



Clayton Beach Restoration Feasibility and Alternative Analysis Design Report

Skagit County, Washington



Prepared for
Northwest Straits Conservation Foundation
Prepared by
Herrera Environmental Consultants, Inc.

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Contents

Introduction.....	1
Project Location	1
Historic Background.....	4
Cultural Resources	4
Historic Conditions	4
Relative Sea-level Rise.....	5
Delta Progradation	6
Anthropogenic Disturbances.....	6
Existing Conditions	9
Nearshore Geomorphology Trends	9
Nearshore Bathymetry	14
Soils and Topography.....	15
Marine and Nearshore	17
Aquatic Vegetation.....	17
Wave Climate.....	21
Net Shore-Drift Cells and Shoretypes	22
Backshore.....	25
Upland Scrub-Shrub.....	25
Upland Forest	25
Shoreline Buffer Functions.....	26
Fish and Wildlife Species and Habitats.....	26
Restoration Concepts	30
Objectives.....	30
Constraints.....	30
Climate Change and Sea Level Rise	30
Design Alternatives.....	31

Conclusions and Next Steps 51

References.....53

Appendices

Appendix A Wave Modeling of Current and Future Conditions

Appendix B Clayton Beach Eelgrass and Dredge Hole Investigation

Tables

Table 1.	Quantitative Evaluations of Shoreline Buffer Functions at Clayton Beach.....	26
Table 2.	Threatened or Endangered Species Listed for Federal Protection at Clayton Beach.	26
Table 3.	Arial Extent of Different Restoration Elements.....	33
Table 4.	Quantity Estimates for Major Project Elements in Each Design Alternative.....	33
Table 5.	Naming Conventions for Model.	39
Table 6.	Permitting Needs for Clayton Beach Nearshore Restoration.	52

Figures

Figure 1.	Clayton Beach Nearshore Restoration, Larrabee State Park Vicinity Map.	2
Figure 2.	Clayton Beach Nearshore Restoration Project Area, Skagit County, Washington.....	3
Figure 3.	T-sheet Showing Historical Condition at Clayton Beach 1887 (US CGS, 1887).....	5
Figure 4.	Historical Shore Change at Clayton Beach, Skagit County, Washington, 1969- 2022.....	11
Figure 5.	Clayton Beach Restoration Design, Expanded Armor Footprint 2006 - 2016.	12
Figure 6.	Clayton Beach Restoration Design, Existing Conditions.	13
Figure 7.	Bathymetry of Dredge Trench and Surrounding Eelgrass at Clayton Beach, Larrabee State Park (WDNR, 2023).	14
Figure 8.	Soils.....	16
Figure 9.	Eelgrass Percent Cover (per square meter) at Clayton Beach, Larrabee State Park (WDNR, 2023).....	18
Figure 10.	Mean Higher-High Water and 100-year Flood Elevations, Clayton Beach, Skagit County, Washington.	20
Figure 11.	Wind Rose for 22 Years of Wind Data Measured at the Padilla Bay National Estuarine Research Reserve.	21
Figure 12.	Coastal Geomorphic Shoretype Mapping of Clayton Beach, Larrabee State Park, Skagit County, Washington.	23
Figure 13.	Net Shore-Drift at Clayton Beach, Larrabee State Park, Skagit County, Washington.....	24
Figure 14.	Forage Fish Habitat.....	29
Figure 15.	Alternative 1: Debris Removal.....	35
Figure 16.	Alternative 2: Debris Removal with Three Pocket Beaches.....	36

Figure 17.	Alternative 3: Debris and Fill Removal with Two Pocket Beaches.....	37
Figure 18.	Model Output for Existing Bathymetry at Low Tide.....	38
Figure 19.	Northern and Southern Transect Profiles in the Immediate Vicinity of Clayton Beach.....	40
Figure 20.	Water Depth at Low Tide for All Conditions, North and South Profile.....	41
Figure 21.	Energy Dissipation in the Immediate Vicinity of Clayton Beach at Low Tide on Existing Conditions (model label "Dredged").	42
Figure 22.	The Restored, Filled Beach (model label "Alt_Dredged" and "Alt_Filled", respectively, in the lower left figure) Display Gradual Energy Dissipation Away from Sensitive Structures.....	43
Figure 23.	As Significant Wave Height Increases, Energy Levels Rise Accordingly.....	44
Figure 24.	Location of a Sensitive Erosional Hotspot Near the Southeast Corner of Clayton Beach, Existing Conditions, Low Tide.....	45
Figure 25.	At the Erosion Hot Spot from Figure 24, Overall Energy Dissipation Increases with Wave Height on the Existing Conditions.....	46
Figure 26.	The Restored, Filled Surface (Alt_Filled) Shows Significantly Decreased Overall Energy Dissipation at the Hot Spot.	47
Figure 27.	Significant Wave Heights at 0.33 Feet Average Wave Height, Existing Conditions (model label "Dredged").	48
Figure 28.	Significant Wave Height at 3.28 Average Wave Height, Restored and Filled Surface (model label "Alt_Filled").....	49

Photo Exhibits

Photo 1.	Circa 1912 – Looking northward during the construction of the trestle section of railway at Clayton Beach.....	7
Photo 2.	Circa 1912 – Looking southward at the completed trestle section of the B&SI Railway at Clayton Beach with the crossing of the GN Railway (left).	7
Photo 3.	Example of the "armored" shoreline condition at the intersection of GN and B&SI Railways (circa 1912).....	7
Photo 4.	Residual armoring along the shoreline near Clayton Beach (2022).	7
Photo 5.	Looking south at containment levee used to contain fill from the suction dredge.....	8
Photo 6.	Looking northerly at Clayton Beach area with suction dredge providing fill for platform construction.	8

Photo 7.	View of eelgrass beds that are present waterward (west) of the outer edge of interurban rock debris and fill along the project area (Herrera, April 20, 2022).....	19
Photo 8.	View south of gravelly substrates in the upper intertidal zone at Clayton Beach (Herrera, April 20, 2022).	19
Photo 9.	View of backshore along the Clayton Beach restoration area. The headland to the north of the site and the mountain slopes above the BNSF railroad tracks and Chuckanut Drive are forested. (Herrera, April 20, 2022).	25
Photo 10.	Barnacles, whelks and red algae observed at Clayton Beach (Herrera, April 20, 2022).....	28
Photo 11.	All three alternative restoration designs will remove artificially placed rocks and regrade the perched beach to more natural conditions conducive to eelgrass growth and forage fish habitat. (Herrera, April 20, 2022).	34

