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Coastal Engineering Analysis and Marsh Restoration Preliminary Design, Roberts Bay FINAL MEMO

Dear Kyle Armstrong,

DHI Water and Environment Inc (DHI) is pleased to submit this technical Memo outlining the coastal engineering analysis and preliminary design related to restoring and expanding the existing marsh within the Roberts Bay, Sidney, British Columbia (BC). The following sections summarize our methodology, assumptions, findings, and recommendations for the project.

1. Introduction

1.1. Background

Roberts Bay is located on the northeast side of the Saanich Peninsula, within the Town of Sidney, BC (Figure 1). Roberts Bay is part of the Shoal Harbour Migratory Bird Sanctuary, which includes Tsehum Harbour directly to the North. The bay is semi-enclosed and exposed to waves primarily from the northeast. A small creek – Mermaid Creek – outlets into the southwest corner of Roberts Bay. A small salt marsh is located on the creek delta, mainly consisting of *Sarcocornia pacifica* (American glasswort or pickleweed) (CORI, 2021). A recent study by Coastal and Ocean Resources (CORI) highlighted that the salt marsh has been narrowing and eroding over the past ~50 years, with the pace of loss increasing since 2005 (CORI, 2021). Salt marsh reduction has resulted in the loss of important ecological habitat, natural protection from waves, and carbon sequestration capacity.

Figure 1 Site location

1.2. Project Scope

Peninsula Streams Society (PSS) wishes to restore or expand the existing salt marsh within Roberts Bay, at the mouth of Mermaid Creek. DHI has been retained to undertake the following tasks:

- Site visit
- Review of available background information
- Undertake a coastal processes study, including numerical wave modeling and qualitative geomorphological assessment
- Development of a preliminary marsh restoration design
- Reporting

1.3. Reference Data and Previous Studies

Relevant background information and previous studies reviewed as part of this project are listed below. General references are provided in Section 7.

- *Roberts Bay Existing Conditions and Draft Preliminary Design* (Coastal Geologic Services 2022)
- *Analysis of Current and Historic Conditions in Roberts Bay, BC* (CORI, 2021)
- *Habitat Enhancement Approach to Seawall Repair and Storm Wave Protection: 10327 Resthaven Dr.* (Balanced Environmental, 2009)
- Digital Elevation Model (DEM) data from the LidarBC Open LiDAR (2019) Data Portal
- Bathymetric data through Fisheries and Oceans Canada (DFO) NONNA-10 dataset
- Tidal elevation data from the Canadian Hydrographic Service
- Wind observational data from Environment Canada (EC)
- Offshore wave conditions from AE & DHI (2021)
- Historical airphotos and salt marsh extents, provided by CORI
- Substrate maps, provided by CORI
- 2021 drone imagery, provided by PSS

2. Site Visit Findings

2.1. Overview

A site visit was conducted on 26 July by DHI (Jessica Wilson, P.Eng, Project Manager and Coastal Engineer) and PSS (Kyle Armstrong, Project Manager). The intent of the site visit was to complete the following:

- Meet with the client to better understand the project needs and site history.
- Obtain a better understanding of the site layout, shoreline condition, and existing infrastructure.
- Assess exposure of the site to prevailing waves and storm surge at the site.
- Complete a visual inspection for possible sediment transport pathways, sources, and sinks.
- Conduct qualitative observations of surficial substrate materials and shoreline vegetation types.
- Assess the feasibility of potential marsh restoration works at the site.
- Assess construction access constraints at the site.

A summary of key observations made by DHI during the site visit are summarized below:

- The lower reach of Mermaid Creek has a mild gradient. The bed appears to be composed primarily of mixed gravel and fine sediments. The banks are vegetated and exhibiting signs of erosion. (Photo 1)
- The salt marsh is situated on the historical deltaic deposits from Mermaid Creek, and spans both sides of the creek outlet. (Photo 2)
- The marsh substrate (deltaic deposits) appears to be a mixed sand, gravel and cobble material, and includes deposits of peat. (Photo 3)
- No erosion was observed at the shoreline behind the marsh.
- The back marsh northwest of the outlet appears to be in poor health, potentially related to insufficient drainage and water ponding. (Photo 4)
- The leading edges of the marsh are eroding (particularly along the north-easterly exposure). Remnant peat deposits are visible seaward of the leading edge of the marsh. (Photo 3)
- A sand and gravel lens are located on the upper intertidal northwest of the creek outlet, extending out onto the northwest marsh. The lens appears to be moving along the shoreline from north to south, burying some of the existing marsh. (Photo 5)
- There are some large woody debris (LWD) deposited on the upper intertidal (including on the marsh). (Photo 3)
- The lower intertidal area is wide and mildly sloping. These tidal flats are largely composed of fine sediments and sands. The lower intertidal coarsens into gravels and cobbles further inland, with some boulder erratics. (Photo 6)
- To the southeast of the marsh, the upper intertidal consists of a fine sand beach, with dune grass growing at the crest. There are only minor signs of erosion along this section of beach. Further along, the shoreline is almost entirely armoured. (Photo 8)
- To the northwest of the marsh, there is a rocky outcrop and three rock groynes positioned near mid-tide. Sediment build-up was observed on the northwest sides of the groynes. (Photo 7)
- The shoreline northwest of the marsh is also almost entirely armoured, with exception of another small creek and delta deposit in the northwest portion of the bay.
- Small vessels are occasionally moored on the tidal flats, becoming dry at low tide. (Photo 6)
- There is a well-used pedestrian pathway running through the salt marsh. Concrete blocks have been placed at the creek outlet to allow pedestrians to cross. (Photo 9)

2.2. Photographs

Photo 1 The lower portion of Mermaid Creek (looking upstream)

Photo 2 The creek outlet (looking downstream), showing salt marsh on either side

Photo 3 Leading edge of the salt marsh and marsh substrate (northwest marsh, looking inland)

Photo 4 Ponding water and poor drainage in area with stressed marsh vegetation

Photo 5 Gravel lens on upper intertidal (looking SE, towards the Mermaid Creek outlet)

Photo 6 Tidal flats in front of the marsh (looking east)

Photo 7 Hard shoreline armouring and rock groynes on the foreshore (looking northwest)

Photo 8 Sand beach southeast of the Mermaid Creek salt marsh (looking southeast)

Photo 9 Pedestrian pathway through the marsh (looking SE, towards the Mermaid Creek outlet)

3. Coastal Design Basis

This section outlines coastal processes in the project vicinity and key design parameters for the marsh restoration project. Ocean levels, winds, waves, currents, and geomorphology are discussed in the following sub-sections.

3.1. Datum

Elevations (including water levels) are referenced to the Canadian Geodetic Vertical Datum of 2013 (CGVD2013), unless otherwise stated. The following formulas were used to convert elevations referenced to the Canadian Geodetic Vertical Datum of 1928 (CGVD28) [1] and Chart Datum (CD) [2] at the project site.

$$Z_{CGVD2013} = Z_{CGVD28} + 0.14 \text{ m}$$ [3]

$$Z_{CGVD2013} = Z_{CD} - 1.99 \text{ m}$$ [4]

Where Z is the elevation, in meters, above the reference datum.

3.2. Design Criteria

3.2.1. Design Life

The design life of a project is the timeframe for which the design components are anticipated to function as intended, within the specified parameters and based on expected future conditions. For structural measures, the design life is relatively easy to define; however, natural systems may be expected to perform in a dynamic manner, and potentially well beyond their specified design life due to their innate ability to adapt to changing environmental conditions and self-repair.

For the purpose of this project, a design life of approximately 80 years (up to year 2100) has been considered. Regular inspection and maintenance – or adaptive management – may be required to meet the design life.

3.2.2. Design Storm Event

The design storm event is associated with the level of durability that may be expected by the design. **A design storm event with a 1-in-50 year (2.0%) annual exceedance probability (AEP) has been considered for the structural components of this project.** Over the design life of approximately 80 years, the design storm has an 80% probability of exceedance.

A 1-in-50 year AEP event was selected as there is little risk to life or livelihood if the structural components become damaged. In addition, designing for a larger event would require overdesign, which may impede the function of the structure during more nominal events. However, some damages may be expected to structural components in the event that a storm exceeds the 1-in-50 year AEP, and repairs may be

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[1] CGVD28 on Vancouver Island is based on: NAD83 (CSRS), HT2 hybrid geoid model, Epoch 1997.

[2] Chart datum refers to the lowest normal tide, such that water levels rarely fall below it. Tidal predictions and hydrographic charts from the Canadian Hydrographic Service (CHS) reference this datum.

[3] Based on local site conversions, provided by Natural Resources Canada Vertical Datum Transformations Tool: https://webapp.csrs-scrs.nrcan-rncan.gc.ca/geod/tools-outils/gpsh.php?locale=en

[4] Based on local site conversions, provided for CHS station 07260 (Sidney) through the online portal: https://tides.gc.ca/en/stations/

required. It is not expected that natural components of the system (such as vegetation) will withstand the design storm event; however, they would be expected to self-repair over time.

3.3. Ocean Levels

3.3.1. *Astronomical Tides*

Tidal elevations for the project site are provided in Table 1, based on elevations provided by CHS through their online portal for station 07260 (Sidney) [5].

Table 1 Tidal elevations at the project site

Description	Tide Elevation (m, CGVD2013)
Highest Astronomical Tide (HAT)	1.54
Higher High Water Large Tide (HHWLT)	1.48
Higher High Water Mean Tide (HHWMT)	1.06
Mean Water Level (MWL)	0.10
Lower Low Water Mean Tide (LLWMT)	-1.25
Lower Low Water Large Tide (LLWLT)	-2.21

3.3.2. *Storm Surge*

Storm surge is the increase in the water level above the astronomical tide level due to atmospheric effects, such as wind shear stress and reduced air pressure. Storm surge and astronomical tide are understood to be independent events within the Strait of Georgia, meaning that surge and high tides will not necessarily occur simultaneously.

As part of the *Sea Level Rise Modelling and Mapping* study (AE & DHI, 2021), the joint probability of tides and storm events occurring simultaneously was assessed throughout the Capital Regional District. AEPs for combined tides and storm surge (i.e., the total still water level) at the project site are also replicated in Table 2.

Table 2 Joint tide and surge levels at the project site (source: Transect 131, Appendix G from AE & DHI, 2021)

Annual Exceedance Probability	Elevation (m, CGVD2013)
1-in-10 year (10%)	2.12
1-in-20 year (5.0%)	2.17
1-in-50 year (2.0%)	**2.22**
1-in-100 year (1.0%)	2.24

[5] https://tides.gc.ca/en/stations/

3.3.3. Sea Level Rise

Local relative sea level rise (SLR) is the combined measure of both global sea level changes due to climate change and local vertical land movements. Global SLR is the result of changes in glacier and ice-sheet mass loss, thermal expansion of the oceans, changing ocean circulation conditions, and human-caused changes in land water storage. Local vertical land movements are the result of tectonic uplift or subsidence, isostatic rebound due to glacial retreat, and sediment consolidation. Near the project site, local uplift is estimated to be 1.4 mm / yr [6]. Relative SLR is the change in ocean height relative to land and is the apparent sea-level change experienced by coastal communities and ecosystems.

Natural Resources Canada (NRCan) developed a new state-of-the-art dataset of relative sea-levels to the year 2100 across Canada (James et al., 2021). The projections are based on the Intergovernmental Panel on Climate Change's Fifth Assessment Report (IPCC AR5) for the following Representative Concentration Pathways (RCPs):

- RCP 2.6 Low emissions: Severe mitigation measures are taken to reduce emissions immediately.
- RCP 4.5 Intermediate emissions: Emissions peak around 2040 and decline thereafter.
- RCP 8.5 High emissions: Emissions continue to rise until around 2100.

