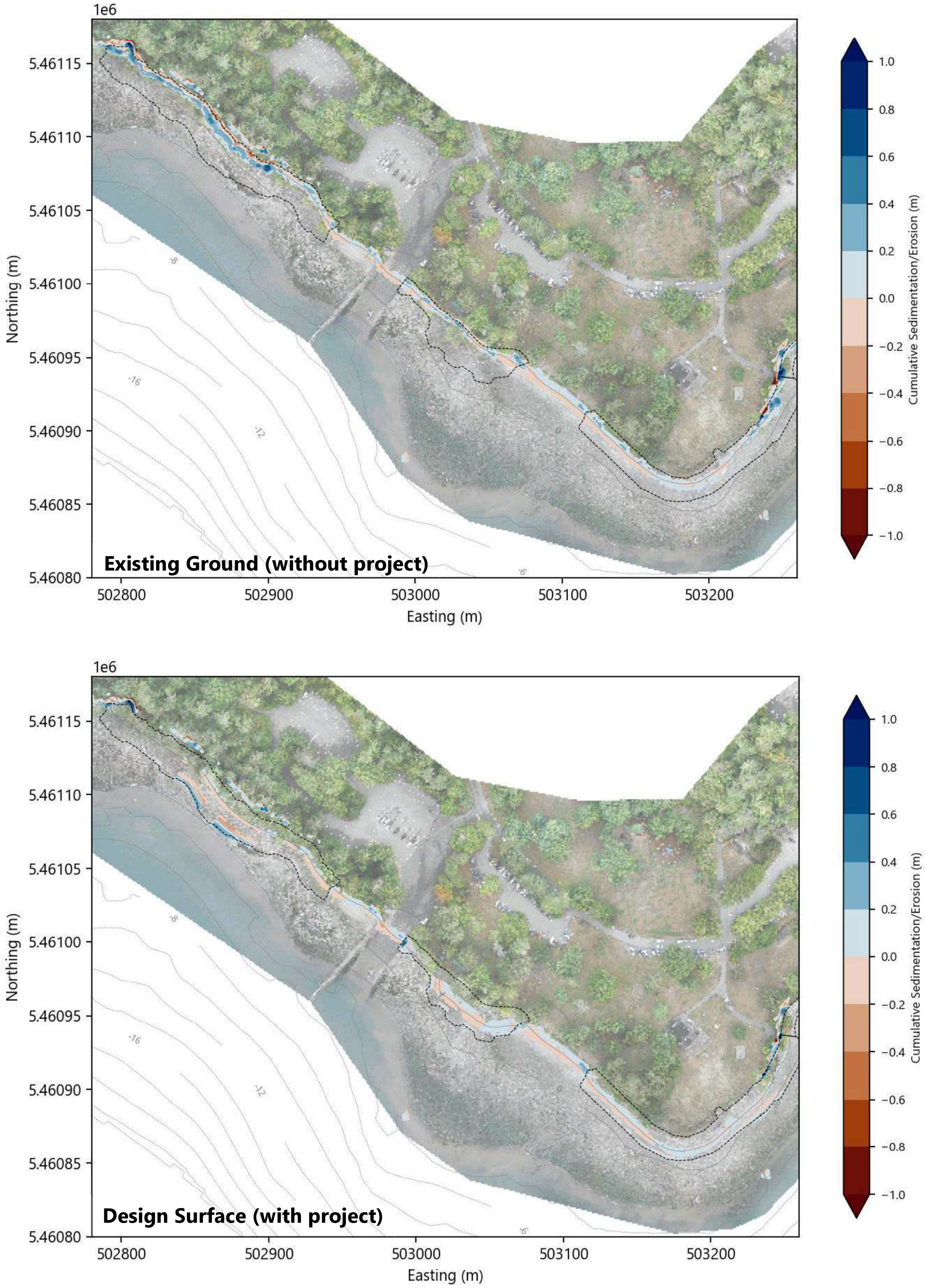


Figure 3 **Cumulative sedimentation/erosion during 5% AEP W wind event occurring during a 10% AEP water level event with the existing beach (top) and the design surface (bottom) with sediment type MSG2. The black dashed line shows the project design footprint.**

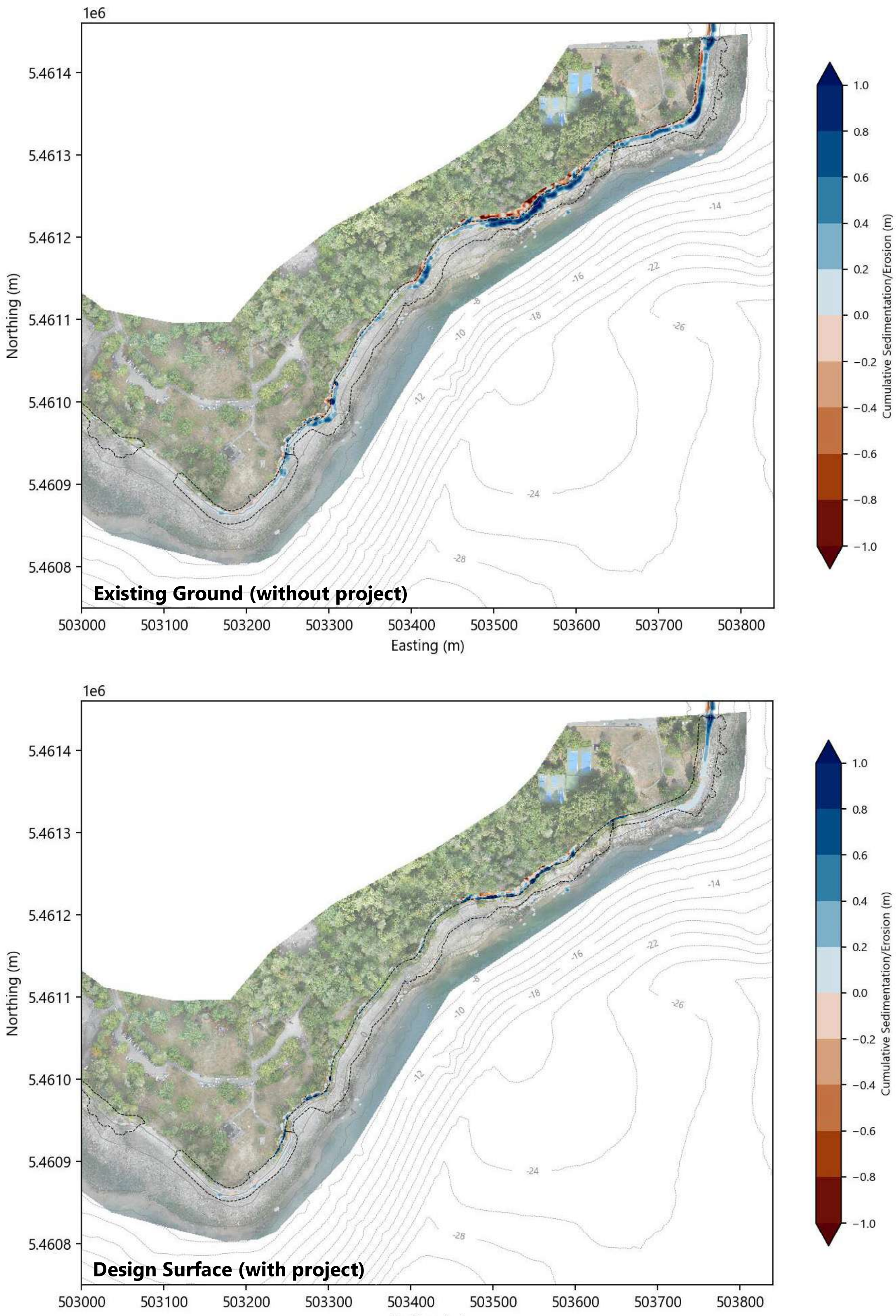
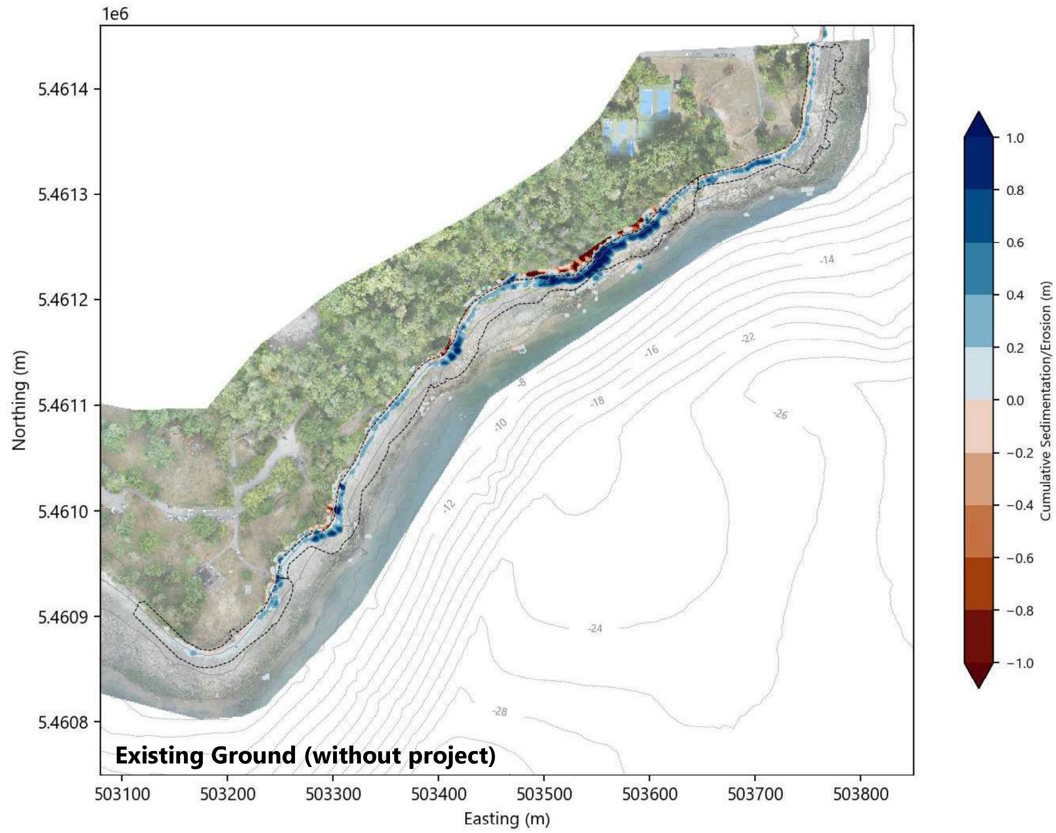