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Introduction

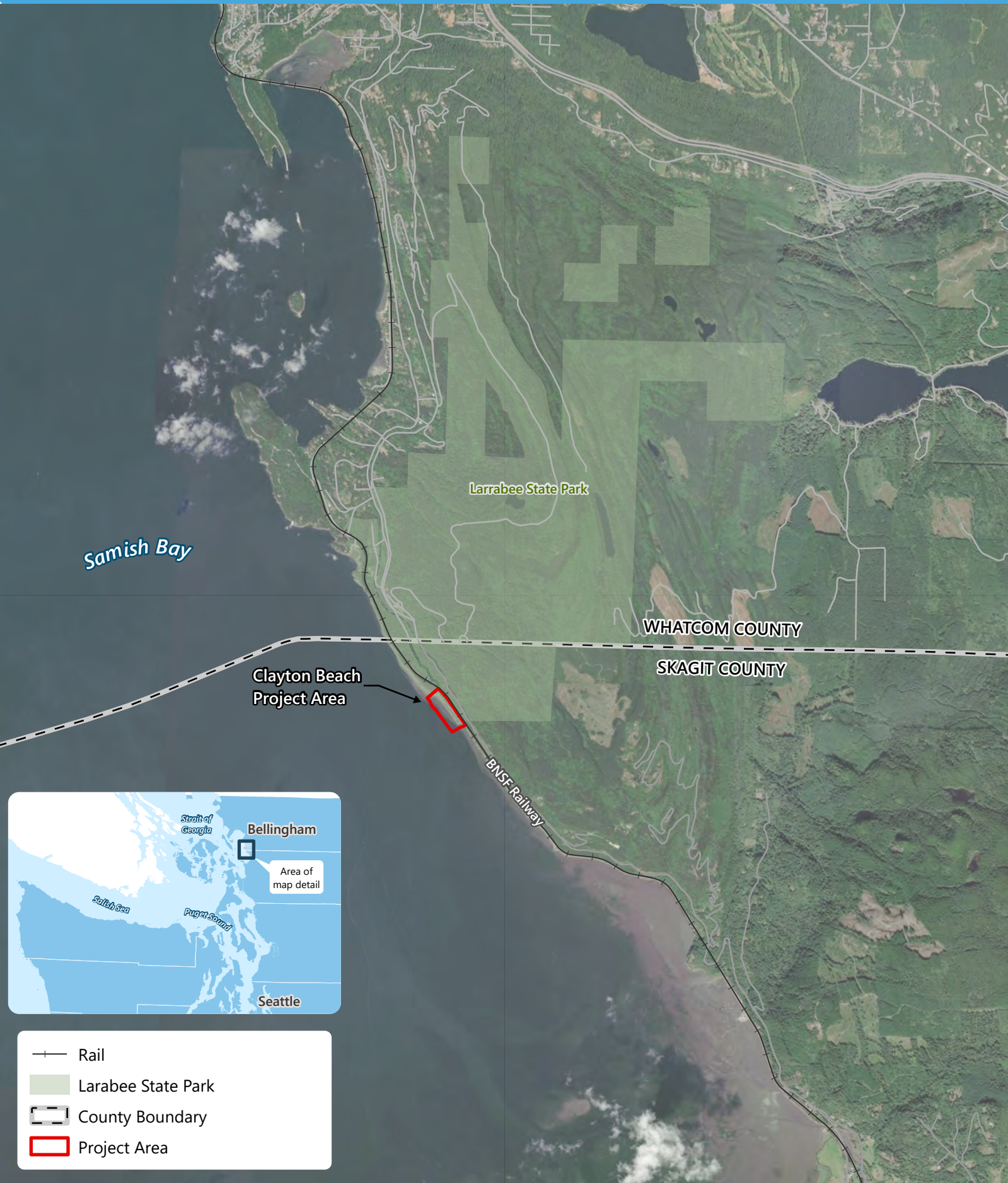
The Northwest Straits Foundation (NW Straits) is leading an effort to restore nearshore conditions and ameliorate degraded habitats at Clayton Beach, located at the south end of Larrabee State Park in Samish Bay, Skagit County, Washington. Extensive fill and debris associated with the historical interurban railway currently functions as the public shore along this popular beach. The interurban railway was only in operation for 18 years between 1912 and 1930; however, the remnant fill and debris have degraded nearshore processes, habitat, structure, and quality for almost a century.

This restoration feasibility assessment was conducted to better understand the implications of the site's history, current conditions, and trends, and to develop an informed, restoration approach that considers the range of stakeholder values and anticipated climate impacts at the site. Based on these results, three restoration design alternatives have been proposed, each of which addresses the historical impacts to nearshore conditions, habitat enhancement, and recreation value, and the integrity of the Burlington Northern Santa Fe (BNSF) rail causeway. This document describes each element of the feasibility assessment, followed by a comparison of the proposed restoration alternatives.

Project Location

Larrabee State Park, founded in 1915, is Washington State's first State Park. Larrabee Park's headquarters are located at 425 Chuckanut Drive in the southwest corner of Whatcom County, Washington. The Park encompasses approximately 2,750 acres; park facilities include a campground, band shell, picnic shelters, parking areas, a boat launch and hiking trails to access freshwater lakes in the forested Chuckanut mountains and beaches along Samish Bay. Clayton Beach is located in the south end of the Park in Skagit County. The project area is situated within the NW 1/4 of Section 6 of Township 30, Range 03 East (Willamette Meridian [W.M]) (Figure 1). The latitude and longitude coordinates for Clayton Beach are 48.64036 North, -122.48158 West (Decimal Degrees).

Clayton Beach is located west of the BNSF rail causeway, which limits shoreline access across over 50 miles of Puget Sound shoreline. A new pedestrian overpass, opened to the public in 2023, provides safe access to the beach, which was previously only accessible by visitors illegally crossing the train tracks that bound the northeastern end of the beach (Figure 2). The Washington State Parks Commission (State Parks) recently completed upgrades to Clayton Beach's trail access, including surrounding trails, honeycomb sandstone bedrock shores, tidepools, and the adjacent pocket beach to the north. The Clayton Beach areas subject to restoration and enhancement include 1,200 linear feet of Samish Bay's shoreline and approximately 9.0 acres in total area.