Projections are also provided for an 'enhanced' scenario which reflects potential contributions from the Antarctic Ice Sheet. For the project site, the enhanced scenario adds a further 72 cm of sea-level rise to the median projection of the highest (RCP8.5) climate scenario for year 2100. Based on historical sea level observations and ongoing emissions, the low emissions scenario is not expected to occur (Wang et al., 2021). Intermediate and high emissions scenarios are still considered to be likely scenarios. Full collapse of the Ice Sheet by year 2100 is still considered to be unlikely. The science of SLR will keep evolving with updated observations and improved model predictions. Implications to infrastructure and coastal flooding should be re-evaluated with periodic updates in SLR projections.

Local relative sea level rise allowances for the project site are provided in Figure 2. Sea level rise projections have been adjusted to the year 2022 to account for local relative sea level rise that has occurred over the past two decades.

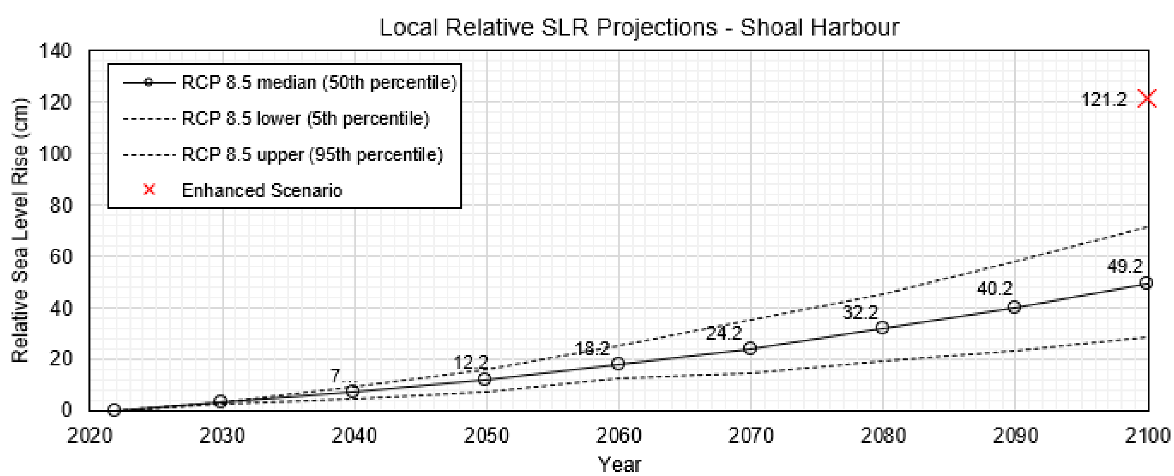

Figure 2 Local relative sea level rise projections based on James et al. (2021)

[6] Local uplift based on the Patricia Bay GPS station (Ausenco Sandwell, 2011)

It should be noted that DHI has adopted these projections for this marsh restoration project as they provide the most up-to-date reflection of the latest scientific research on relative sea level rise across Canada. For other purposes (such as defining flood construction levels for habitable spaces), it may be more appropriate to consider alternative sea level rise predictions and allowances – or a range of values – depending on the application.

For year 2100, a 0.49 m of local relative SLR has been adopted for this study, corresponding to a median RCP 8.5 emission scenario, (James et al., 2021).

3.3.4. Design Water Levels

For the purpose of design, a range of water levels have been considered for present day and future (Year 2100) conditions. Design water levels are summarized in Table 3.

Table 3 Design water levels

Scenario	Water Level (m, CGVD2013)	
	Present Day	Year 2100
Mean Sea Level, MSL	0.10	0.59
Higher High Water Mean Tide, HHWMT	1.06	1.55
1-in-50 Year AEP Tide + Surge	2.22	2.71

3.4. Winds and Waves

3.4.1. Wind Characteristics

Haro Strait and Sydney Channel are understood to have relatively complex wind patterns, due in part to complicated orographic forcing in the region. The closest wind observation stations are shown in Figure 3. Wind roses illustrating the dominant wind directions and frequencies are provided in Figure 4 for each station.

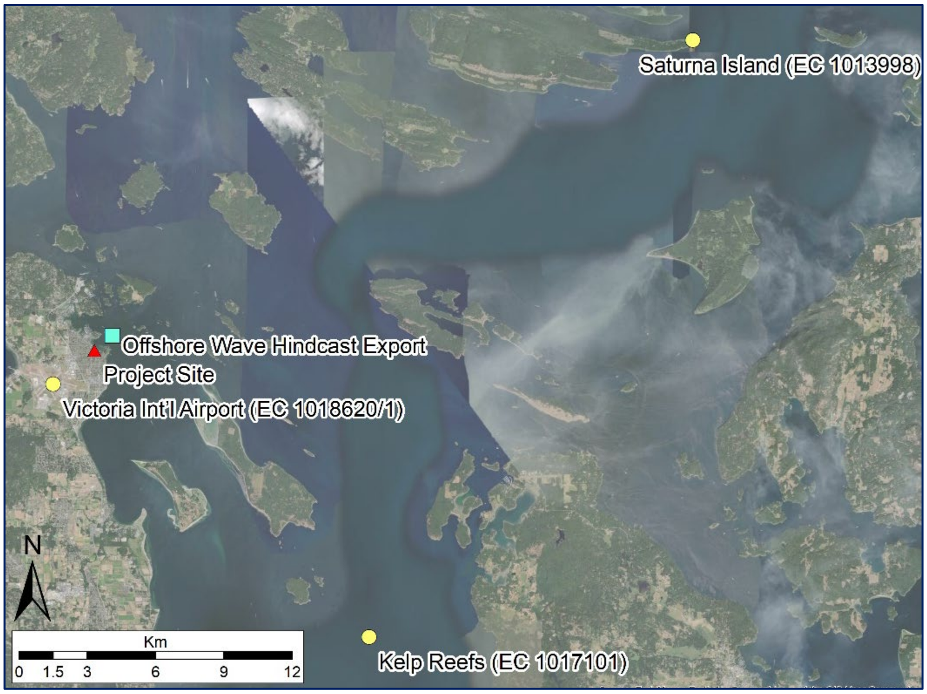

Figure 3 Map of Environment Canada wind observations, offshore wave hindcast export point, and project site

The region experiences severe storms during winter months, corresponding to large low-pressure systems passing up the coast, and frequently coinciding with large storm surges. Strong south-easterly winds are generally experienced during these events, however, winds may shift from south-westerly to south-easterly and easterly (SNC-Lavalin, 2017). Severe northerly and north-easterly events occur less frequently, but typically correspond to the passing of low-pressure systems (which are often followed by a high-pressure ridge) or polar continental outflow events.

Observations from Kelp Reefs are expected to be largely representative of winds that generate waves regionally (up Sidney Channel and Haro Strait) from the south-easterly direction. North-easterly winds are also capable of generating waves regionally; north-easterly winds are well represented in both the Saturna Island and Kelp Reefs measurements. Local winds, which generate waves within Roberts Bay, are expected to be more easterly oriented, similarly to Victoria International Airport. However, Victoria airport appears to underestimate the magnitude of overwater wind speeds due to its location farther inland. The project site is generally sheltered from westerly winds.

A peak-over-threshold (PoT) and extreme value analysis (EVA) was completed for each of the wind observation records. An estimate of the AEPs for winds in the region was developed based on the average wind speed at Kelp Reefs and Saturna Island for 0^{o} (N) to 120^{o} (ESE) and Kelp Reefs alone for 150^{o} (SE). Results are provided in Table 4.

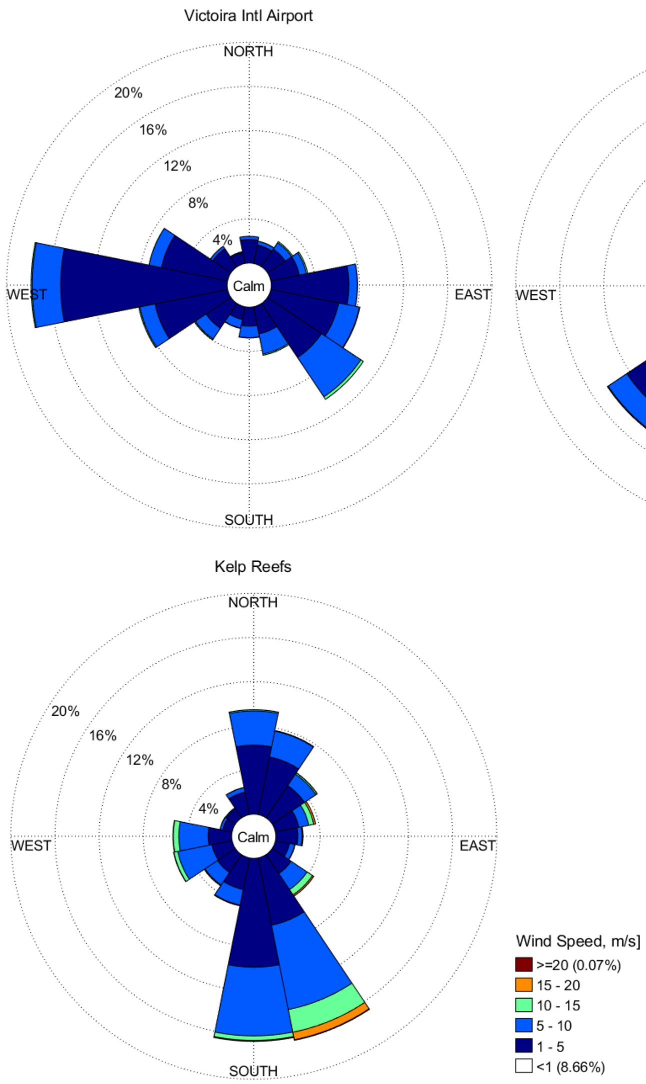

Figure 4 Wind roses for measurements at: (top left) Victoria Int'l Airport, (top right) Saturna Island, (bottom left) Kelp Reefs

Table 4 Extreme wind speeds by direction

Annual Exceedance Probability	Wind Speed (m/s)					
	Averaged from Kelp Reefs and Saturna Island					Kelp Reefs
	N (0°)	NNE (30°)	ENE (60°)	E (90°)	ESE (120°)	SSE (150°)
1-in-2 year (50%)	10.5	13.7	17.0	14.3	16.2	22.0
1-in-10 year (10%)	12.5	16.2	19.4	17.1	19.1	25.0
1-in-20 year (5.0%)	13.4	17.1	20.2	18.2	20.1	26.3
1-in-50 year (2.0%)	**14.8**	**18.4**	**21.1**	**19.6**	**21.3**	**28.2**
1-in-100 year (1.0%)	15.9	19.3	21.8	20.6	22.1	29.6

3.4.2. *Offshore Waves*

There are no wave buoys near the project site to help inform the offshore or incident wave climate. However, as part of the *Sea Level Rise Modelling and Mapping* study (AE & DHI, 2021), a 40-year numerical wave hindcast (from 1979 – 2018) was completed for the Capital Regional District (CRD). Wave hindcast results were exported for a point offshore of the project site (see Figure 3). A wave rose showing the dominant wave directions and offshore of the project site is provided in Figure 5.

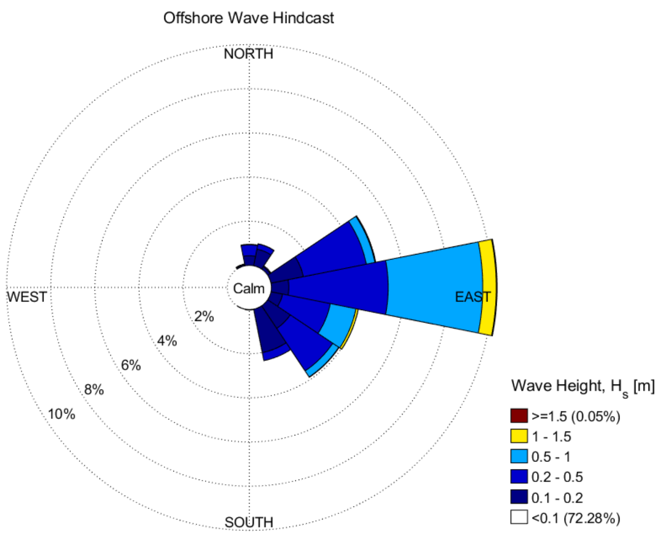

Figure 5 Wave rose for modelled wave heights offshore of the project site (as per AE & DHI, 2021).