Figure 4 **Cumulative sedimentation/erosion during 5% AEP NE wind event occurring during a 10% AEP water level event with the existing beach (top) and the design surface (bottom) with sediment type MSG3. The black dashed line shows the project design footprint.**



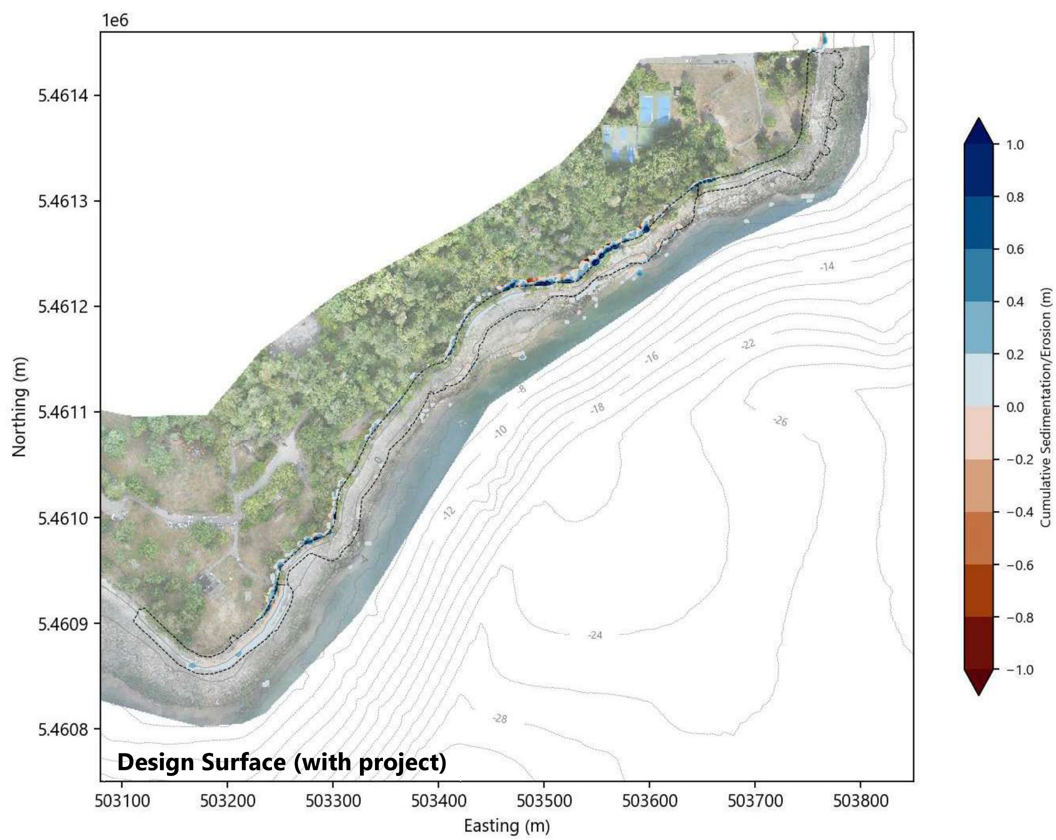


Figure 5 **Cumulative sedimentation/erosion during 5% AEP E wind event occurring during a 10% AEP water level event with the existing beach (top) and the design surface (bottom) with sediment type MSG3. The black dashed line shows the project design footprint.**