File Path: K:\Projects\2023\2023-07684-000_Proj_ClaytonBeach_FeasibilityAlternativeAnalysis\Design\Report\2023.aprx Figure 2 Project Area
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Historic Background

Cultural Resources

Clayton Beach and the surrounding Whatcom and Skagit County area are on the traditional lands of the *Nuwaha* and Samish Indian Nation. It is also adjacent to the south of the traditional territories of the Lummi and Nooksack. Lummi, Samish, and Nooksack territories joined at Chuckanut Bay. Shared territory between the *Nuwaha* and Samish were focused around Samish Bay (Drayton 2024). The Upper Skagit Indian Tribe also owns one of the parcels that is found in the nearshore at Clayton Beach. Indigenous people have lived in the region from time immemorial and have stewarded the land and its marine shorelines for generations. The rich bounty of marine life along this area's coast has sustained local Tribes, relying on fish and shellfish as a major food sources. A cultural resources assessment was conducted as part of this project, the details of which are not included in this report.

Historic Conditions

Nearshore conditions at Clayton Beach have been in a state of geomorphic transition over the past millennia. The greatest influences on the evolution of the nearshore and the physical processes driving the evolution Clayton Beach, include late Holocene sea level rise, late Holocene Skagit River delta progradation, and dramatic anthropogenic disturbances, largely associated with the development of the Great Northern (now Burlington Northern Santa Fe, BNSF) rail causeway and the Bellingham & Skagit Interurban Railway (B&SI). Each of these influences have shaped and altered the current conditions and general geomorphic processes at Clayton Beach.

Prior to the anthropogenic disturbances, historical T-sheets documented a minor cove protected by a sandstone bedrock outcrop landward of which a small tidal marsh with waterward mud flat was found (Figure 3). The adjacent uplands were relatively high in relief and were fronted by narrow and gravel beaches. Intermittent bedrock promontories and large boulders and glacial erratics were common along the shoreline.

Figure 3. T-sheet Showing Historical Condition at Clayton Beach 1887 (US CGS, 1887).



Relative Sea-level Rise

Relative sea-level elevations increased over the Late Holocene due to the combined retreat and melting of glacial ice from the Fraser glaciation. Relative sea-level rise is understood to have attenuated, and rates of sea level change have slowed over the past few thousand years. Combined with the large tidal range and limited waves, this has enabled the formation of wave cut benches or platforms and the gradual formation and evolution of depositional beaches.

A shallow wave-cut platform exists at the Clayton Beach site that includes the formation of cliff faces cut into the Chuckanut Formation bedrock by wave-erosion processes. Small pocket beaches along the shoreline have accumulated sediment, but significant depositional beaches and landforms are absent. Overall, the predominant supply of sediment recruitment to the shoreline has been from the upland areas of Clayton Beach and shoreline erosion. Upland geology in the area predominantly consists of the sandstone, siltstone and shale of the Chuckanut Formation, which erodes very slowly. Erosion is typically caused by freeze-thaw cycles combined with physical and chemical weathering. The rate of sediment recruitment is anticipated to have been relatively low and sediment transport conditions would have likely been considered “supply limited”. This supply-limited condition affects the formation, size, and stability of deposition beaches or accretionary shore forms. In summary, a naturally occurring, large sandy beach would not be expected in this area given the limited upland sediment supply conditions.

Delta Progradation

While the sea-level changes were slowing in the Late Holocene, the sediment and wave conditions at Clayton Beach were evolving rapidly. An emerging and significant influence of sediment delivery into the marine and littoral areas of Clayton Beach was the progradation of the Skagit River delta. Several distributary branches of the Skagit River historically outlet into Samish Bay, delivered a significant volume of fine-grained sediment (silt and sand). Some of this sediment would be transported northward by the predominant southerly winds, waves, and tidal currents, and eventually reach and deposit on the narrow wave cut platform waterward of Clayton Beach. These fine-grained sediments also began to fill and form the vast tidal flats in Samish Bay. The progradation of the delta altered the wave environment by reducing fetch from the south and the amount of wave energy reaching the shoreline by depth-limiting wave height. The net result is that there was a large increase in fine-grained sediment into the Samish Bay environment and a decrease in wave energy. Under these emerging conditions, it is possible that accretionary shoreforms could have developed as the sediment supply was increasing.

Anthropogenic Disturbances

Nearshore processes and conditions at Clayton Beach have been significantly altered due to both direct and indirect impacts by people over the past 150 years. The magnitude of historical changes to the landscape and land uses have contributed to Clayton Beach's condition currently being dominated by derelict engineering and debris, degraded nearshore processes, and in a state of responding to these disturbances. The combination of both river and coastal management actions to support transportation corridors and agricultural land use have driven much of the historical changes to the Clayton Beach area.

The Skagit River does not currently deliver sediment to Samish Bay due to a system of levees, which has dramatically reduced sediment accretion and progradation of the tidal flats. As a result, the wave cut platform waterward of Clayton Beach. Clayton Beach has reverted to a sediment supply-limited condition once again, where shoreline erosion processes are anticipated to increase. In addition, the Samish River and relict Skagit River delta front, between Blanchard and Samish Island has been armored and diked, which further contributes to a reduction in sediment available to the littoral zone at Clayton Beach.

Two railway transportation corridors, the Great Northern Railway (GN: now owned by BNSF) and the Bellingham & Skagit Interurban Railway (B&SI), were developed along the Clayton Beach nearshore during in the late 1800s to early 1900s. The construction of these two railways introduced widespread grading, fill, and armor into the nearshore environment. These disturbances have left a distinct and evolving mark on the shoreline to this day. One railway (formerly GN, now BNSF) still utilizes this shoreline railway corridor and continues to exert influences on nearshore conditions through the expansion and maintenance of riprap used to support and protect the rail causeway.

The GN Railway was constructed in the late 1800's prior to the Bellingham and Skagit Interurban (B&SI) Railway which was constructed in approximately 1912. In the process of building the GN railway, a bench was blasted into the Chuckanut Formation bedrock to create a foundation for the railbed. Blasted debris and graded materials were side cast where they typically accumulated along the shoreline. Historic photographic information supports this hypothesis (Photos 1 and 2).

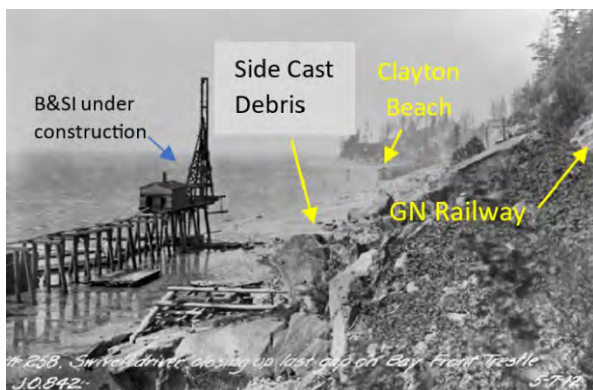


Photo 1. Circa 1912 – Looking northward during the construction of the trestle section of railway at Clayton Beach. Photo from Western Washington University, Heritage Resources.