A peak-over-threshold (PoT) and extreme value analysis (EVA) was completed on the wave hindcast results to determine the AEP for waves offshore of the project site. AEP results are provided in Table 2.

Table 5 Extreme offshore wave heights by direction

Annual Exceedance Probability	Significant Wave Height, H_{m0} (m)					
	N (0°)	NNE (30°)	ENE (60°)	E (90°)	ESE (120°)	SSE (150°)
1-in-2 year (50%)	0.53	0.40	0.78	1.61	1.35	0.74
1-in-10 year (10%)	0.70	0.58	1.09	1.82	1.64	0.89
1-in-20 year (5.0%)	0.79	0.67	1.25	1.92	1.75	0.94
1-in-50 year (2.0%)	**0.92**	**0.80**	**1.50**	**2.05**	**1.89**	**0.99**
1-in-100 year (1.0%)	1.02	0.92	1.71	2.16	2.00	1.02

3.4.3. *Incident Wave Modelling*

To determine the incident wave climate at the project site, discrete extreme storm scenarios were modelled using a DHI MIKE21 flexible mesh (FM) spectral wave (SW) model. The model simulates the growth, decay and transformation of wind-generated waves and swell in offshore and coastal areas. MIKE21 SW includes the following physical phenomena:

- Wave growth by action of wind

- Non-linear wave-wave interaction
- Dissipation due to white capping
- Dissipation due to bottom friction
- Dissipation due to depth-induced wave breaking
- Refraction and shoaling due to depth variations

The total model domain is depicted in Figure 6 and is intended to capture extreme wind-driven waves generating, propagating, and transforming within Roberts Bay. Elevation data was obtained from the LidarBC Open LiDAR (2019) Digital Elevation Model (DEM) and the Fisheries and Oceans Canada (DFO) NONNA-10 bathymetric dataset. Elevation data is interpolated across a flexible unstructured mesh with high resolution in the area of interest, as shown in Figure 6.

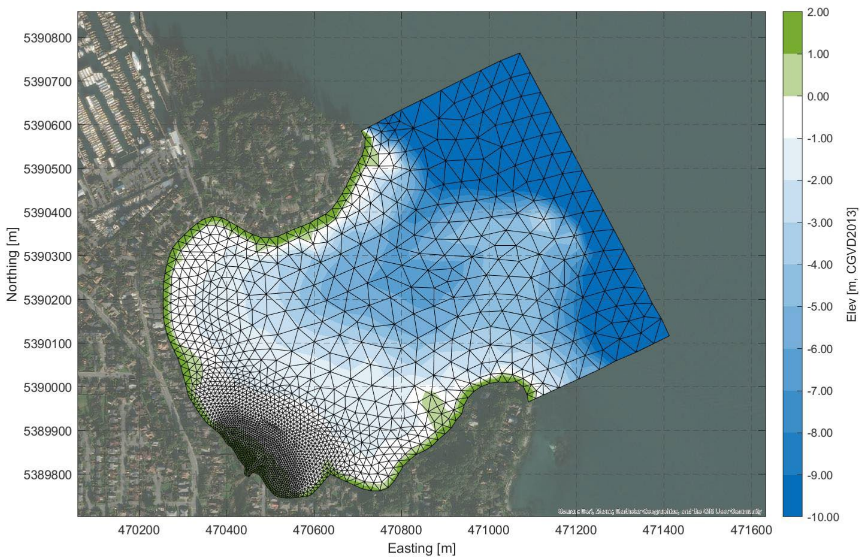

Figure 6 Spectral wave model domain and resolution

The model was set up with a fully spectral, quasi-stationary formulation that is suitable for wave studies of discrete extreme conditions. Water levels within the model are static and based on the combined joint tide and surge levels outlined in Table 3. The local model was forced with extreme offshore wave conditions from between 0º (N) – 150º (SSE) as outlined in Section 3.4.2 and sustained extreme winds from Kelp Reefs as described in Section 3.4.1. A total of 36 simulations were completed. Modelled scenarios are summarized in Table 6.

Table 6 Summary of modelled scenarios

Variables	Water Level (m, CGVD2013)
Storm Events	1-in-2 year AEP storm at MSL 1-in-2 year AEP storm at HHWMT 1-in-50 year AEP storm at the 1-in-50 year total water level
Sea Level Rise	0.0 m (present day) 0.49 m (year 2100)
Wind and Wave Directions	0º (N) – 150º (SSE)

The spectral wave model has not been calibrated to locally observed wave conditions, since no measurements were available. It is understood that the collection of wave data for the purposes of model calibration is outside of the present scope of work. DHI has previously reliably applied its models, using regionally tuned settings and parameters, to simulate extreme wave conditions, for a design exercise of this purpose. It is therefore anticipated that the spectral wave model developed for this study will provide robust and reliable design wave inputs for the purposes of this investigation.

3.4.4. *Wave Model Results*

Wave model results for key simulations are provided in Figure 7 to Figure 10. Key findings are as follows:

- At present day MSL, waves are not expected to reach the toe of the existing marshland. The toe of the existing marshland is expected to become exposed at MSL with 0.49 m of sea level rise.
- At HHWMT, waves are capable of reaching the toe of the existing marshland. As sea levels rise, the marshland is expected to become inundated, with waves reaching the backshore.
- Due to the orientation of Roberts Bay, waves originating from Sidney Channel enter the bay from a NE to SE direction, but generally approach the project site from the NE (~45°), approximately perpendicular to the shoreline.
- Waves may also be generated locally. In particular, N (0°) and NNE (30°) storms are capable of generating waves up to ~0.5 m high (H_s) within the bay.
- The governing scenario for design purposes is the 1 in 50 year AEP storm from the E (90°) with 0.49m SLR. Incident wave characteristics offshore of the Mermaid Creek Delta are as follows:
  - Significant Wave Height, H_s: 1.2 m
  - Peak Wave Period, T_p: 5.65 s
  - Mean Direction, Dir: 49 °
  - Water Depth, d: 2.4 m

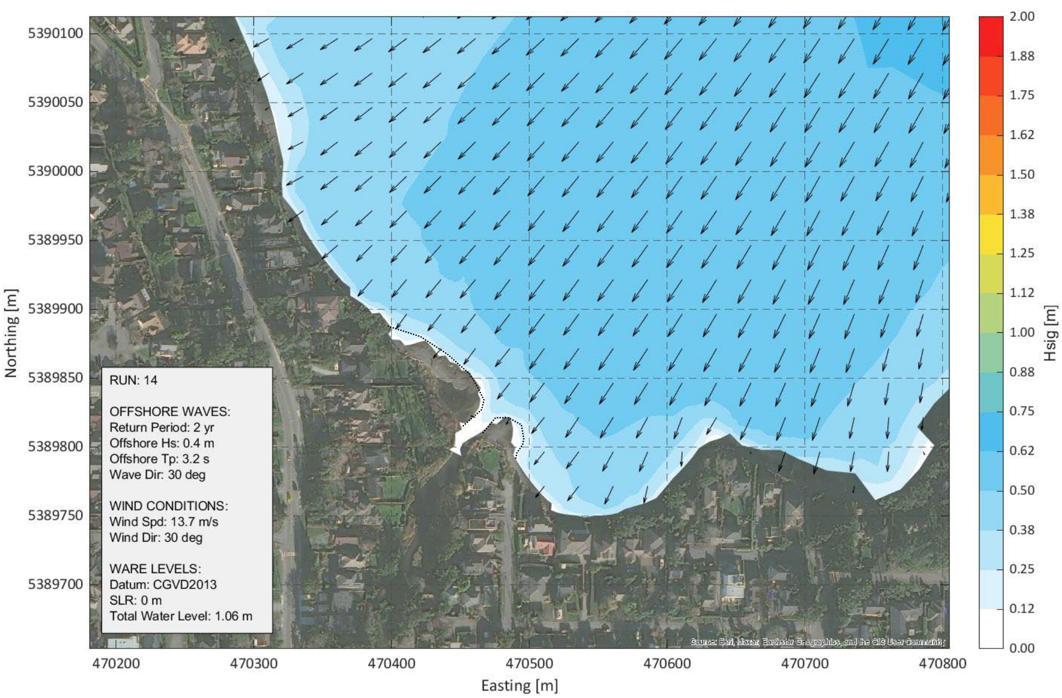

Figure 7 Spectral wave model results near Mermaid Creek Delta for nominal storm conditions (1-in-2 year AEP storm) from 30° (NNE) at HHWMT with 0.0m SLR.

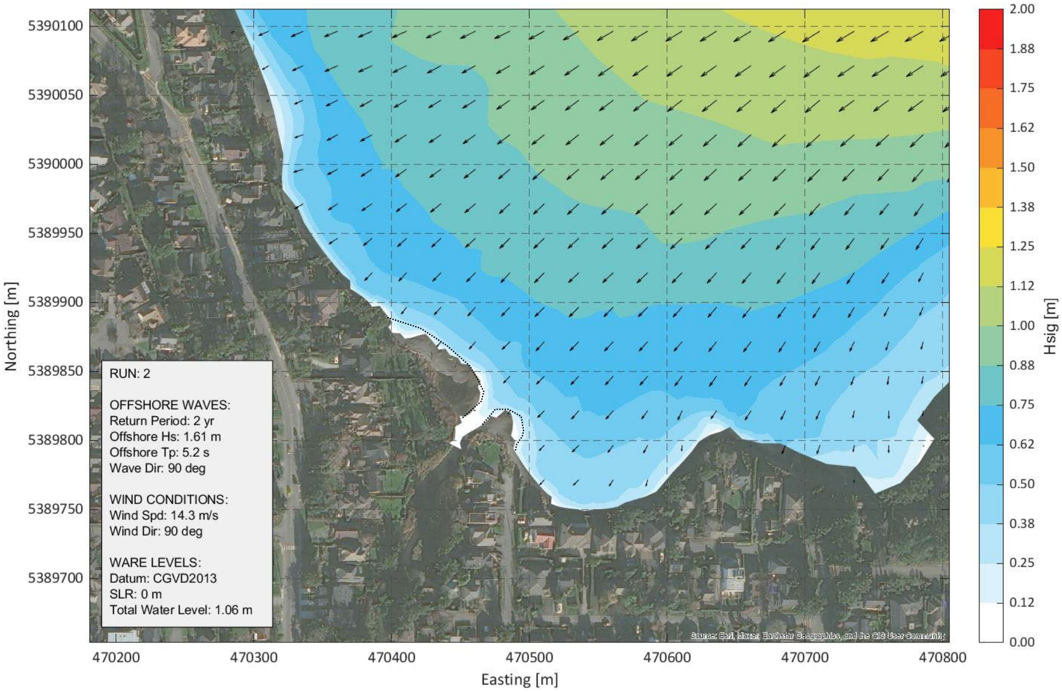

Figure 8 Spectral wave model results near Mermaid Creek Delta for nominal storm conditions (1-in-2 year AEP storm) from 90° (E) at HHWMT with 0.0m SLR.