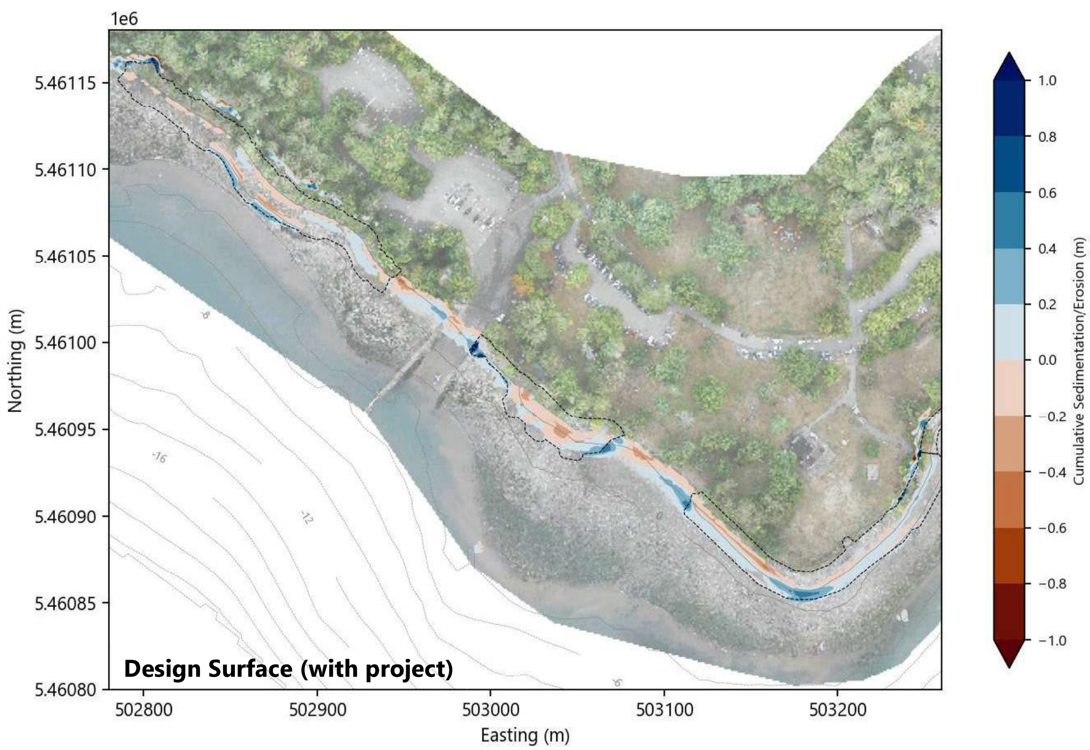


Figure 6 **Cumulative sedimentation/erosion during 5% AEP W wind event occurring during a 10% AEP water level event with the existing beach (top) and the design surface (bottom) with sediment type MSG3. The black dashed line shows the project design footprint.**

XBeach-G 1D Results

Roche Point (D-5) – West Section (MSG2)

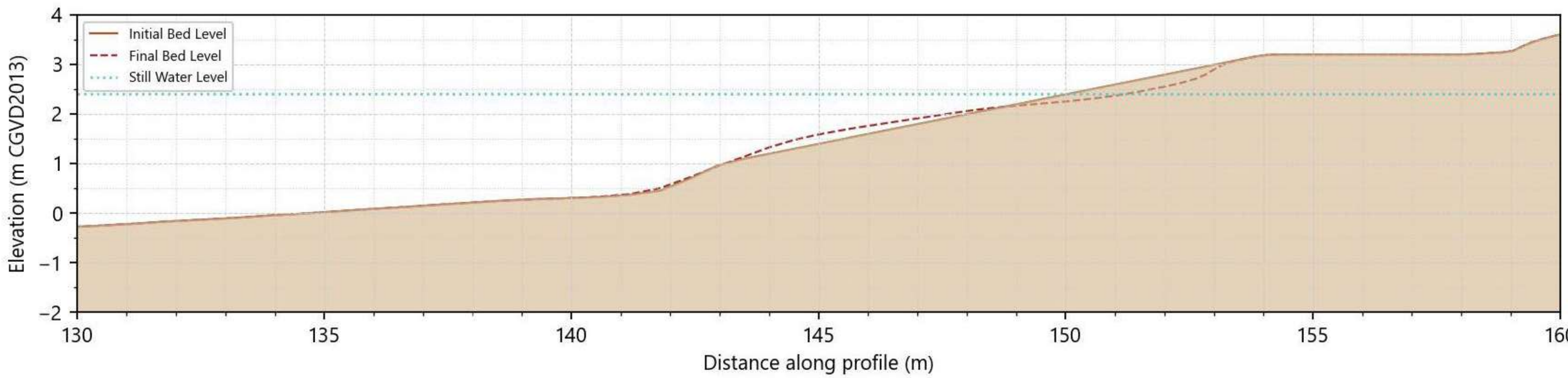


Figure 7 **XBeach-G 1D Roche Point – southwest section before and after 5% AEP storm with 10% AEP water level and MSG2 sediment type.**

Roche Point (D-7) – East Section (MSG2)

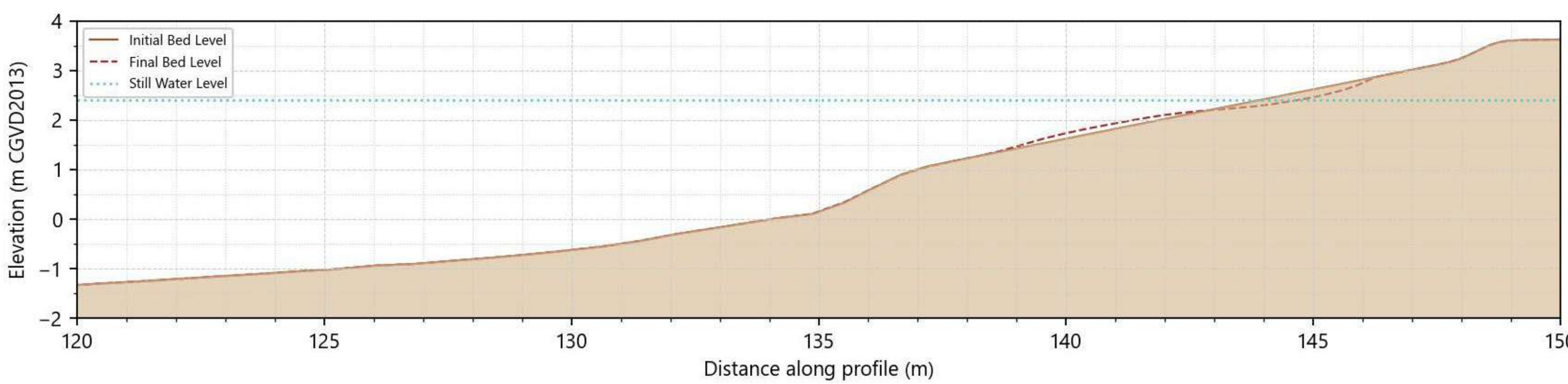


Figure 8 **XBeach-G 1D Roche Point – east section before and after 5% AEP storm with 10% AEP water level and MSG2 sediment type.**

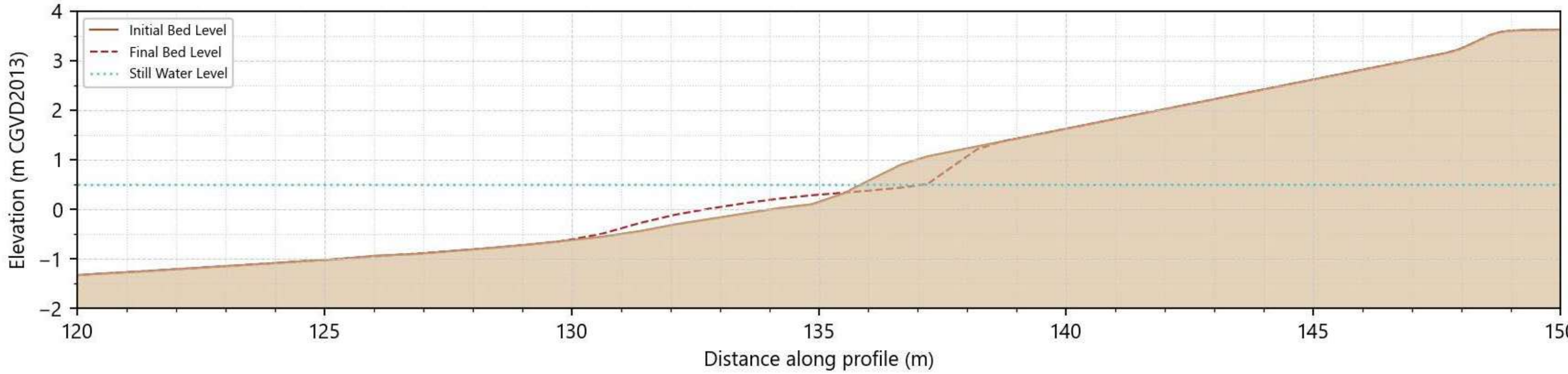


Figure 9 XBeach-G 1D Roche Point – east section before and after 5% AEP storm with MWL water level and MSG2 sediment type.