Photo 2. Circa 1912 – Looking southward at the completed trestle section of the B&SI Railway at Clayton Beach with the crossing of the GN Railway (left). Photo from Western Washington University, Heritage Resources.

Invariably, the blasted material was delivered to the shoreline environment where it created a coarse, “armor-like” fill that extended into the intertidal zone (Photo 3). The introduction of this fill material would have influenced wave and erosion processes along the shoreline by effectively armoring it with large boulders and changing the configuration of the natural, historical position of the shoreline. While the shoreline already represented a supply-limited transport condition because of the loss of sediment from the Skagit River, the effective armoring of the shoreline south of Clayton Beach area with large side cast would have further interrupted sediment supply delivered from the upland areas adjacent to the shoreline, thus compounding the upland sediment supply-limited conditions. This armored condition persists to this day (Photo 4).

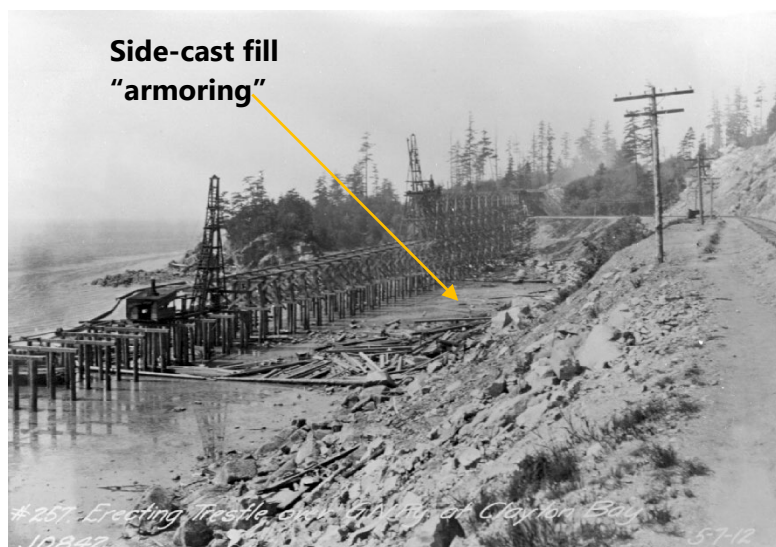


Photo 3. Example of the “armored” shoreline condition at the intersection of GN and B&SI Railways (circa 1912). Photo from Western Washington University, Heritage Resources.



Photo 4. Residual armoring along the shoreline near Clayton Beach (2022).

As part of the B&SI Railway development, a program of suction dredging of the subtidal area adjacent to Clayton Beach was initiated to provide fill to construct a platform for a B&SI Railway station platform. This fill also potentially structurally improved the large wooden railway causeway but left a legacy of a 13-acre unvegetated deep hole offshore (Photos 5 and 6).



Photo 5. Looking south at containment levee used to contain fill from the suction dredge. Photo from Western Washington University, Heritage Resources.



Photo 6. Looking northerly at Clayton Beach area with suction dredge providing fill for platform construction. Photo from Western Washington University, Heritage Resources.

Constructed in 1912, the trestle immediately became a problem for the overwater sections of the route. Service diminished following World War 1 when paved roads and the growing popularity of automobiles increased. Service ended in 1928 and the line was officially abandoned in 1930, but the fill remained.

Existing Conditions

Clayton Beach's existing environmental conditions as described in this report are based on review of existing environmental data from applicable agencies and other resources, site visits conducted by Herrera ecologists, scientists and engineers, and a professional survey of the site's topography. The High Tide Line (HTL)/Ordinary High-Water Mark (OHWM) of Samish Bay was delineated by Herrera biologists and professionally surveyed by PowerTek Surveyors of Bellingham, Washington on April 20, 2022 (Figure 6).

Clayton Beach's backshore and nearshore have been altered from the past and existing railway land uses. Sand and ballast rock have been installed along the backshore to support the historic interurban route and the existing BNSF railroad tracks that bound the eastern edge of the site.

Remnants of the historical trestle covers considerable intertidal area at Clayton Beach, extending from the northern beach access trail southward for at least 1,300 feet alongshore and encompass an area of approximately 3.5 acres, not including the existing beach, upland fill, and the offshore dredge hole. An estimated volume of 5,200 cubic yards of large rock covers a 50-foot-wide and 1,300-foot-long mound that extends down to MLLW at the southern end and the middle of the beach face (approximately + 5 feet MLLW) at the northern end. The armor has resulted in the formation of a landward perched beach (culminating roughly 12,000 cubic yards of sediment at approximately 5.5 feet MLLW) comprised of muddy fines over a mix of gravel over sand. Within the length of relict armor and perched sits a network of wooden bulkhead posts and wales with wood tiebacks set at 8-foot intervals. None of this wood appeared to be treated. Armor stones behind the wall were strictly surficial, indicating that the armor had originally been placed in front of the wall and then thrown by waves over the top. There are several breaches in the rock mound that enable the beach to flood the perched beach.

Behind the rock, extends a series of piles, 5 in a line every 15 feet. 189 piles are visible, and another 72 piles were estimated at just below the beach surface given their regular pattern. It's like that additional piles extend up to the BNSF rail line but they are buried by the fill placed during construction. The piles were generally 18 to 24 inches in diameter, only a few feet tall, and were heavily damaged. They did not exhibit signs of creosote treatment, although no testing of the wood was conducted as part of this project.

Suction dredged subtidal sediment was used to fill the uplands, beach and support construction of the interurban trestle. The remnant dredge area is roughly 300 feet off-shore of the southern part of Clayton Beach, measures 13-acres in area, and is entirely devoid of submerged aquatic vegetation.

Nearshore Geomorphology Trends

The extent to which nearshore conditions and processes have been altered at the site, has resulted in Clayton Beach being a largely artificial landscape feature dependent on derelict engineering with additional constraints to its natural landward transgression due to the BNSF rail causeway. Without either

continued maintenance or redesigning of the engineered condition at Clayton Beach; the beach will continue to narrow and erode at the cost of the nearshore habitats and recreational value found along this popular beach in Larrabee State Park.

The following summary of nearshore geomorphic trends documents the recent evolution of the Clayton Beach based on air photo analysis. Results of these analysis documents a trend of consistent shoreline retreat of the historic fill placed for the B&SI Railway. The rate of erosion is relatively high. Figure 4 shows the retreat of the high-water shoreline over the past half-century where a maximum annualized erosion rate of approximately 1.2 feet per year and a minimum annualized erosion rate of approximately 0.2 feet per year were calculated. The greatest erosion rates were observed along the southern extent of the study area, which is outlined as an erosional hotspot. The fill placed for the B&SI Railway is dredged sediments which are predominantly sand that can be easily eroded. The increases in sea level, both observed and forecasted, resulting from climate change are likely to accelerate the erosion rates over the coming decades and beyond. It is foreseeable that B&SI Railway fill could be virtually eliminated by erosion over the next 50 years.