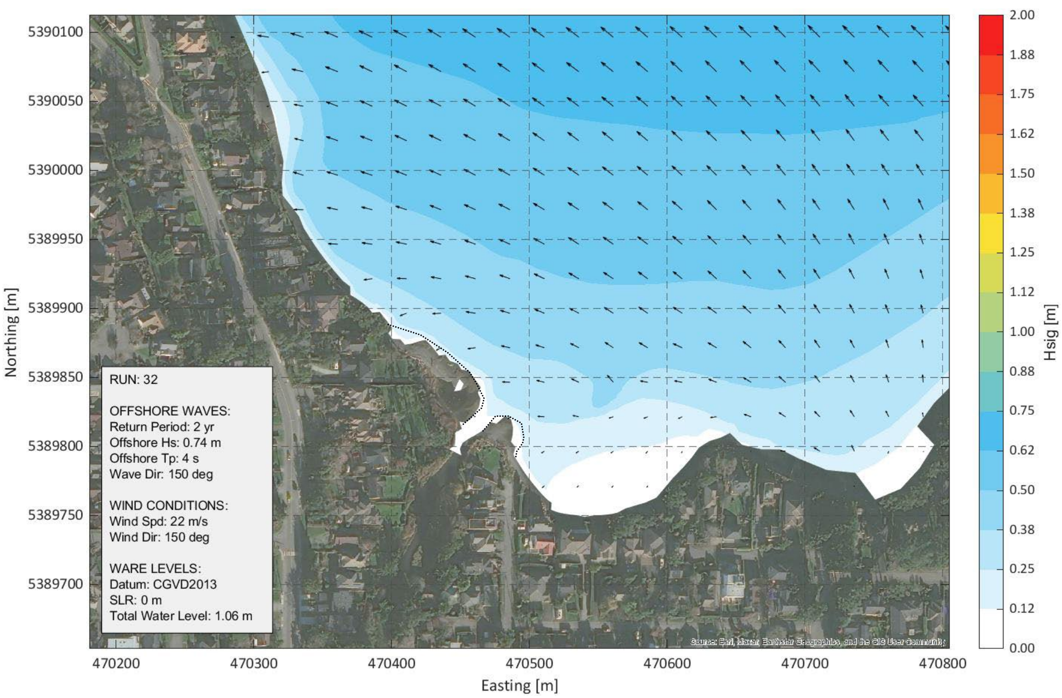

Figure 9 Spectral wave model results near Mermaid Creek Delta for nominal storm conditions (1-in-2 year AEP storm) from 150° (SSE) at HHWMT with 0.0m SLR.

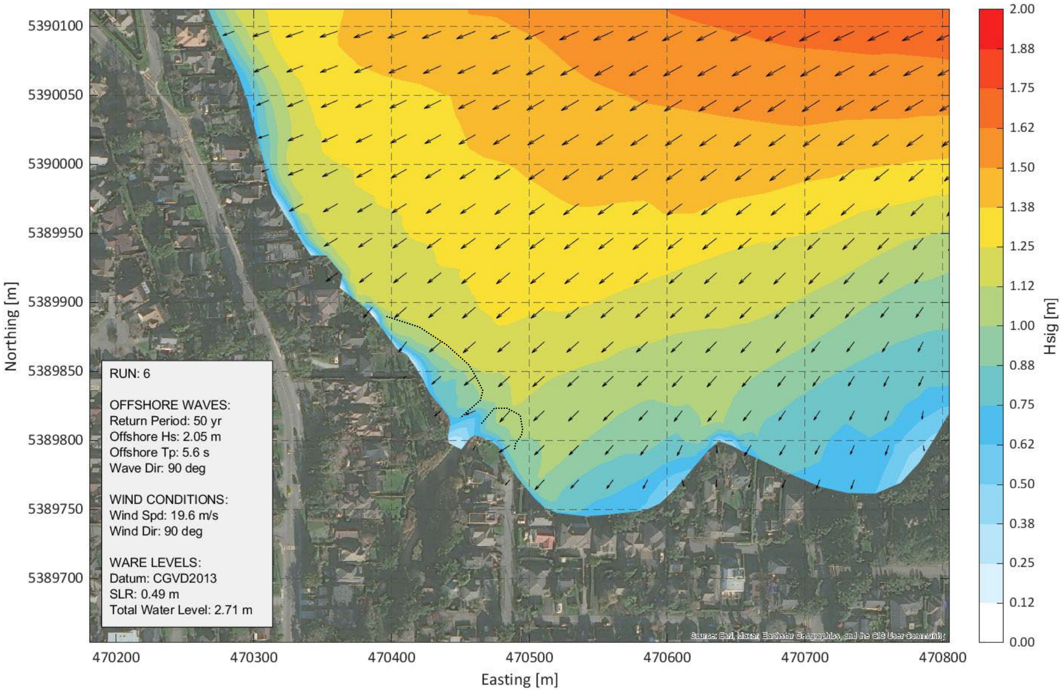

Figure 10 Spectral wave model results near Mermaid Creek Delta for the governing storm scenario (1-in-50 year AEP storm) from 90° (E) with 0.49m SLR.

3.5. Currents

3.5.1. *Creek Flows*

There is no available information on flows from Mermaid Creek. However, the Client has communicated that Creek flows are relatively low due to upstream constrictions. In addition, there are no signs of erosion along the creek-facing portions of the marsh. Creek flows are therefore not expected to be a governing factor for design of the marsh restoration.

3.5.2. *Tidal Currents*

Tidal currents within Haro Strait and Sidney Channel may exceed 2.0 m/s, particularly in deep water, where the channels are constricted (Thomson 1981). Roberts Bay is located away from the main channels and has relatively shallow water. As such, it is expected that tidal currents are relatively week and are not a significant driver of sediment transport (in comparison to wave-driven sediment transport) and therefore not a governing factor in design. Wave induced sediment transport is discussed in Section 3.7.

Additional numerical modelling may be conducted to confirm tidal currents within the Bay; however, this requires significant effort that is beyond the current scope of the project.

3.6. Salt Marsh Extents

To better understand how the Mermaid Creek salt marsh has changed over time, CORI (2021) reviewed historical airphotos and mapped the extent and location of the salt marsh. The change in salt marsh extent between 1964 and 2022 is replicated in Figure 11 for reference.

Notably, by 1999, the salt marsh extent was reduced by approximately 42 % compared to 1964. Much of this loss appears to be through burial of the marsh from sediments, rather than recession of the leading edge of the marsh. By 2005, the marsh had almost entirely recovered. Over the next two decades, however, the marsh extent reduced significantly. By 2022, approximately 58 % of the marsh area had been lost. The loss appears to be a result of both burial and erosion of the leading edge.

It can be concluded that the marsh experiences annual variations in its extent. Partial burial of the marsh is visible in many of the airphotos, but appears to be transient in nature without resulting in permanent loss of the salt marsh. However, there also appears to be chronic erosion along the leading edge of the salt marsh, which is resulting in a long-term trend of salt marsh loss. The salt marsh extent should not be expected to fully recover without intervention and erosion protection measures. Further discussion on geomorphology and erosion potential is provided in Section 3.7.

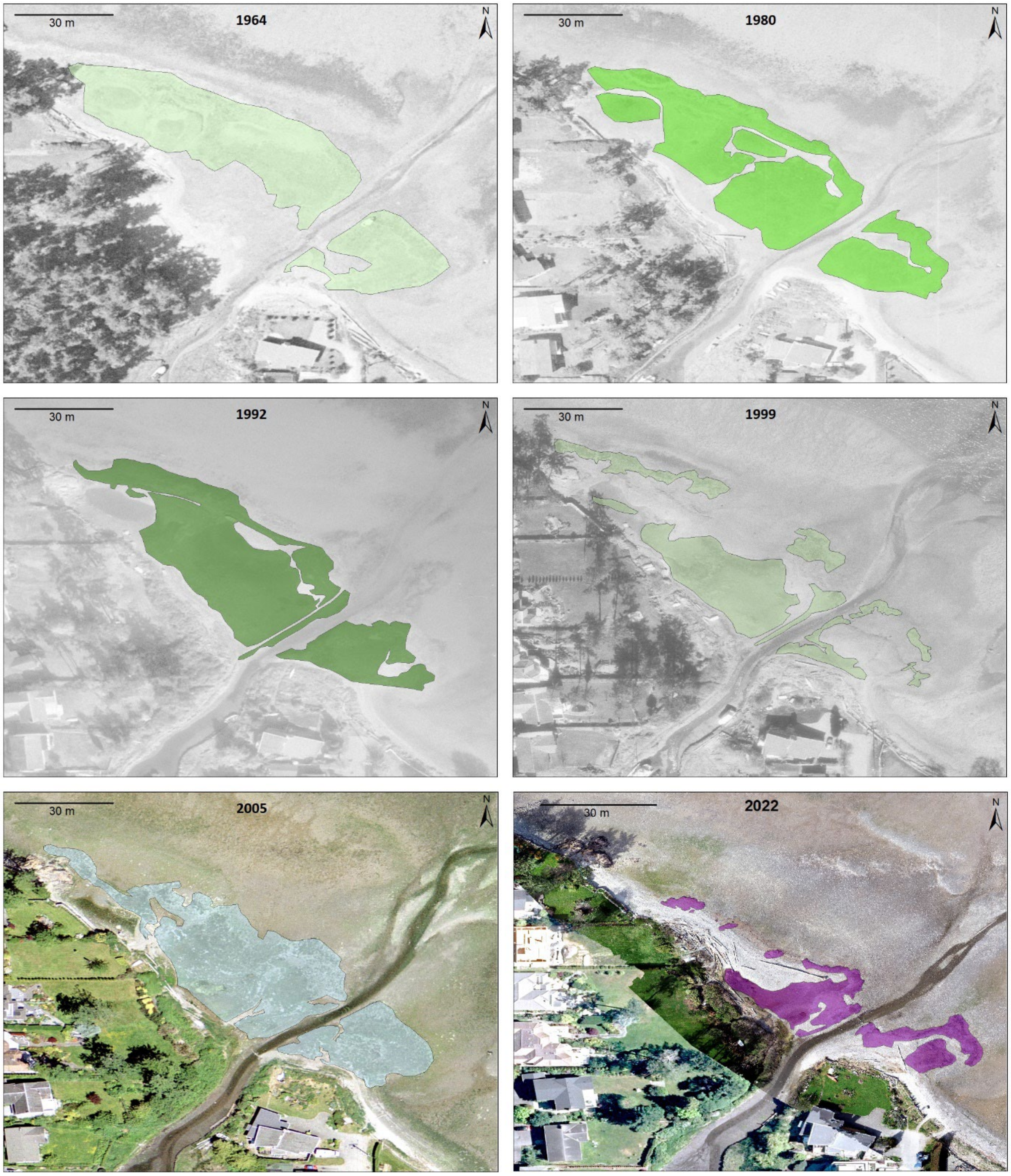

Figure 11 Salt marsh extent between 1964 and 2022 (Source: CORI, 2021)

3.7. Coastal Geomorphology

Coastal geomorphology is strongly linked to the shoreline character (sediment size and shape, slope, elevation, etc), presence of structures, vegetation characteristics, and other coastal processes. Historical airphotos, background information on coastal processes (as described in the preceding sections), site observations, and the site history were reviewed and coupled to develop a preliminary understanding of the coastal geomorphology – and thereby the potential for erosion and the suitability of measures to support marsh restoration – at the project site. The following sub-sections describe DHI's assessment of the coastal geomorphology at the project site.

3.7.1. Historical Aerial Imagery

A compilation of historical aerial imagery between 1950 and 2021 is provided in Figure 12. The airphotos illustrate the dynamic nature of the region over the long-term. Although there is significant year-to-year variation, it can be seen that both the delta and marsh have experienced a long-term erosional trend since 1950. In particular, the northwest edge of the delta and the seaward face of the delta appear to have receded significantly, which may be tied to marsh erosion during this period (see Section 3.6). The beach fronting the marsh now appears deflated.

3.7.2. Physical Setting & History

The Saanich Peninsula was formed through a series of geologic, glacial, and post-glacial processes over thousands of years (Blyth and Rutter, 1993). Dynamic growth and decay of glacial ice sheets resulted in thick deposits of glacial and inter-glacial sediments. During each glaciation, the tectonic plates would deform and subside under the weight of the ice sheets, causing sea levels to rise relative to the land. The last major glaciation within the region ended approximately 12,000 – 15,000 years before present (BP) (Blyth and Rutter, 1993). As the ice sheet retreated, extensive deposits of Glaciomarine silts were deposited throughout the region. Tectonic plates rebounded over a period of many thousands of years following glacial retreat, causing the sea level to drop more than four meters below present levels in the Saanich Peninsula region. Eustatic (i.e. global) changes and local land subsidence and uplift have since caused sea levels to reach their present levels (Wyatt, Glenda Joan, 2015).