East Beach (D-9) – Cobble Berm (MGC1)

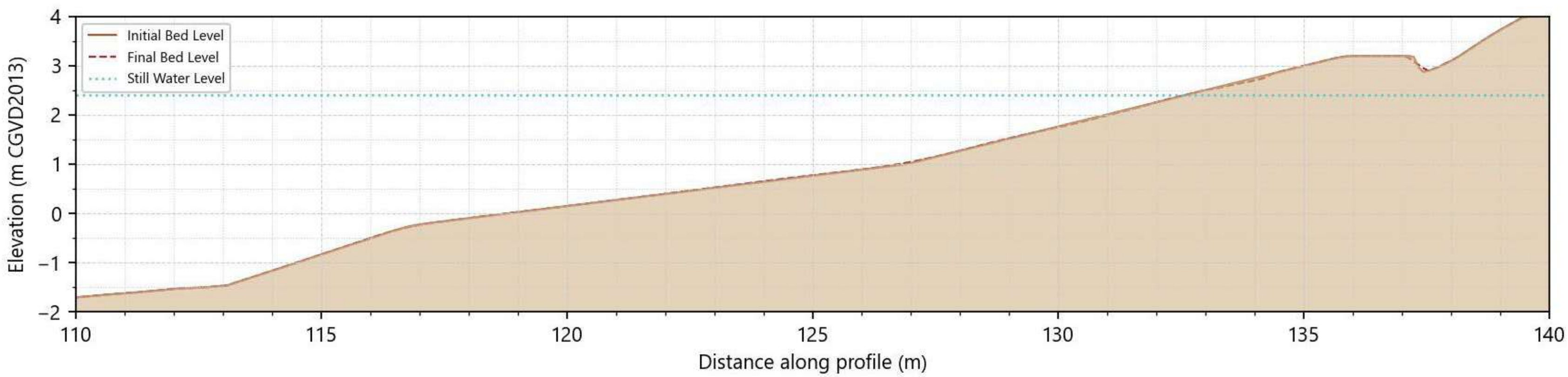


Figure 10 XBeach-G 1D East Beach section before and after 5% AEP storm with 10% AEP water level and MGC1 sediment type.

East Beach (D-9) – Beach Nourishment (MSG2)

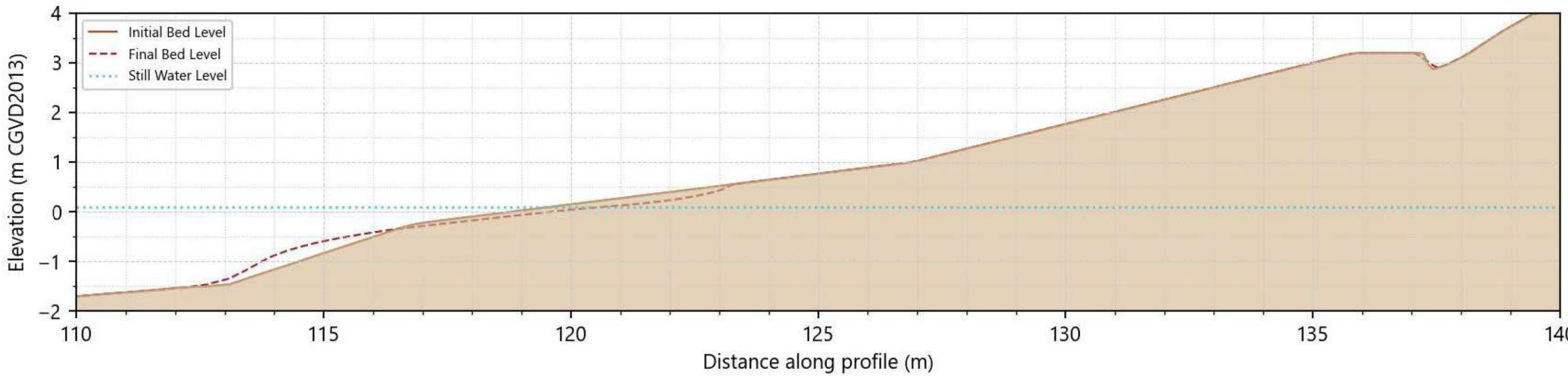


Figure 11 XBeach-G 1D East Beach section before and after 5% AEP storm with MWL water level and MSG2 sediment type.

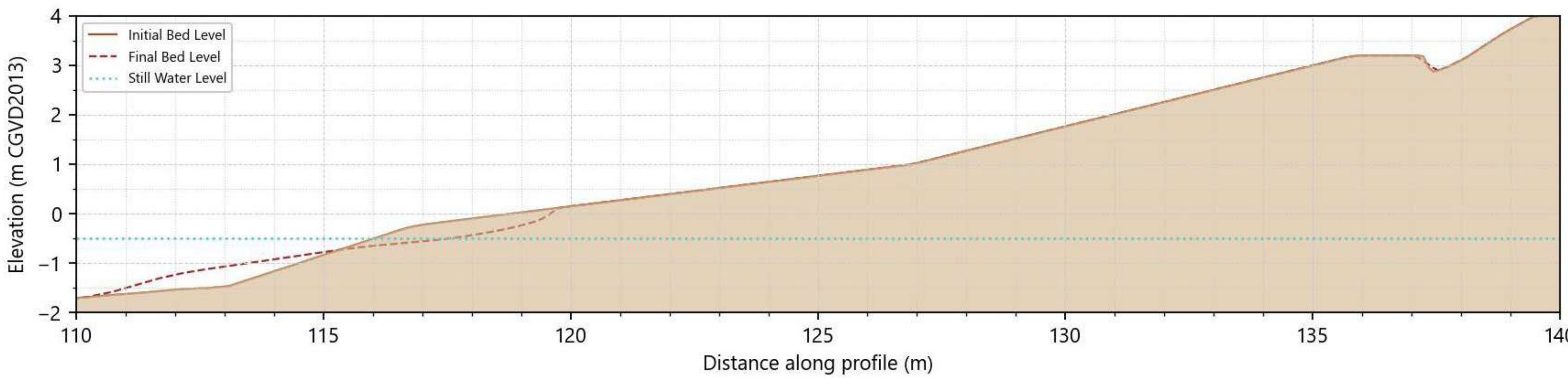


Figure 12 XBeach-G 1D East Beach section before and after 5% AEP storm with -0.5 m CGVD28 water level and MSG2 sediment type

Revised Design

Roche Point – Southwest Section (D-5) – Beach Nourishment (MSG2)