The erosion of the fill is the primary source of sediment currently supporting Clayton Beach. Once this fill is eroded, it is anticipated that the shoreline will become progressively more sediment supply limited and evolve to resemble the historic shoreline conditions with a narrow, armored beach and potentially a small pocket beach at the northern end of Clayton Beach (near today's trail access). The hightide beach will likely continue to recede landward toward the BNSF railway, similar to the erosion that has occurred along the southern reach of the beach (Figure 4). It is anticipated that BNSF Railway will respond to the continued erosion and loss of the B&SI fill that threatens their railway by expanding the existing armor protecting the southern reach to maintain the structural integrity of their corridor. This process is already underway as the southern erosion expands (Figure 5). Recent aerial photography shows that the shoreline armor has expanded 100 feet along the southern bank adjacent to the BNSF railway between 2006 and 2016. Figure 6 displays the area of the rock debris, fill, derelict piles, and expanding erosional hotspot adjacent to the BNSF railway.



File Path: K:\Projects\2021-07684-000\Project\GIS\Working\ClaytonBeach.aprx Figure 4. Clayton Beach Historical Shore Change
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Author: lodes@herra.com

Figure 5. Clayton Beach Restoration Design, Expanded Armor Footprint 2006 - 2016.



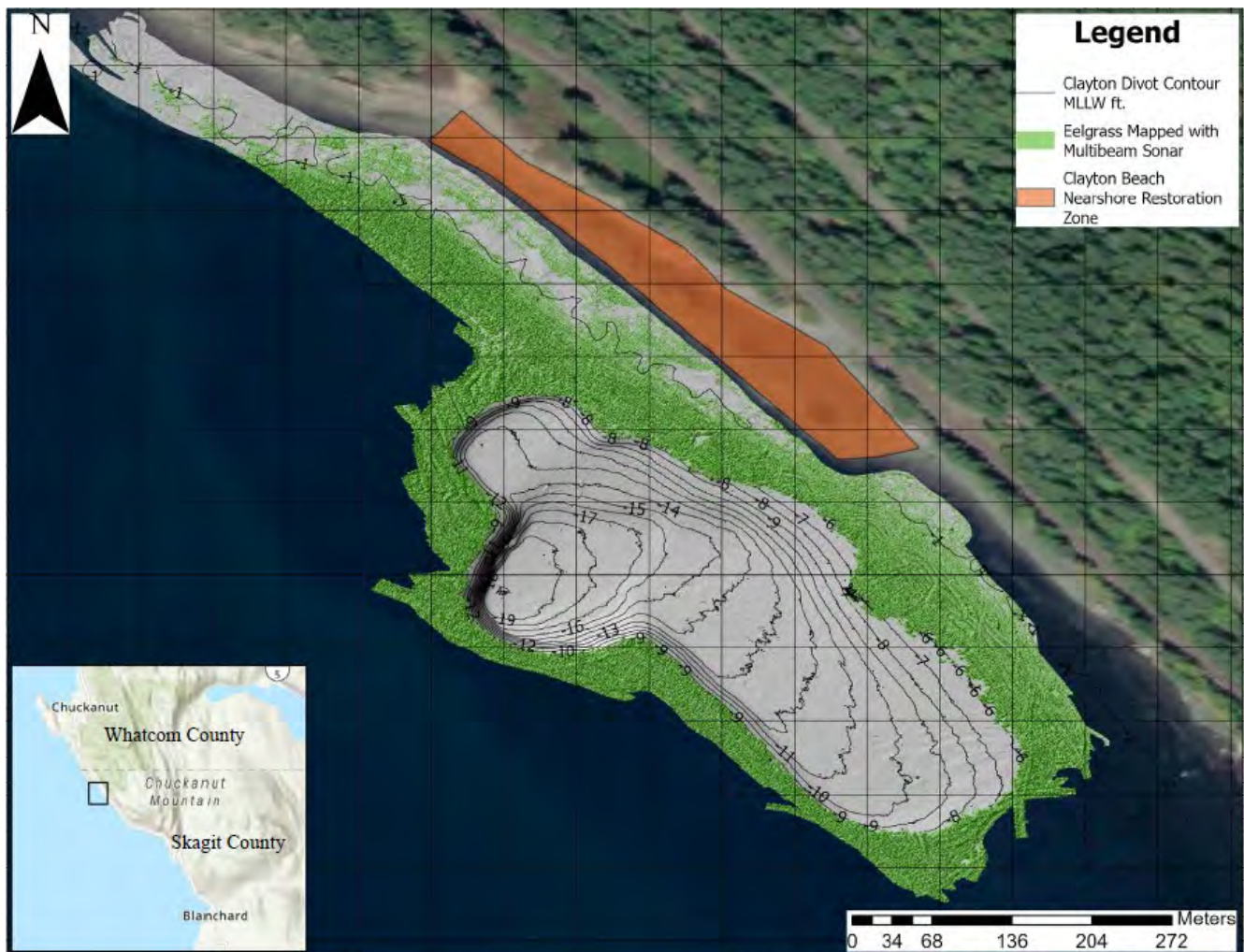


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Nearshore Bathymetry

Clayton Beach is a highly modified shoreline. The beach has been subject to multiple and significant engineering projects to provide shorefront access, and the nearshore bathymetry reflects this history of anthropogenic influence (Figure 6). A significant feature is a dredged trench located approximately 250 feet offshore from the southernmost point of the historical rock armor, where sediment was removed from the subtidal (Figure 7, WDNR). The dredged trench covers an area of 300,000 square feet (13.9 acres) and is approximately 7 feet deeper than the surrounding area (WDNR 2023). The natural bathymetry consists of a seaward slope with a water depth of 1.2 feet near the shore and approaching 24 feet of depth 0.5 miles offshore (NOAA 2024a).

Figure 7. Bathymetry of Dredge Trench and Surrounding Eelgrass at Clayton Beach, Larrabee State Park (WDNR, 2023).