Post-glacial processes have shaped the area significantly, including erosion and deposition due to streams and wave action, as well as construction of shoreline and foreshore structures. Notable historical features in the area include the following (Figure 13):

- **The Mermaid Creek Delta:**
  The delta formation is the result of historical sediment transport from the creek into the marine environment. It is understood (based on Client communications) that freshwater supplies through mermaid creek are constricted and it is expected that sediment loading in the creek is now restricted to relatively small quantities of fine sediments. It is therefore anticipated that Mermaid Creek no longer provides a significant source of sediment.
  Historical airphotos also indicate that dredging activities may have been undertaken along the lower reaches of Mermaid Creek to facilitate boat access.

- **The Ardwell Street Delta:**
  The delta formation at the end of Ardwell Street appears to be a relict feature (CORI, 2021). The feature indicates that a creek historically outlet onto the beach at this location. At present day, a culverted storm drain empties onto the beach here. It is expected that the outlet does not provide a significant source of sediment.

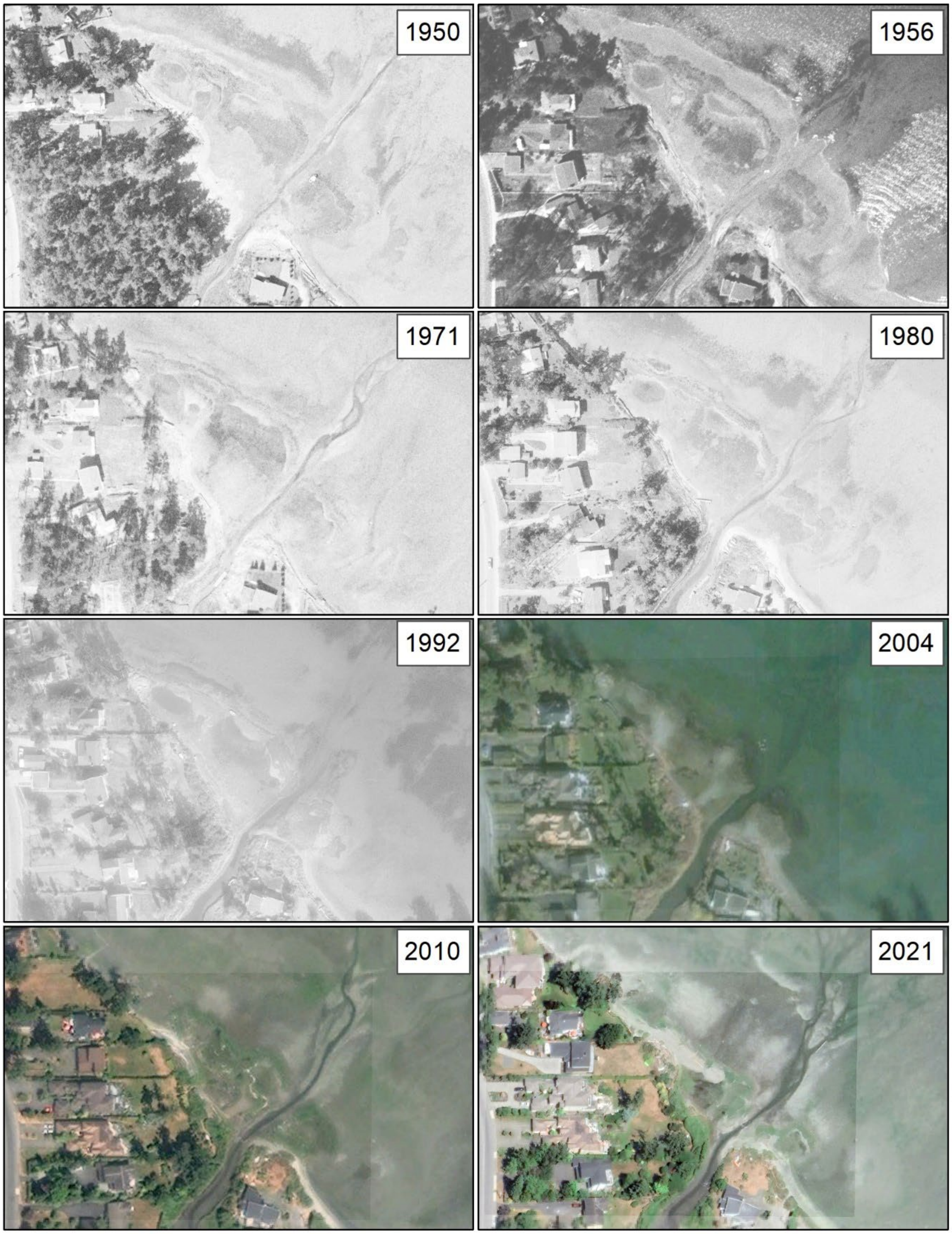

Figure 12 Historical aerial imagery between 1950 and 2021. Note that photos are taken at different tide heights. (Source: Historical airphotos provided by CORI; Google Earth)

- **Historical Pier:**
  A long, narrow pier was historically positioned on the southeast side of Roberts Bay and extended across the shallow foreshore into deep water. It is unclear when the pier was constructed and for what purpose; However, it is visible in the 1950s airphoto, and had been removed prior to the 1956 airphoto. If the jetty structure was constructed on a solid, impervious foundation, it would have provided significant sheltering against waves and interrupted longshore currents. If the jetty structure was constructed on piles and semi-open, it may still have interrupted these processes, albeit to a much lesser degree. The removal of the structure prior to 1956 may have increased exposure of the Mermaid Creek area to wave action and changed sediment transport patterns, but is not expected to be a primary cause of subsequent erosion.

- **Shoreline Armouring:**
  Prior to colonial settlement, the shoreline would have had a relatively mild slope, with vegetation and trees abutting the water's edge. The Roberts Bay area underwent significant development sometime prior to 1950. During this time, and during the years that followed, the shoreline underwent significant armouring. Shoreline armouring negatively impacts the sediment transport regime by cutting off upland sediment supplies and by promoting scouring at the base of the structures.

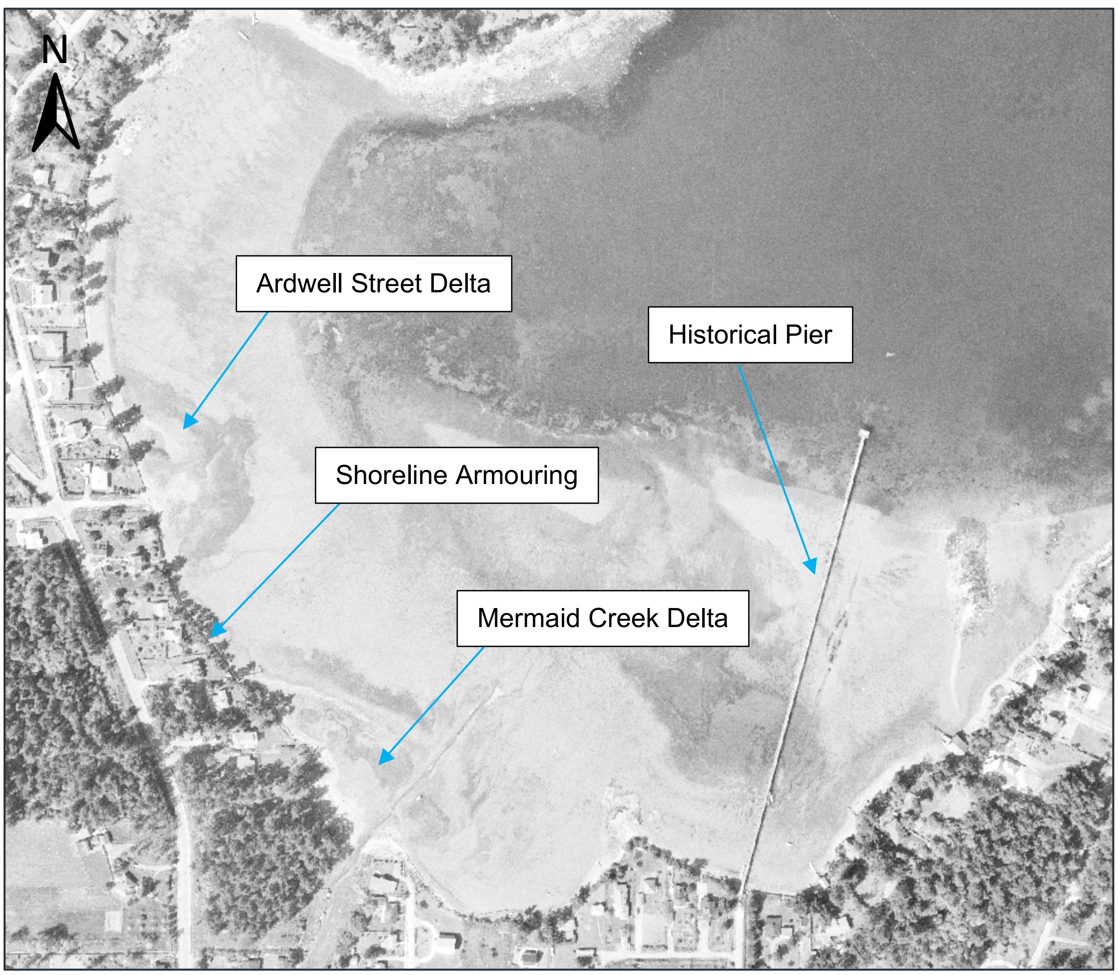

Figure 13 Physical features within Robert's Bay overlayed onto a 1950s airphoto (Source: Historical airphoto provided by CORI)

3.7.3. *Surficial Geology*

The surficial geology near the project site generally consists of a thin veneer of loose, unconsolidated sediments (i.e. colluvium) overtop bedrock on either side of the entrance to Roberts Bay, as well as poorly-sorted glacial deposits (i.e. mixed gravel and cobble, mixed into a matrix of finer material) within the bay (Blyth and Rutter, 1993). CORI (2021) also mapped the material sizes for surficial substrate across the intertidal area within Roberts Bay (Figure 14).