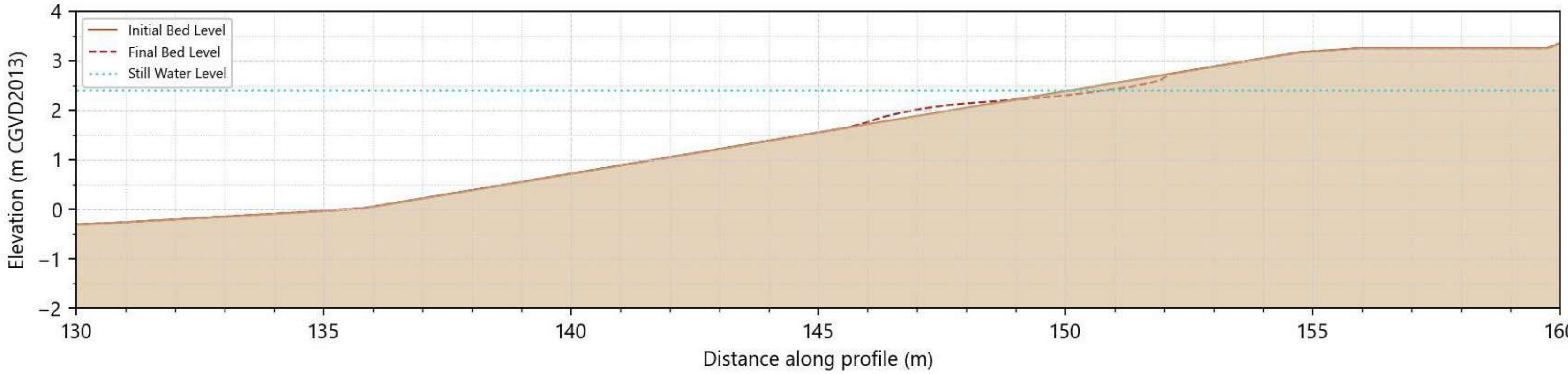


Figure 13 XBeach-G 1D Roche Point – southwest revised section before and after 5% AEP storm with 10% AEP water level and MSG2 sediment type. Beach slope reduced to 6H:1V and extended to existing ground.

Roche Point – East Section (D-7) - Beach Nourishment (MSG2)

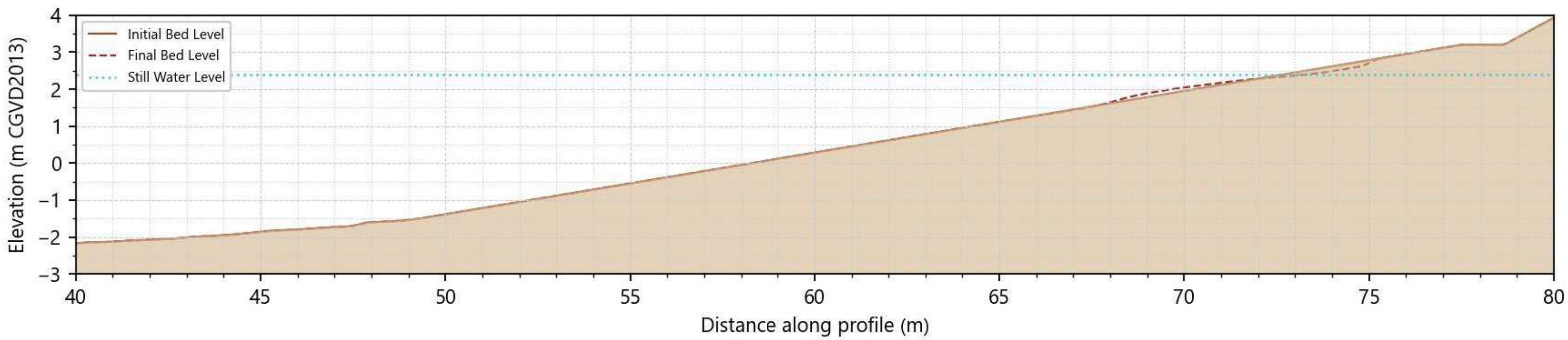


Figure 14 XBeach-G 1D Roche Point – east revised section before and after 5% AEP storm with 10% AEP water level and MSG2 sediment type. Beach slope reduced to 6H:1V and extended to existing ground.

East Beach Section (D-9) – Cobble Toe (MGC2)

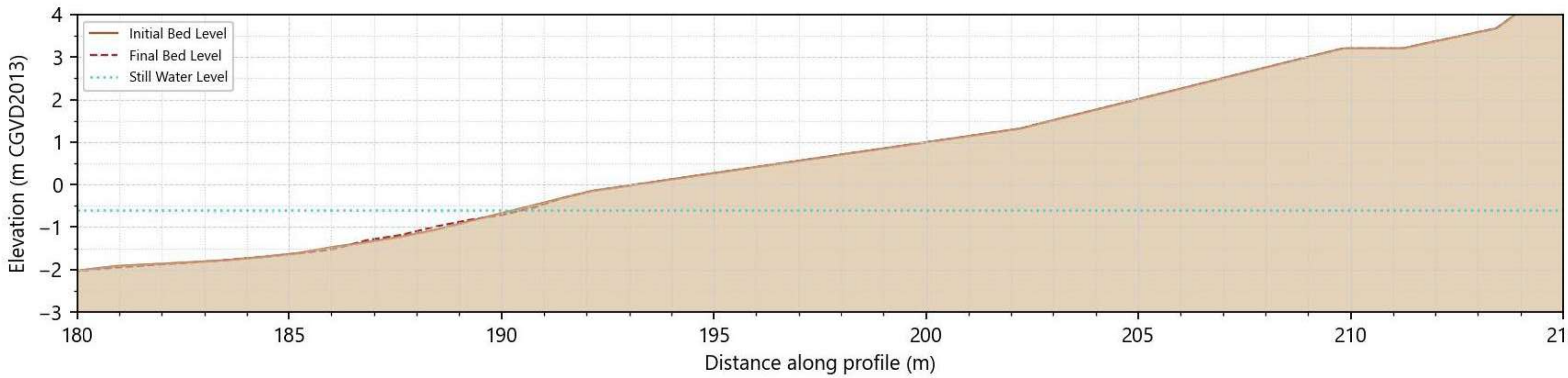


Figure 15 **XBeach-G 1D East Beach (D-9) revised section before and after 5% AEP storm with -0.5 m CGVD28 water level and MSG2 (beach nourishment) and MGC2 (toe) sediment types. Toe slope reduced to 4H:1V and sediment type changed to cobble with D50 = 90 mm.**

East Beach – Pocket Beach Section (D-11) – Beach Nourishment (MSG2)