The nearshore sediment primarily consists of tertiary continental sedimentary rocks, including fluvial sandstone, conglomerate, and mudstone with thick coal seams. Large chunks of bedrock populate the northern section of Clayton Beach, produced by erosion of surrounding sedimentary rock. These

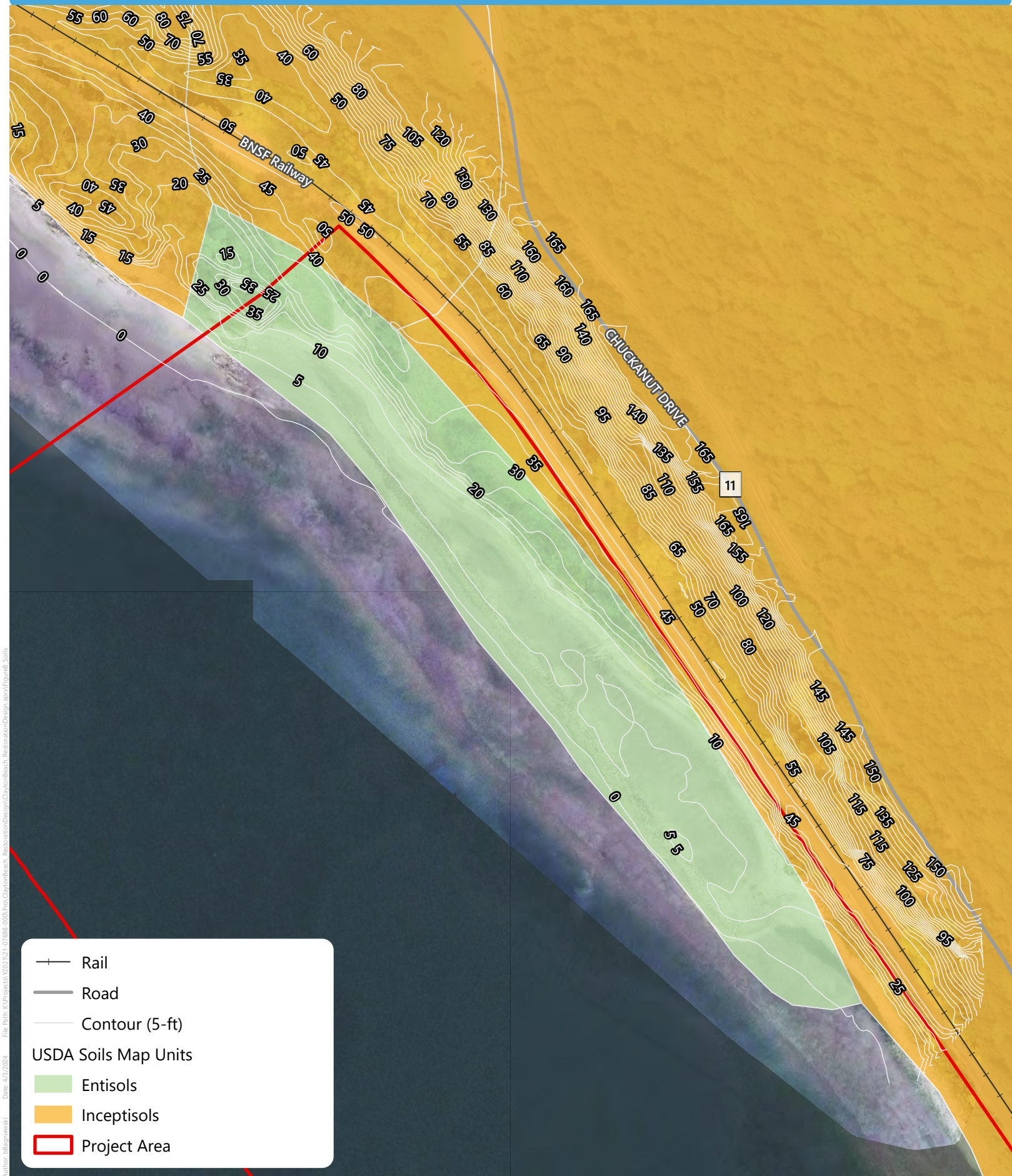
sandstone boulders dampen wave energy. The intertidal consists of cobbles mixed with sand from the suction dredging, while the subtidal is finer sand (DNR 2006).

In Samish Bay to the south, the bathymetry remains shallow with depths ranging from approximately 1 to 10 feet. At the southern edge of the bay, the mouth of the Samish River is characterized by a large muddy tidal flat, limiting the depth and fetch over which waves can develop from the south. Bellingham Bay, to the north and west, significantly deepens to approximately 100 feet (NOAA 2024a).

Soils and Topography

The Natural Resources Conservation Services' ([NRCS] 2023) *Web Soil Survey* identifies somewhat excessively drained Indianola loamy sand (Soil Unit #75) as present along the beach (Figure 8). This doughty, non-hydric soil is located on terraces with 0 to 5% slope. Ballast and angular rocks to support the active BNSF railway that bounds Clayton Beach to the east have been placed along the shoreline slope in landslide prone areas.

Dystic Xerochrepts-Rock outcrop complex, 65% to 90% slopes (Soil Unit #48) is mapped on the steep mountainside that is upslope of the railroad tracks and Chuckanut Drive. Gravelly silt loam and very gravelly loam soils overlay unweathered bedrock that is present at approximate depths ranging between 45 to 49 inches from the ground surface.



Marine and Nearshore

Aquatic Vegetation

The Washington State Department of Ecology's (Ecology) Coastal Atlas maps continuous eelgrass bed fringing the shoreline of Samish Bay (Ecology 2023). The Washington State Department of Natural Resources recently surveyed the eelgrass at Clayton Beach (Figure 9, WDNR, 2023). The purpose of the study was to document the distribution of eelgrass at the site, especially in regard to the unvegetated historic dredge hole that is present immediately offshore, and to determine the feasibility of restoring the site for eelgrass restoration. Eelgrass distribution at the site is classified as patchy at elevations below -1 ft MLLW to a depth of -10-feet (MMLW), and a more continuous bed, extending above 0 ft (MLLW).

The dredge trench results in an absence of eelgrass at -5 to -6 feet (MLLW) along the southeastern edge of the eelgrass bed and -9 to -10 feet (MLLW) along the west edge (of the trench) (WDNR 2023, Figure 7). Based on their analysis of the eelgrass presence of surrounding shores, DNR predicts that following removal of the rubble, fill, and pilings on the beach; eelgrass will likely move into the newly restored zone (WDNR 2023). In addition to the shoreward expansion, restoring the natural bathymetry by filling the dredge trench provides the opportunity to restore an additional 13.9 acres of eelgrass in this area (WDNR 2023).

Based on the tide predictions for Bellingham Bay (Station ID (9449211), the estimated tide elevations during the afternoon on April 22, 2022 when Photo 7 was taken by Herrera's biologists, ranged between -1.0 feet and -2.0 feet (Mean Lower Low Tide = 0.0-feet) (NAVD88)(NOAA, 2022).