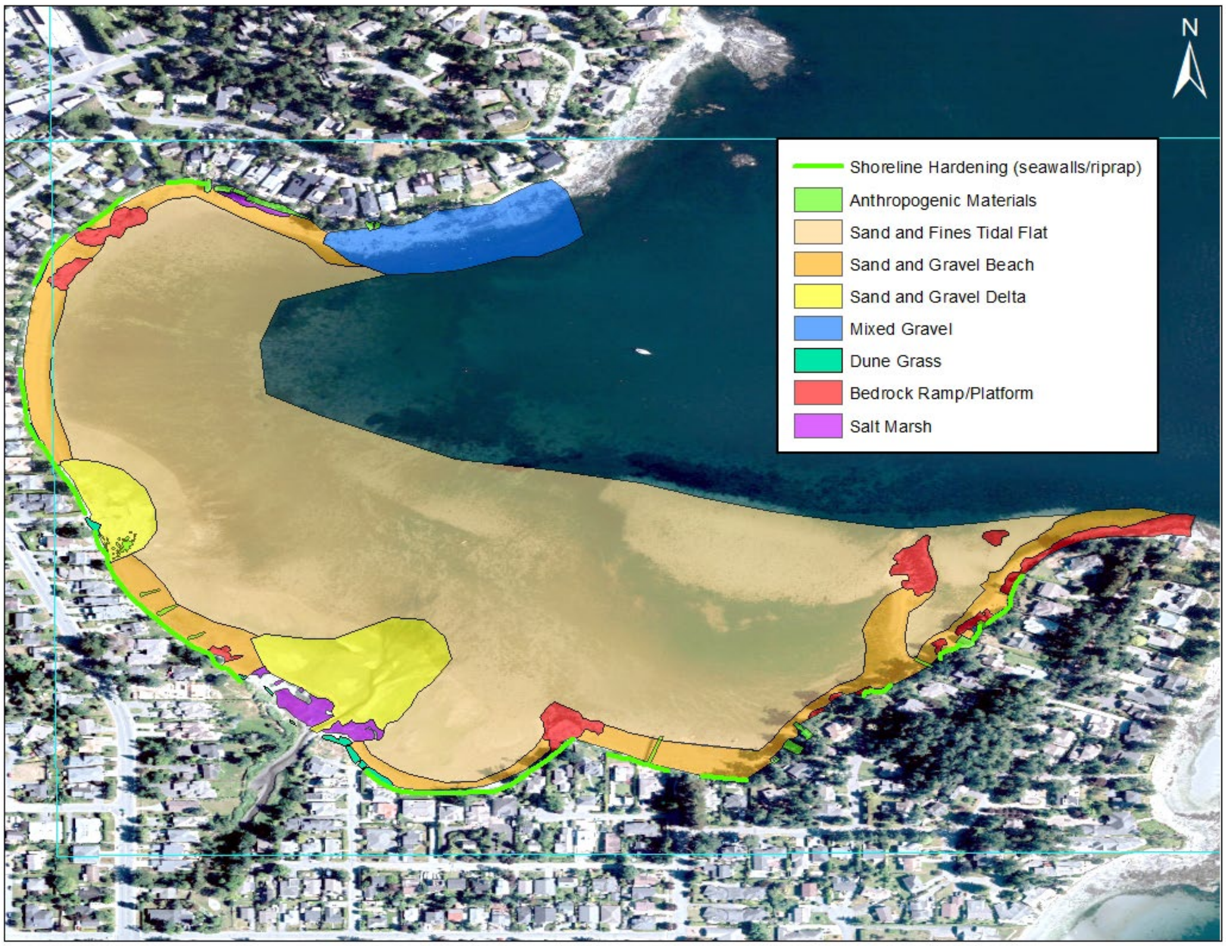

Figure 14 Surficial substrate mapping (Source: CORI, 2021)

3.7.4. *Susceptibility to Erosion*

In relatively shallow water, waves result in shear stresses along the bed that are sufficiently strong to mobilize and transport sediments. On horizontal beds, small sediments (such as silts and fine sands) may be mobilized by relatively small waves and shear stresses below 1 N/m^2 (see Table 7) (Soulsby, 1997). Larger sediments (such as gravels and cobbles), require shear stresses of more than 10 N/m^2. Sediments are also more easily mobilized on slopes.

Table 7 Threshold of motion on a horizontal bed

Sediment Type	Grain Size Range (mm)	Critical Shear Stress, τ_{cr} (N/m^2)
Large Cobble	128 - 256	168
Small Cobble	64 - 128	84
Coarse Gravels	32 - 64	42
Medium Gravels	8 - 32	18
Fine Gravels	2 - 8	4.0
Coarse Sands	1 - 2	0.79
Medium Sands	0.25 - 1	0.31
Fine Sands	0.0625 - 0.25	0.16
Coarse Silt	0.0313 - 0.0625	0.11

As an indication of the susceptibility of the salt marsh to erosion, wave model results (see Section 3.4.4) were used to calculate wave-induced shear stresses for each simulation. Shear stress maps for key simulations are provided in Figure 15 to Figure 18. Key findings are as follows:

- During NE and E storms (governing storm conditions), large waves result in high shear stresses (between 1 – 10 N/m^2) across the intertidal, which are capable of eroding and transporting fine gravels, sands, and silts (Figure 16). These frequent storm events are expected to drive sediment transport towards the northwest corner of the bay.
- During N and SE storms, waves are locally generated and smaller in height and period (Figure 15 and Figure 17). These waves result in low shear stresses across the foreshore, but relatively high shear stresses near Mermaid Creek, particularly when water levels are high. During N storms, shear stresses are sufficiently large near Mermaid Creek to mobilize fine gravels, sands, and silts and transport them upslope and towards the south a short distance.
- At present day MSL, waves are not expected to reach the toe of the existing marshland, and sediment transport is limited to the mid- to lower- intertidal. The toe of the existing marshland is expected to become exposed at MSL with 0.49 m of sea level rise, thereby resulting in increased shear stresses and erosion of the marsh edge.
- At HHWMT, shear stresses at the toe of the existing marshlands (between 1 – 10 N/m^2) are expected to be capable of eroding and transporting fine gravels, sands, and silts (Figure 15 - Figure 17). As sea levels rise, erosion of the leading edge of the marsh will increase.
- Notably, model results show that if storms occur at high water levels (which inundate the existing marsh), they may be expected to cause erosion along the leading edge of the marsh, and drive sediment transport up onto the marsh resulting in burial of the marsh. This finding is consistent with field observations of recent marsh burial, which is expected to have occurred when northerly storm events coincided with sustained high water levels during the previous winter storm season. As sea levels rise, these erosive and burial events are expected to occur more frequently.
- The governing scenario for design purposes is the 1-in-50 year AEP storm from the E (90^o) with 0.49m SLR. During this event, shear stresses may exceed 20 N/m^2 and be capable of mobilizing coarse gravels. Significant erosion of the leading edge of the marsh is expected during this event.

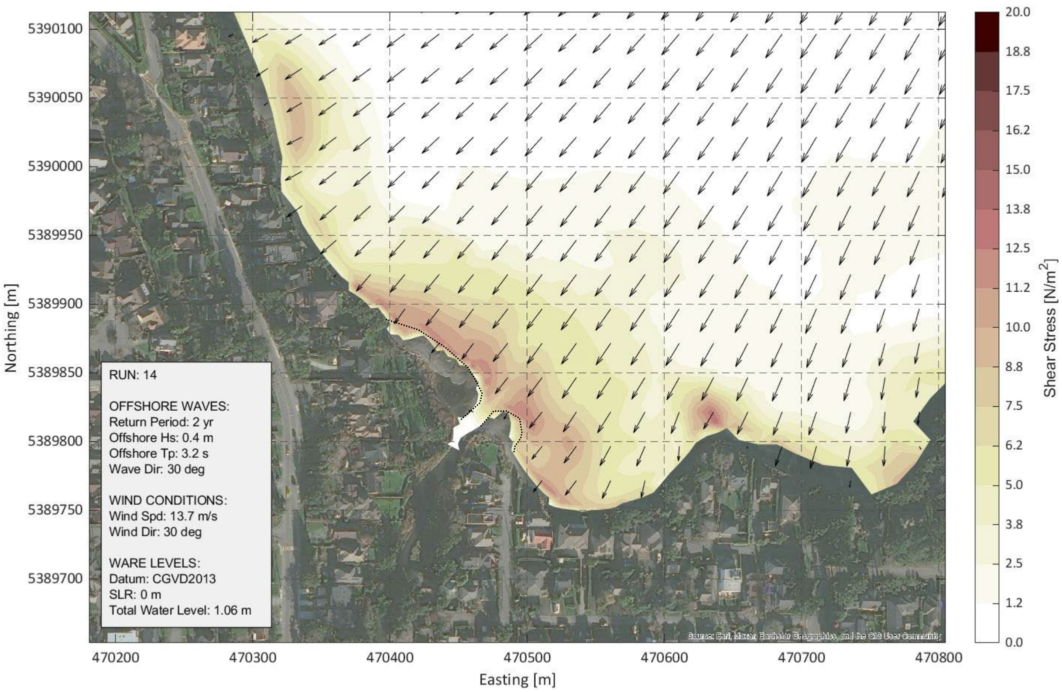

Figure 15 Shear stresses due to wave action near Mermaid Creek Delta for nominal storm conditions (1-in-2 year AEP storm) from 30º (NNE) at HHWMT with 0.0m SLR.

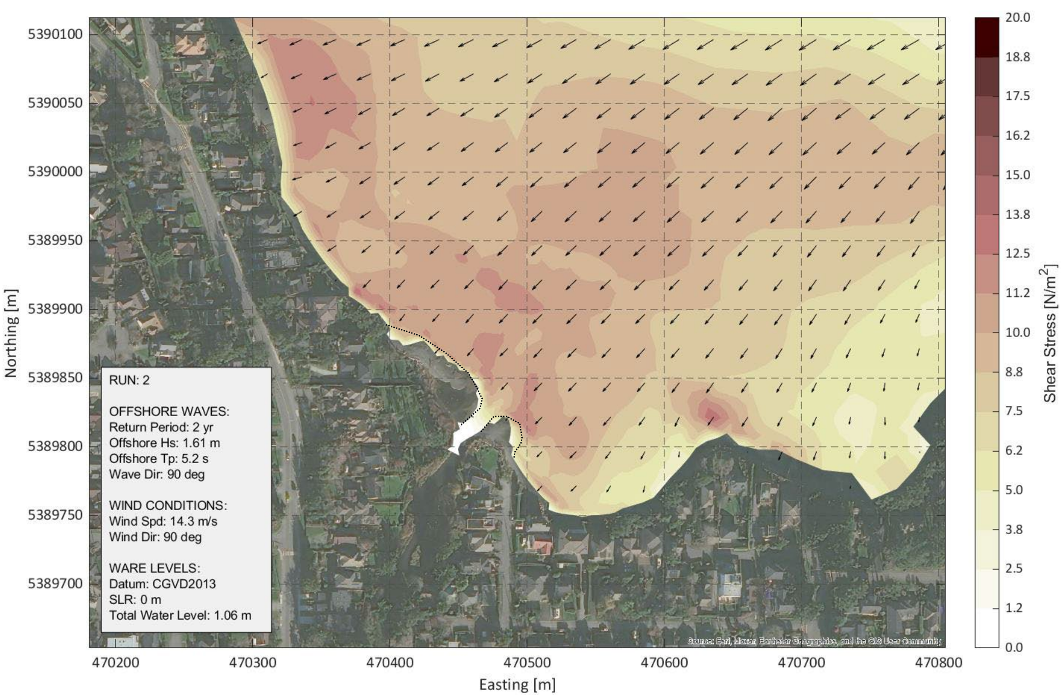

Figure 16 Shear stresses due to wave action near Mermaid Creek Delta for nominal storm conditions (1-in-2 year AEP storm) from 90º (E) at HHWMT with 0.0m SLR.

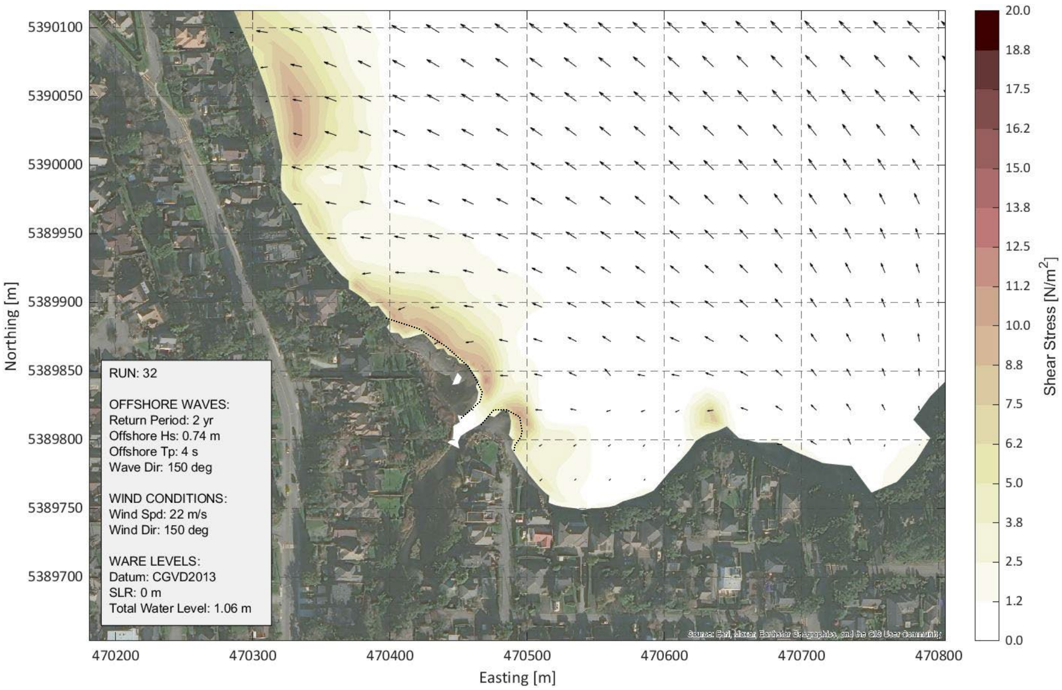

Figure 17 Shear stresses due to wave action near Mermaid Creek Delta for nominal storm conditions (1-in-2 year AEP storm) from 150° (SSE) at HHWMT with 0.0m SLR.