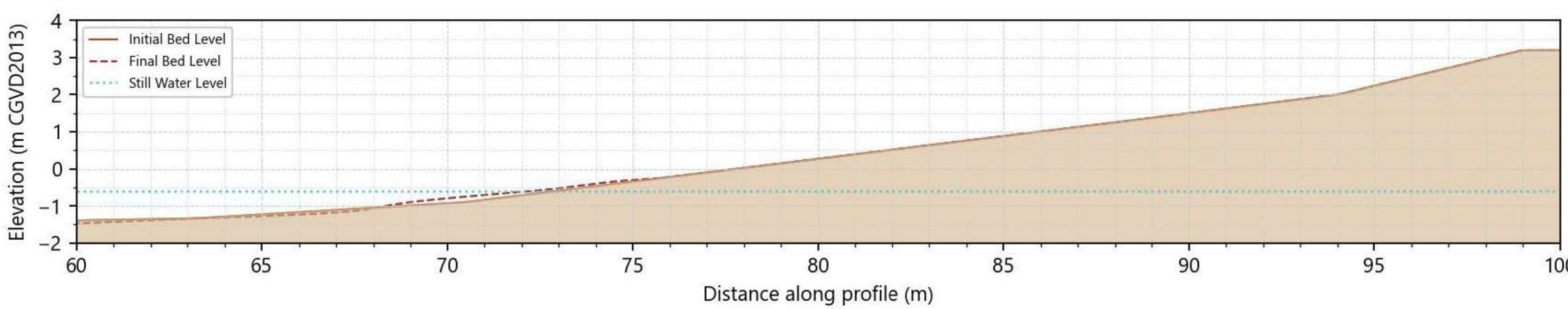
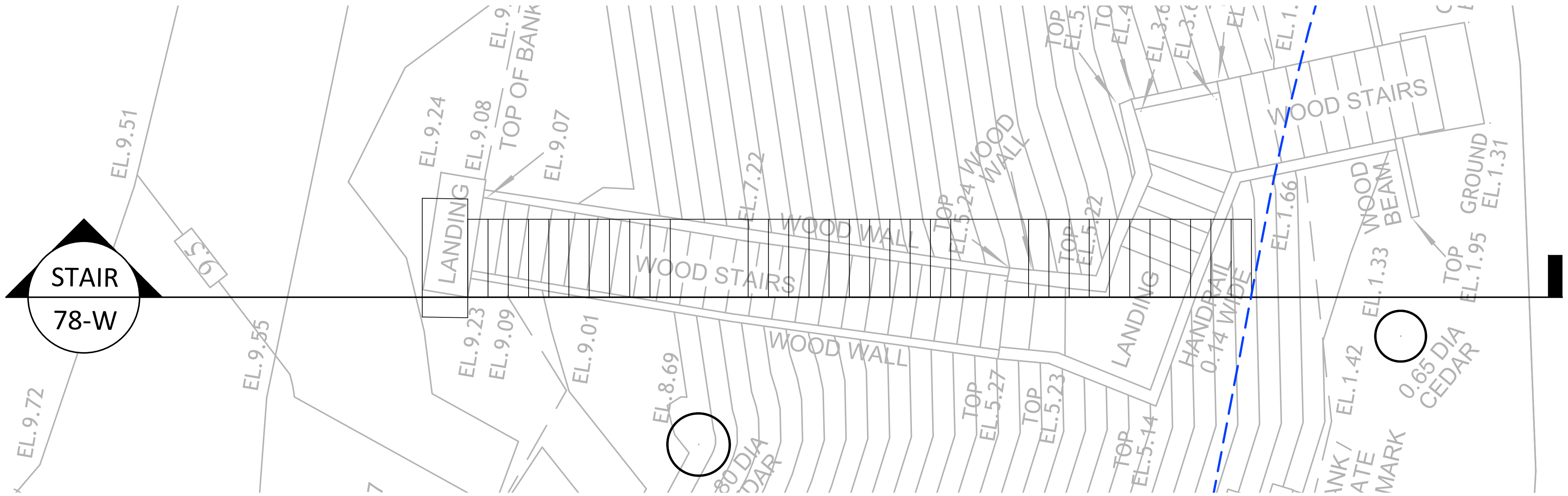
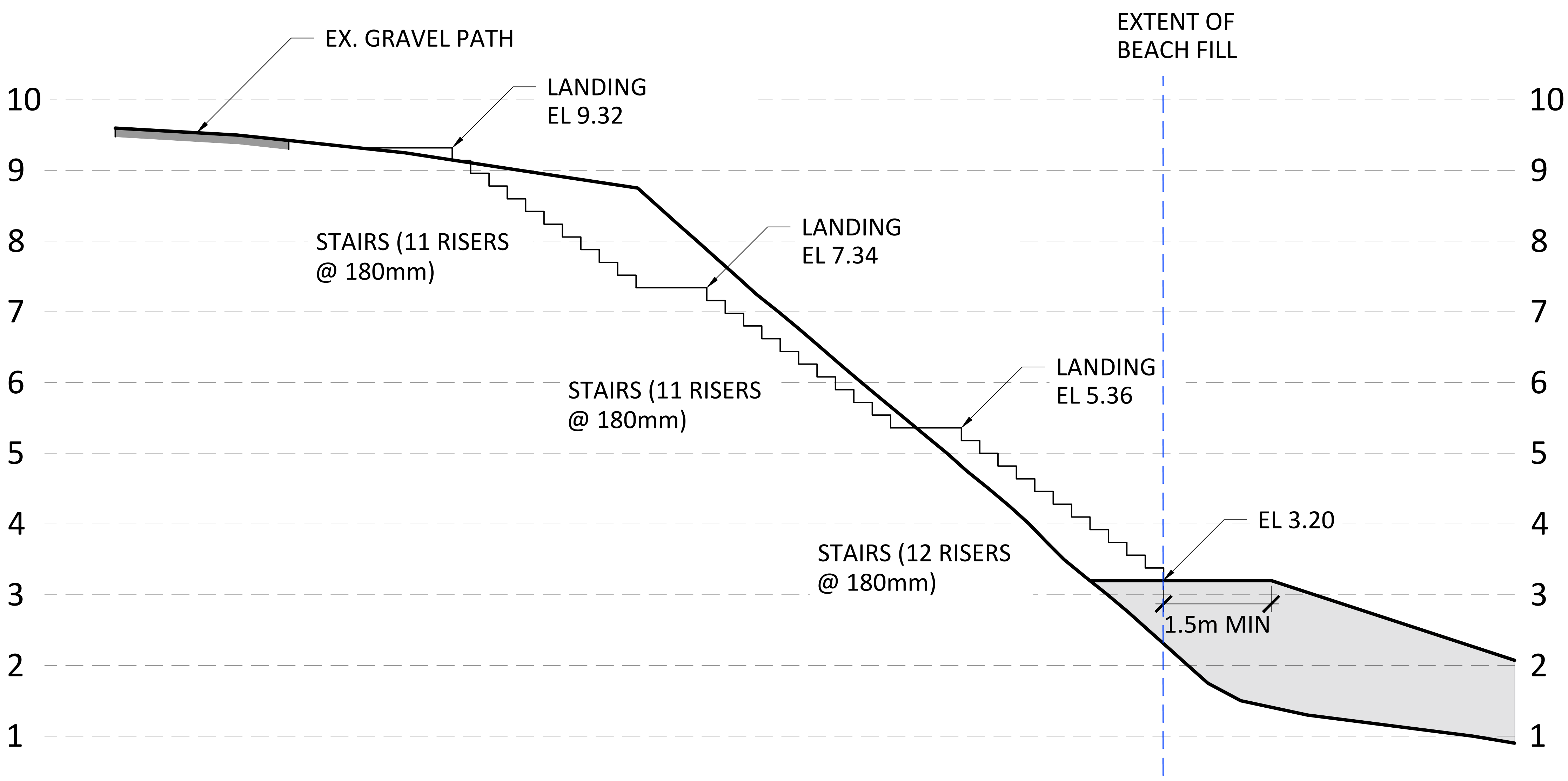


Figure 16 **XBeach-G 1D East Beach - Pocket Beach (D-11) revised section before and after 5% AEP storm with -0.5 m CGVD28 water level and MSG2 sediment type. Beach slope extended to existing ground at an 8H:1V slope.**