Japanese eelgrass (*Zostera japonica*) was also observed to be present shoreward of native eelgrass (*Z. marina*). Eelgrass is important in providing habitat and refuge for many aquatic species, including forage fish. Eelgrass also traps sediment that stabilizes substrate and reduces the force of wave energy, reducing coastal erosion.

Green (*Ulva lactuca*), red (*Porphyria*) and brown algae (*Fucus* sp.) were recorded by Herrera's biologists on shoreline rocks at the Clayton Beach project site.

Figure 9. Eelgrass Percent Cover (per square meter) at Clayton Beach, Larrabee State Park (WDNR, 2023).

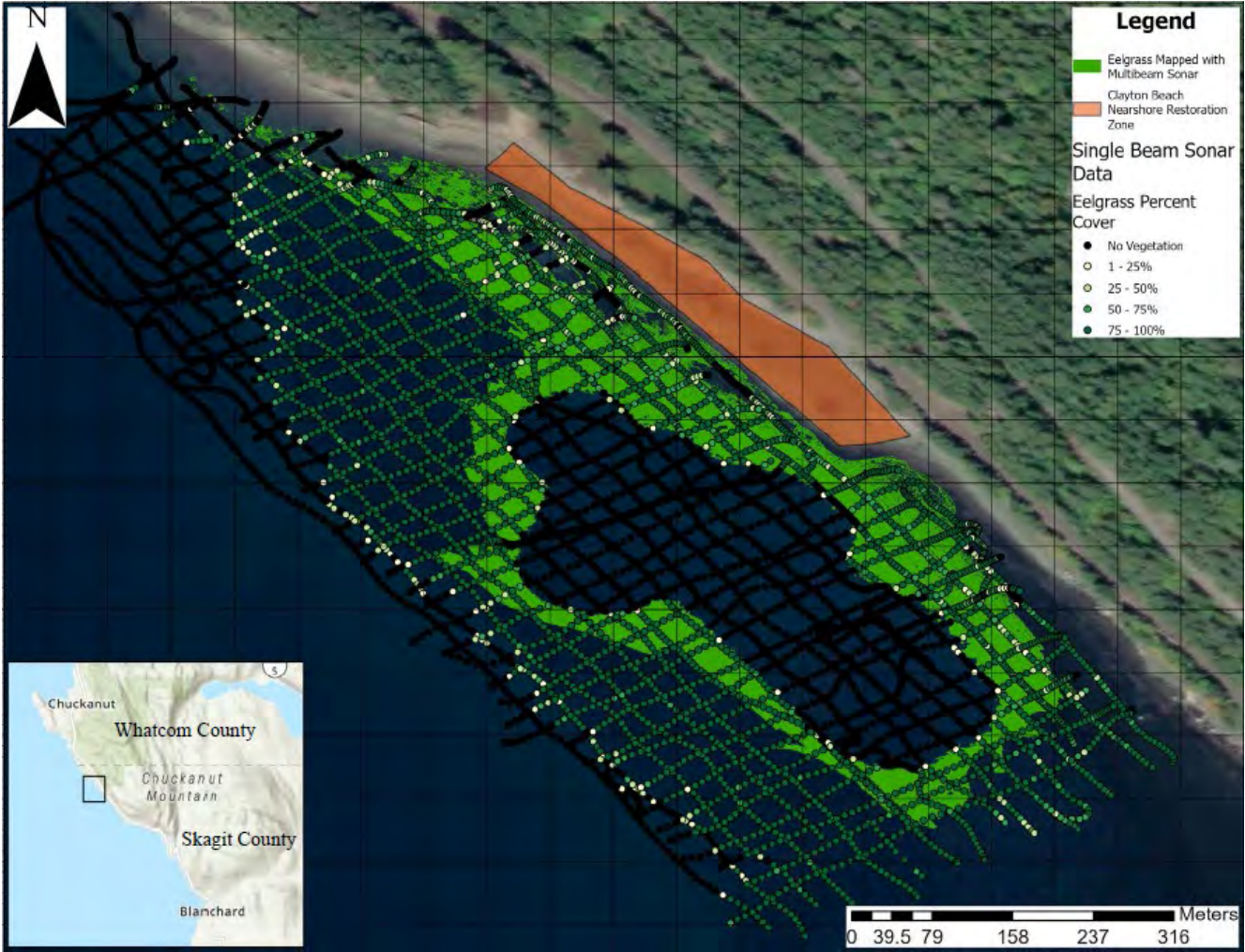




Photo 7. View of eelgrass beds that are present waterward (west) of the outer edge of interurban rock debris and fill along the project area (Herrera, April 20, 2022).



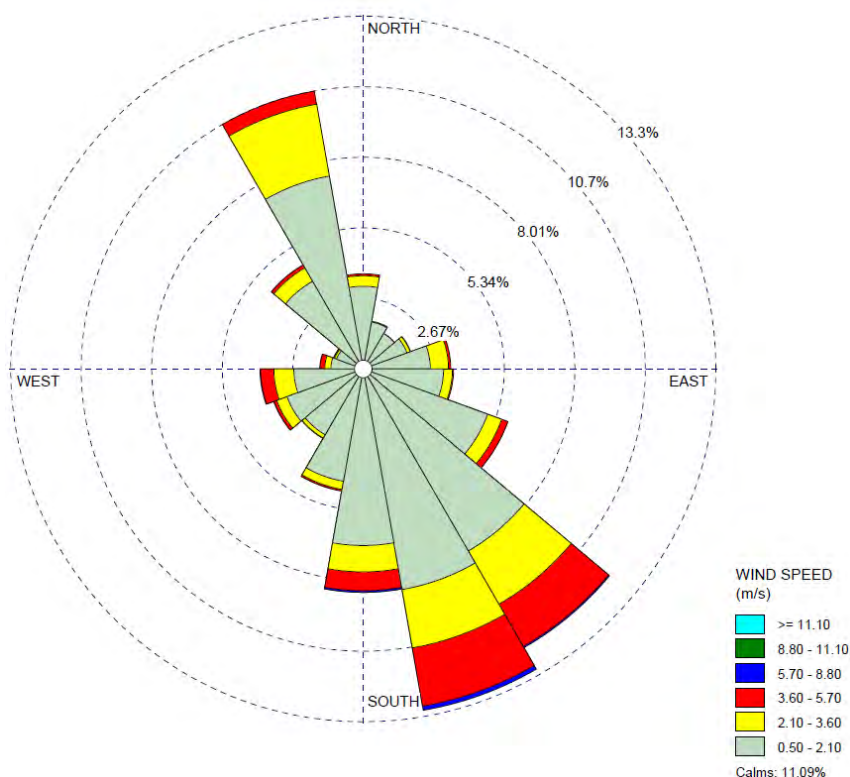
Photo 8. View south of gravelly substrates in the upper intertidal zone at Clayton Beach (Herrera, April 20, 2022).