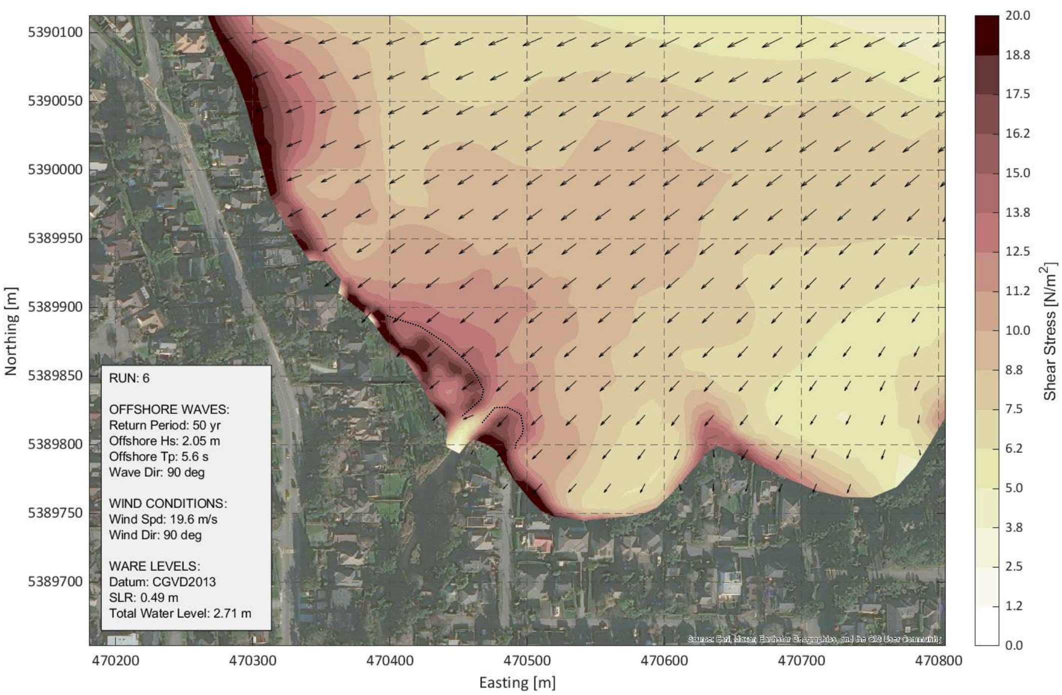

Figure 18 Shear stresses due to wave action near Mermaid Creek Delta for the governing storm scenario (1-in-50 year AEP storm) from 90° (E) with 0.49m SLR.

3.7.5. *Geomorphic Processes*

DHI has developed a conceptual model of present-day geomorphic processes (Figure 19). The model illustrates that sediment transport within Roberts Bay is driven primarily alongshore from southeast to northwest during severe storms originating from Haro Strait and Sidney Channel; However, local wave fields may be developed during southerly and northerly storms that are also capable of mobilizing sediments, albeit to a lesser degree.

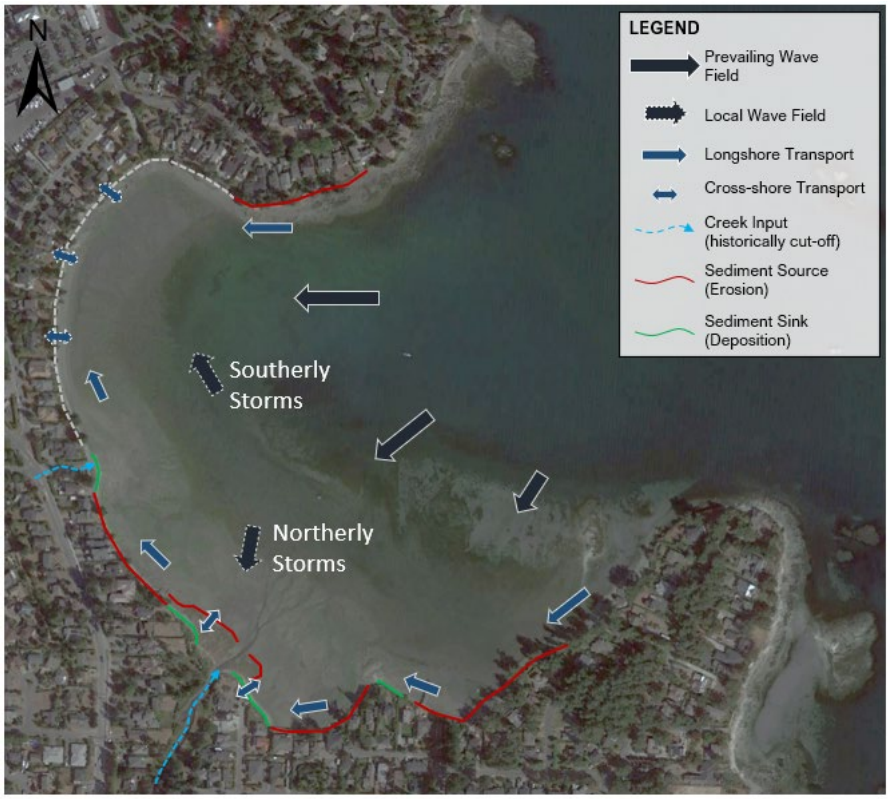

Figure 19 Conceptual model of present-day geomorphic processes in Roberts Bay

At mid- to high- water levels, waves reach the toe of the marsh and are expected to have sufficient energy to mobilize sediments and erode the marsh edge. Mobilized sediments may be transported seaward (onto the tidal flats) or landward. If storms coincide with high water levels (when the marsh is inundated), waves may drive sediments onto the marsh surface, where they deposit due to relatively low shear stresses. As such, during years where strong storms coincide with high water levels, the marsh is expected to become partially buried with small gravels, sands, and fines. Based on historical salt marsh extents (see Section 3.6), the marsh is expected to recover from burial, but not from edge erosion. Notably, burial may also help to raise the elevations of the marsh long-term, mitigating the effects of sea level rise.

Historically, upland sources (i.e., through shoreline erosion and creek loads) would provide sediment input into the Bay. Sediment sources in the Bay were effectively eliminated following the cut-off of both creeks and the armouring of most of the shoreline in Roberts Bay. Erosion at Mermaid Creek is expected to continue without the introduction of an additional sediment source and/or erosion protection measures.

Note that the processes illustrated in Figure 19 exist over a long time-scale and may be expected to vary over short time-scales (i.e., seasonally or annually). Trends may shift in response to sediment input into the geomorphological system, or as a result of climate changes and sea level rises.

4. Preliminary Design

A preliminary design has been prepared by DHI for expansion and erosion protection of the Mermaid Creek Marsh. The design is presented and discussed within the following sub-sections.

The preliminary design presented herein represents the project intent for the purpose of planning and discussion with permitting and approval agencies. The design will require additional study and detailed engineering design in subsequent phases, and that the design may change as the understanding of the site is advanced. The design should not be implemented without further engineering assessment, study, permitting, and approvals.

Note that other design options were also considered in this study. However, preference was given to the option presented herein in order to: (1) as much as possible, avoid the requirement for regular nourishment and maintenance (which would be expected for nourishment options that do not include erosion protection or rely on boulder clusters, for example), requiring difficult site access and regular disturbances to foreshore habitat, (2) to avoid trapping sediment and interrupting existing sediment transport processes as much as possible, which may impact adjacent sections of shoreline, and (3) to avoid unnecessary hard armouring, which may promote scouring (which would be expected for large, steep, and continuous rock armouring designs).

4.1. Functional Requirements

Functional requirements for the design are as follows, based on discussions with PSS:

- Expand the Mermaid Creek marsh to at least 1964 extents
- Mitigate erosion of the offshore edge
- Provide suitable substrate for vegetation growth
- Avoid damage or removal of existing habitats and materials
- Provide defined pedestrian pathways to reduce habitat damage from pedestrian usage
- Allow for a phased approach

4.2. Design Overview

The design includes an extensive marsh expansion on the northwest and southeast sides of Mermaid Creek, as well as low rock berms to provide edge protection (Figure 20 and Figure 21). The proposed design restores the northwest marsh to approximately the 1964 extent. The southeast marsh provides an option to expand the marsh beyond historical extents. The rock berms are designed to be both discontinuous and low-lying, in order to avoid potential unintended impacts to sediment transport processes within Roberts Bay. All material (including the marsh substrate) should be sourced from off-site to avoid removing (i.e., trapping) sediment from the existing sediment budget. Examples of similar projects which utilized rock edging to mitigate erosion as part of marsh restoration work are shown in Figure 22.

Key details of the design as depicted in Figure 20 and Figure 21 are provided below.

- *Marsh Area to be Developed (light green area in Figure 20):*
  - NW marsh: 1350 m^2
  - SE marsh: 2460 m^2
  - Total: 3810 m^2
- *Marsh Substrate:*
  - Slope (H:V): 6:1 to 100:1
  - Elevation: 1.0 – 1.5 m CGVD2013
  - Substrate size (D_{50}): 1 – 20 mm sand and gravels, mixed with fine organic material

- *Rock Berms:*
    - Length: 10 – 20 m
    - Height: 0.7 – 1.2 m
    - Crest elevation: 1.2 m CGVD2013, which may be increased to adapt to sea level rise
    - Crest width: 1.2 m
    - Rock size (D_{n50}): 0.4 m
    - Stone Gradation: 100 -200 kg
- *Plantings:*
  Plantings should include native marsh vegetation species, as directed by the QEP.
- *Drainage Channels:*
  Drainage channels may be field fitted during construction to improve drainage of the marsh, as directed by the QEP or Engineering Site Representative.
- *Pedestrian Crossing:*
  A pedestrian crossing (bridge or stepping stones, for example) may be considered to provide defined access across the creek, and reduce potential damage to the marsh (particularly during the period following construction). Signage directing pedestrians to stay off the marsh and along dedicated trails may also be considered. Design of these items is not included in the present scope of work.
- *Construction Phasing:*
  Both marshes may be constructed simultaneously, or in a phased manner. If a phased approach is taken, monitoring should be conducted following construction of the first marsh, to inform design modifications prior to construction of the second marsh. If phasing is adopted, the NW marsh is recommended for the first phase, as it appears to be experiencing more rapid erosion than the SE marsh. It is also anticipated that construction access would be gained from the Fifth St beach access (near the SW marsh), and as such construction of the SW marsh should preferentially be completed last. Monitoring data from the first phase of work will also inform refinement of the headland spacing and size for the second phase of work.

All measurements, elevations, and material sizes should be confirmed during detailed design, in consideration of topographic survey results and design recommendations from a Qualified Environmental Professional (QEP) and archaeologists (if any). See Section 4.4 for additional considerations related to permitting and approvals.