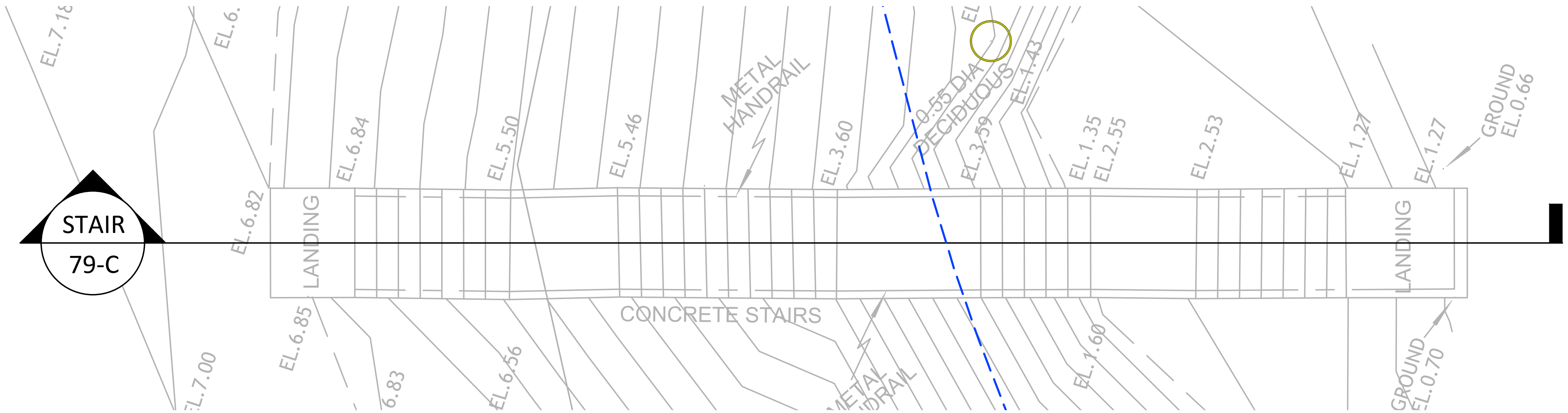


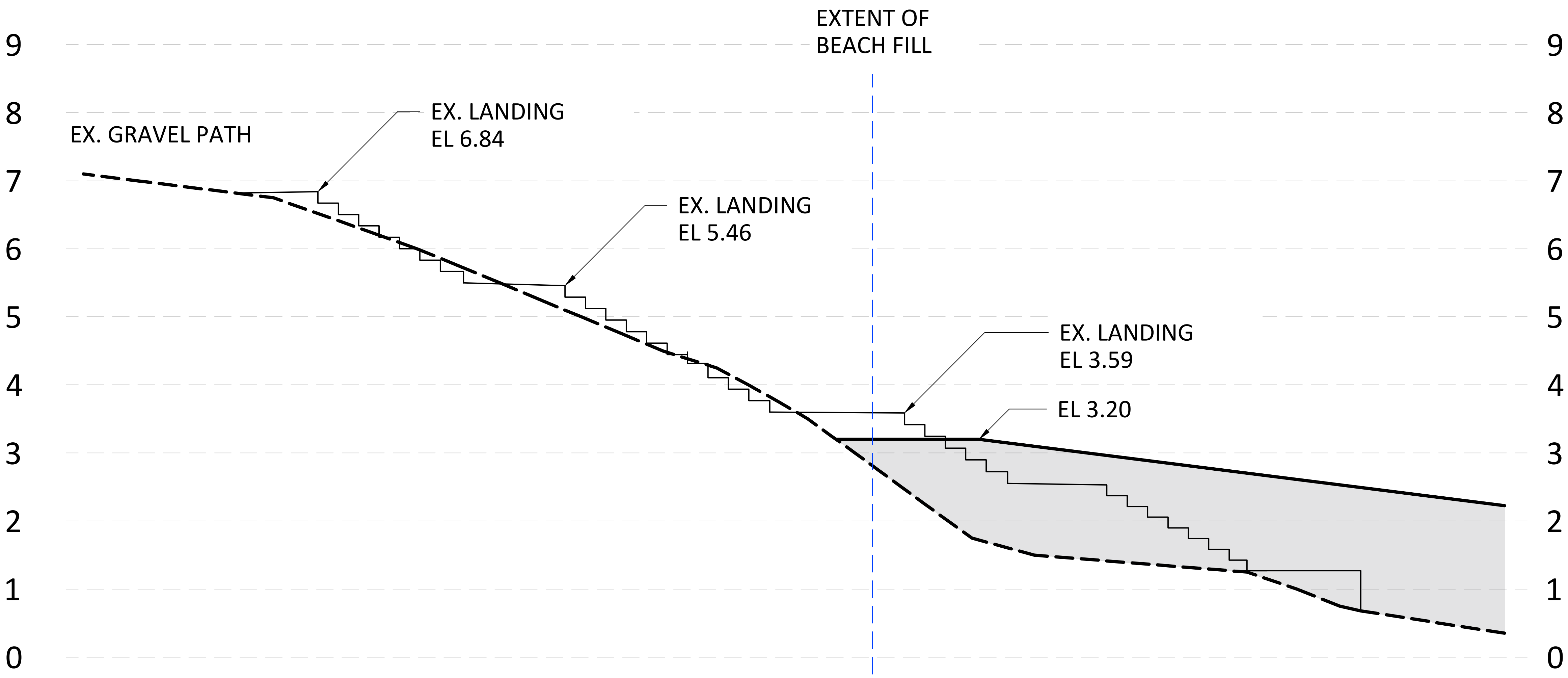


2

STAIR 78-W

SCALE: 1:75

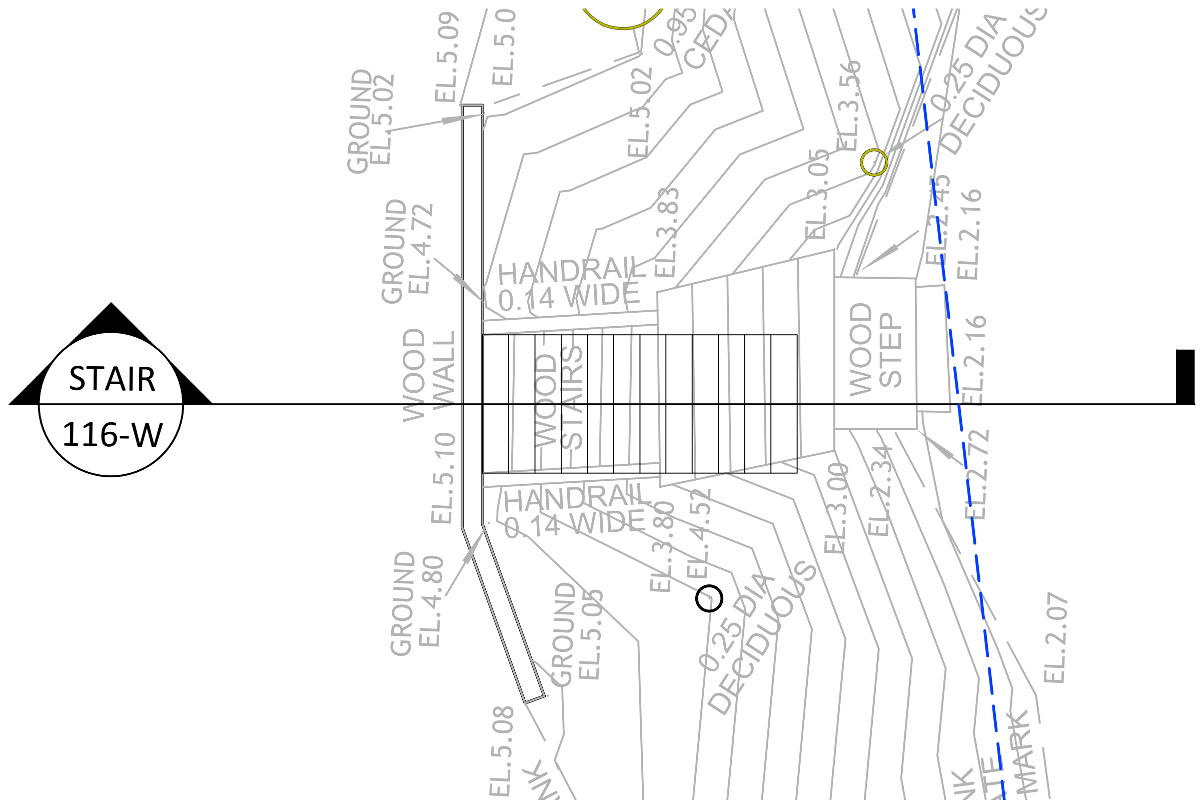


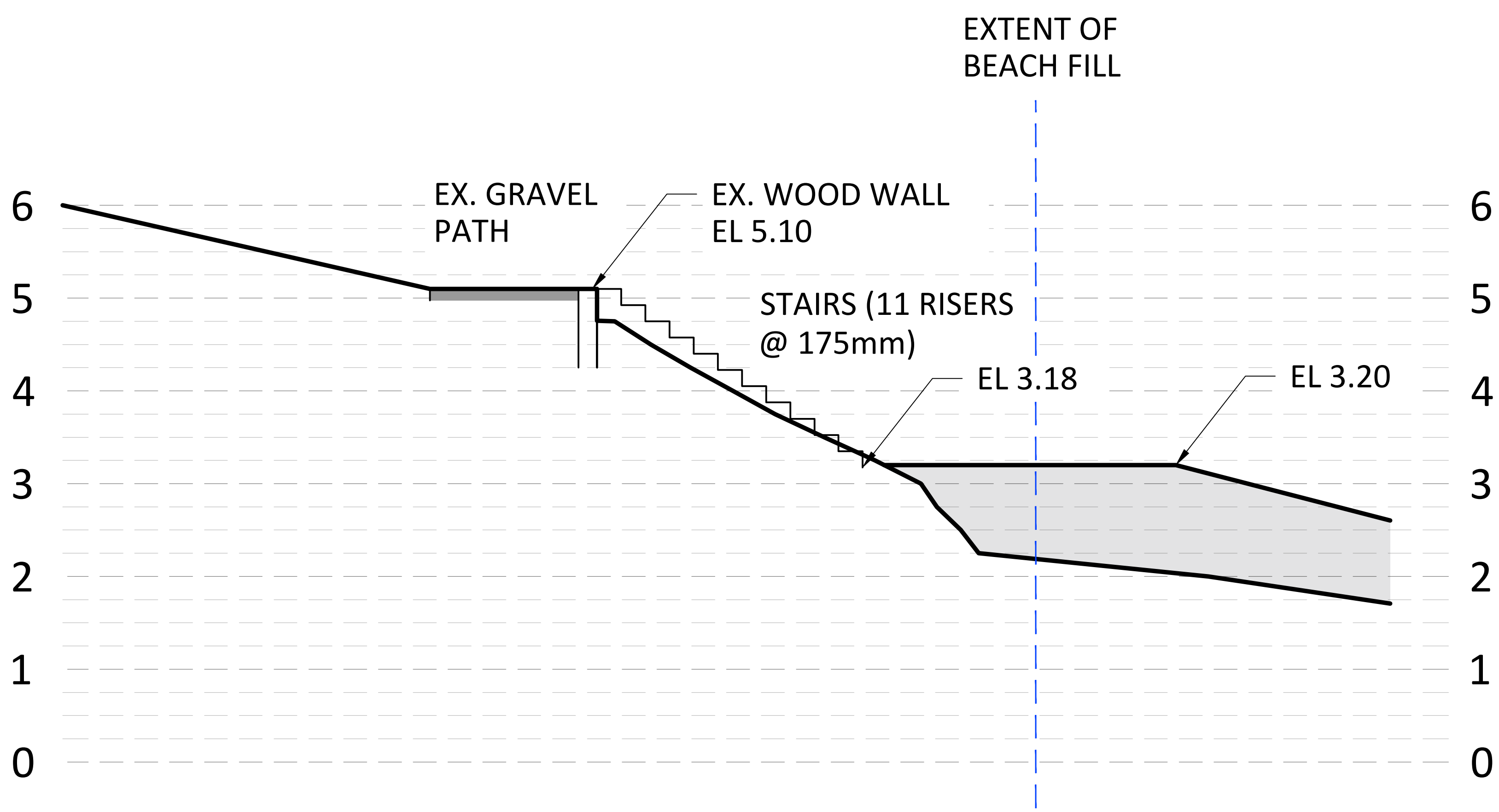


1

STAIR 79-C

SCALE: 1:75

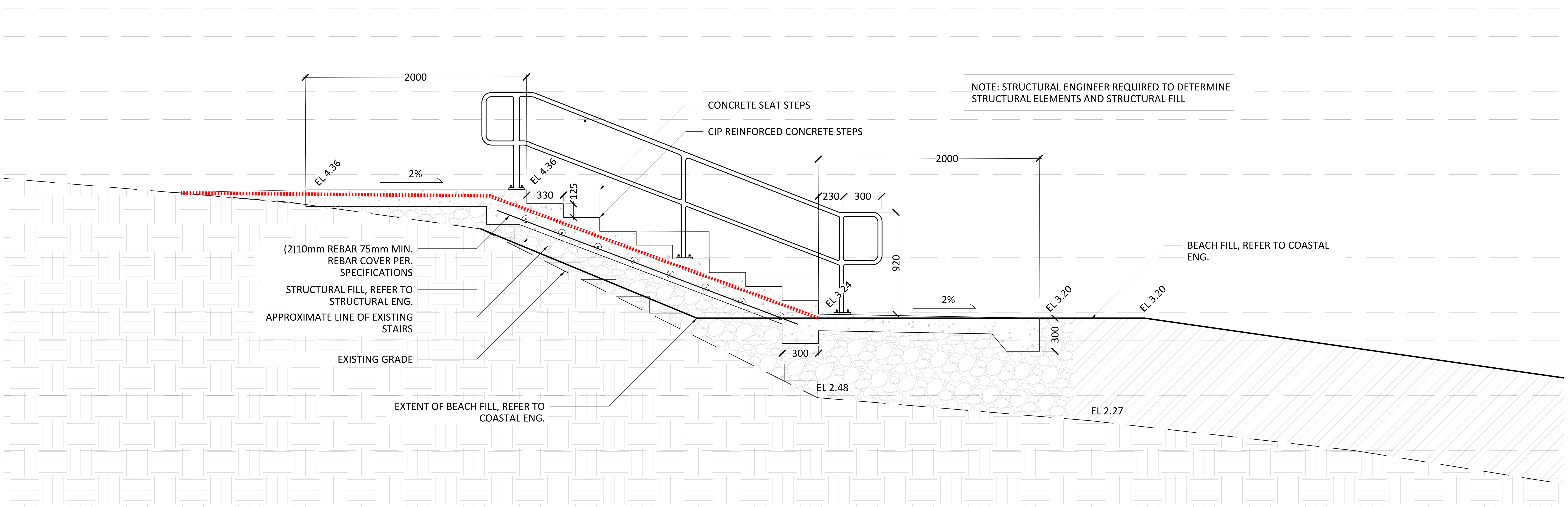




3

STAIR 116-W

SCALE: 1:75



1 ROCHE POINT - CONCRETE STAIRS
SCALE: 1:20

LEES + ASSOCIATES
Landscape Architects
509-318 Homer Street Vancouver British Columbia Canada V6B 2V2
Tel: (604) 899-3806 Web: www.elac.ca Email: info@elac.ca

Revisions

No.	Date	Status	By
1	AUGUST 8, 2024	ISSUED FOR REVIEW	LZ
2	SEPT 20, 2024	ISSUED FOR REVIEW	LZ

ISSUED FOR REVIEW
NOT FOR CONSTRUCTION

Client

Project
DNV SHORELINE RESTORATION FOR WHEY-AH-WICHEN

Drawing Title
ROCHE POINT CONCRETE STAIRS

Date
JULY 2024

ELAC Project No.
23-975

Scale (On 24 x 36 Inch Sheet)
As Noted

Drawing No.
LX.X

Drawn By
CO

Checked
LZ