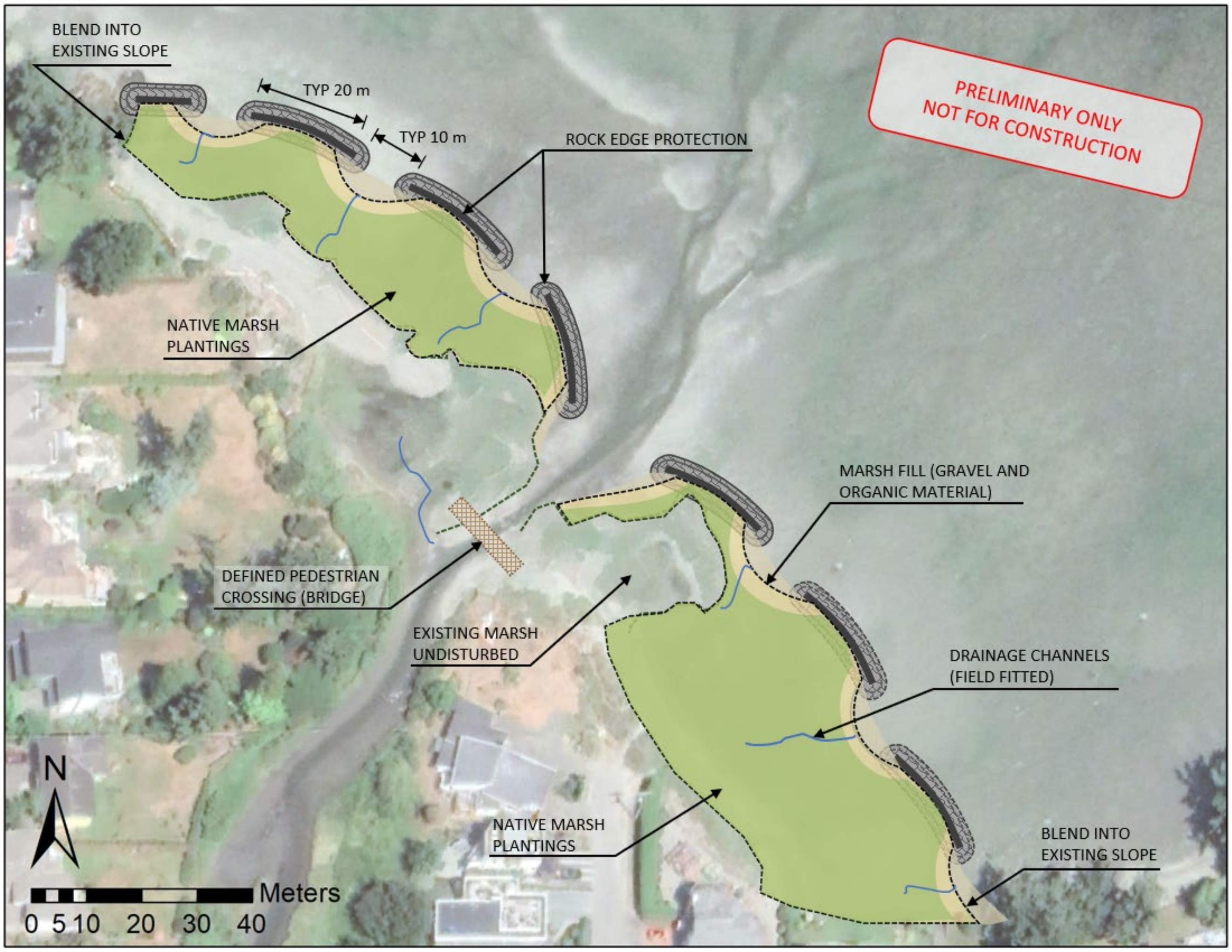

Figure 20 Plan view of preliminary design

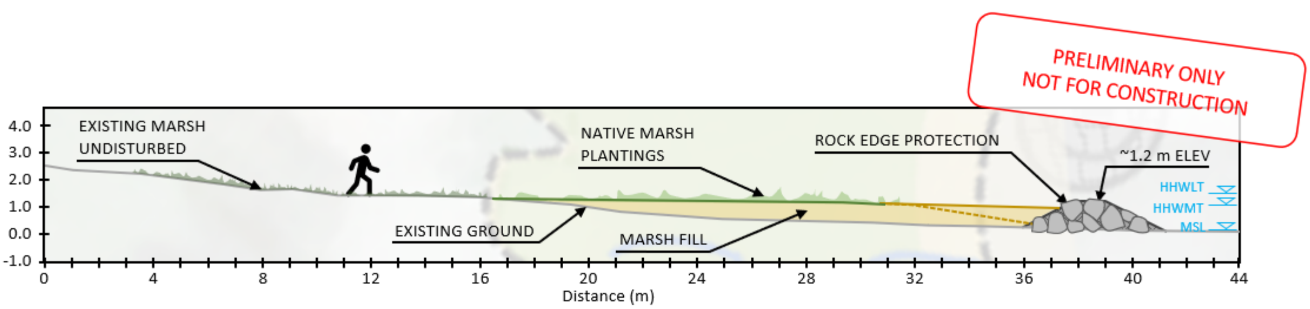

Figure 21 Cross-sectional view of preliminary design

Figure 22 Examples of rock erosion protection along the leading edge of marsh restoration projects (sources: www.southernenvironment.org/news/shift-to-living-shorelines-preserves-precious-coast/ and https://floridalivingshorelines.com/what-is-a-livingshoreline/)

4.3. Material Estimate

Estimated material quantities are provided in Table 8. Material quantities should be confirmed during the detailed design phase, in association with an accurate topographic survey.

Table 8 Estimated material quantities

Material Type	Estimated Quantity			Units
	NW Marsh	SE Marsh	Total	
Rock Edge Protection (Cobble – Boulder)	740	620	1360	tonnes
Marsh Fill (Gravel and Organic Material)	1130	2660	3790	m^3
Vegetation Plantings	1350	2460	3810	m^2
Pedestrian Bridge & Signage	N/A	N/A	1	lump

4.4. Additional Considerations

Additional considerations related to implementation are described below.

Archaeological Review

Archaeological sites are protected under the Heritage Conservation Act (HCA). Should construction require disturbance to the existing ground (for example, if existing peat materials are excavated for beneficial re-use), an archaeological review may be required. Owners, or archaeological consultants serving on behalf of the Owner, may request archaeological information about the property through the Archaeological Branch of the Provincial Government. If an archaeological site is in the area of disturbance, it will be necessary to hire a Qualified Archaeologist to determine the next steps and obtain necessary permits and approvals.

Note that because no excavation is proposed as part of the design, it is expected that an archaeological review will not be required.

DFO Project Review & Timing of Work

All projects requiring work below the high-water mark will required a habitat impact assessment to be completed by a Qualified Environmental Professional (QEP). The assessment should include recommendations to avoid or limit harm through design and construction management practices. The QEP would also submit a Project Review request under the Fisheries Act to the Department of Fisheries and Oceans (DFO). DFO will review the request, determine if the project may result in Harmful Alteration, Disruption, or Destruction (HADD) of fish or fish habitat, and recommend mitigation measures. If the project will result in a HADD despite implementation of the mitigation measures, an Authorization may be required, which sets terms and conditions that must be followed to avoid, mitigate, offset, and monitor impacts. It is expected that the design would not require Authorization; however, this should be confirmed by the QEP during the next phase of design.

In addition, work below the highwater mark is generally expected to respect windows of least risk defined by DFO for the project region. According to the DFO website, the timing windows for least risk for the project area (Area 19 – Victoria) are between July 1 – October 1 (summer window) and December 1 – February 15 (winter window). Generally, work should be completed in the 'dry' at low tide. Consequently, work during the winter window may review night-time construction and an associated increase in cost.

Crown Land Tenure

Development on crown land (i.e., areas seaward of the existing natural boundary) requires the occupant to obtain a Crown Land Tenure. As part of the tenure, an agreement is made between the upland property owner and the Province of BC, and an annual rental is paid. A legal land survey will be required to support the Crown Land Tenure application. Crown Land Tenures generally can take significant effort to apply for, often resulting in a lengthy review process. However, the Province of BC is currently piloting an expedited application process for nature-based shoreline projects[7].

Due to the nature of the project (i.e., a restoration project, which does not involve occupation), it is possible that the crown land tenure requirement may be waved or the annual rental may made nominal by the Province. If a Crown Land Tenure is required, it is expected that the project could utilize this expedited process.

Navigation Protection Act

Under the Navigation Protection Act, the Navigation Protection Program (NPP) sets the terms and conditions for works within navigable waters. Construction within or across navigable waters may require approval under the NPP by Transport Canada. If the project is classified as *Minor Works*, they may be constructed without review or approval. *Minor Works* involving erosion protection are still required to submit information and notify Transport Canada at least 48 hours prior to construction and publish a public notice during construction. Major Works require an application under the NPP, publish a public notice for input, and await a decision from Transport Canada. It is expected that the project will fall under the *Minor Works* designation.

Municipal and Regional Approval

Municipal and Regional District approval for the project may also be required. This would generally include providing design details to the Municipality and the Regional District, including (but not limited to) the design basis report (i.e., this document), design drawings, and a habitat report. The process may also require Council approval. It is recommended that the Municipality be engaged to provide additional guidance for this restoration project.

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[7] https://www2.gov.bc.ca/gov/content/industry/crown-land-water/crown-land/crown-land-uses/residential-uses/nature-based-erosion-protection

Migratory Bird Sanctuary Permit

The project is located within the Shoal Harbour Migratory Bird Sanctuary. If construction is expected to "scare migratory birds, destroy eggs or nests, relocate birds or their nests, or kill birds" (Government of Canada, 2022), a Damage or Danger Permit will be required under the Migratory Regulation, through the Canadian Wildlife Service (CWS).

It is recommended that a habitat assessment be completed during the next phase of design and measures be identified to avoid potential harm to migratory birds during construction.

5. Conclusions & Next Steps

The Mermaid Creek salt marsh has been narrowing and eroding over the past ~50 years (CORI, 2021). Salt marsh reduction has resulted in the loss of important ecological habitat, natural protection from waves, and carbon sequestration capacity. This report outlines coastal engineering analysis and preliminary design related to restoring and expanding the existing marsh within the Roberts Bay. Key findings include the following:

- The existing marsh is exposed to waves generated within the Haro Strait and Sidney Channel, as well as locally generated waves from within Roberts Bay.
- Storms that occur at water levels above MSL may erode the leading edge of the salt marsh.
- Storms that occur at high water levels may result in partial burial of the marsh. However, based on a review of historical airphotos, the marsh is expected to recover from these partial burials. Sediment transport onto the marsh may also help to raise the marsh and adapt it to future sea level rise.
- Sediment sources within Roberts Bay have been effectively cut-off due to shoreline armouring and limited creek inflows. There do not appear to be significant sediment sources available that would allow the marsh to self-repair to historical extents.
- As sea levels rise, increased erosion of the salt marsh is expected, unless mitigative measures are taken.

Proposed measures include an expanded salt marsh with a low-lying rock berm for erosion protection. The proposed design would expand the salt marsh by ~250 % (to 3810 m^2) relative to 2022 extents. The project may also be completed in phases to facilitate budgetary constraints and inform design modifications.

Recommended next steps to advance the preliminary design are outlined below. DHI can assist in developing the project delivery model that best meets PSS's needs.

- Begin discussions with permitting and approval agencies
- Environmental assessment and develop design recommendations. Review by a bird specialist may be required.
- Request archaeological information and determine if an archaeological assessment is required. Undertake archaeological assessment and develop design recommendations, if necessary.
- Begin permit application process.
- Detailed design, including development of design drawings, cost-estimates, construction methodology, and construction specifications.
- Develop monitoring and adaptive management plan, for implementation post-construction.
- Tender, including contractor quotation and selection.
- Construction, which may include environmental monitoring (if required by permit approvals) or engineering inspections.
- Monitoring and maintenance, as needed.

6. Closure

We trust that this report meets your current needs. Please do not hesitate to call or email us (contact information below) with any questions or comments.

Best regards,

DHI Water & Environment Inc.

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2022-11-29

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Classification	**Confidential:** This document is only accessible to the project team members and sharing it outside the project team is subject to the client's prior approval.

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