Wave Climate

Clayton Beach is defined by the Marine Shoreline Design Guidelines as having a high energy wave environment (Johannessen et al. 2014). Its maximum fetch (open water distance) is approximately 14 miles from the west. An analysis of local wind conditions was conducted as part of this study using 22 years (2001 to 2023) of wind records collected at the Padilla Bay National Estuarine Research Reserve. Most winds come from the south-southeast (Figure 11) where the fetch is approximately 5 miles. Less than 5 percent of the winds measured at Padilla Bay were out of the west. While the measuring station is somewhat protected from the west by topography of Fidalgo Island, winds in our region generally come from the south or north.

Figure 11. Wind Rose for 22 Years of Wind Data Measured at the Padilla Bay National Estuarine Research Reserve.



When wind blows over the surface of water energy is imparted to the water and waves begin to form. How large waves get depends on the strength, duration, and distance over which the wind blows. The Puget Sound is generally considered a fetch-limited environment, meaning fetch length is the main factor for how large waves can become in each storm. The highest wind speed in the data record was 18 m/s, which has the potential to produce deep water waves up to 3 feet in height. Swell is another factor in the wave environment. Waves from fully developed seas travel beyond the conditions that create them, lengthening and reducing in height as the distance from their origin increases. These low-frequency waves organize into smooth, regular groups, and can travel thousands of miles unchanged in height and period. When swell waves interact with the seafloor in the vicinity of land, their height can

increase to 1.5 times their deep-water height, creating high surf (NOAA 2023). The low fetch that protects Clayton Beach from wind waves also provides protection from the full brunt of ocean-going swell; however, waves from the Pacific may enter the Strait of Juan de Fuca and reach Clayton Beach. As waves approach shore and begin to interact with the sea floor they get higher and steeper until they break and impart their energy on the shore. How and where this energy is dissipated greatly impacts the location and severity of erosion along the shoreline. A wave model for Clayton Beach has been developed to help understand the existing wave environment as well as to better understand waves with respond to the different proposed restoration alternatives.

Net Shore-Drift Cells and Shoretypes

When waves approach the shore at an oblique angle an alongshore current develops. This alongshore current drives alongshore sediment transport, which is more commonly referred to as shore-drift or littoral sediment transport. All the beaches in Washington have been delineated into distinct sediment sub-systems in which there is a dominant direction of sediment transport. Referred to as net shore-drift cells, each of these systems consists of areas of sediment input, throughputs (transport), and outputs or sinks. Inputs are the eroding bluffs that deliver most of the sediment in the drift cell, which are commonly referred to as feeder bluffs. Throughputs are neither eroding nor accreting but the place in which sediment is stored in beach berms, shoals, broader backshore areas, and wider beaches. Sinks are depositional shores, in which wave energy diminishes and sediment falls out of suspension, resulting in long-term deposition and coastal landform development.

Net shore-drift generally reflects the combined shore orientation and fetch. Beaches that have their greatest fetch (the overwater distance across which wave can develop) exposed to the south, typically exhibit northward transport, while those exposed to the north, exhibit southward transport. This pattern is largely driven by both the prevailing (most common) and predominant (strongest) winds and waves originate from the south.

Clayton Beach was originally mapped as a feeder bluff (Figure 12, MacLennan et al. 2013) with waterward shoreline armor. The eroding bank, comprised of dredged fill does provide sediment to the nearshore environment; however, the mappers were unaware of the scale and nature of dredge and fill history at the site at the time of the mapping. Northward net shore-drift occurs through this reach of shore (SKMA001, Figure 13; MacLennan et al. 2013). At Clayton Beach, much of the sediment that erodes from the bank is limited in the extent of transport by the bedrock exposures found north of the study area, though some sediment transport likely occurs waterward of the bedrock. The erosion of the bank is valuable to the nearshore environment as it is one of the few intact sources of sediment in this drift cell. No appreciable drift is mapped north of Clayton Beach, due to the bedrock geology.



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Backshore

Upland Scrub-Shrub

The backshore's scrub-shrub vegetation is dominated by non-native and invasive Scotch broom (*Cytisus scoparius*) and Himalayan blackberry (*Rubus armeniacus*) shrubs that are typical of disturbed sites. With exception to a couple of black cottonwood (*Populus balsamifera* ssp. *trichocarpa*) saplings, trees were observed to be lacking along the Clayton Beach's nearshore restoration site. Mixed coniferous and deciduous forest vegetation is present upslope of the railway, east of the restoration study area. Herbaceous plants are also generally lacking, as landslides deposit sand and rocks along the sloping backshore. Canada thistle (*Cirsium arvense*), an invasive weed, is present.



Photo 9. View of backshore along the Clayton Beach restoration area. The headland to the north of the site and the mountain slopes above the BNSF railroad tracks and Chuckanut Drive are forested. (Herrera, April 20, 2022).

Driftwood logs and wrack are deposited along the toe of the slope (Photo 9). The logs are subject to movement with the tides, during storm events, and from park visitors that commonly build driftlog structures in the backshore.

Upland Forest

The headland to the north of the project area is forested. Native shore pine (*Pinus contorta*), Douglas fir (*Pseudotsuga menziesii*) and Pacific madrona (*Arbutus menziesii*) trees dominate the canopy. The

shoreline bluff at the south end of Clayton Beach is also forested. Big-leaf maple (*Acer macrophyllum*), grand fir (*Abies grandis*) and western snowberry (*Symphoricarpos albus*) are additional species present.

Shoreline Buffer Functions

Buffers to protect shorelines generally perform functions according to their vegetation class. Forested buffer areas typically serve buffer functions at the highest levels, while areas dominated by herbaceous vegetation provide most functions at the lowest levels. Scrub-shrub habitats typically serve functions at moderate levels.

The shoreline buffer along Clayton Beach is highly disturbed due to historic fill and the existing active BNSF railway that bounds the site to the east. Shoreline stability, temperature moderation (shade), bank integrity (root reinforcement), recruitment of large woody debris and wildlife habitat are each being served at low levels (Table 1). Runoff filtration shoreline function is rated as moderate.

Table 1. Quantitative Evaluations of Shoreline Buffer Functions at Clayton Beach.

Shoreline Stability	Recruitment of Large Wood Debris (LWD)	Temperature Regulation (Shade)	Bank Integrity (Root Reinforcement)	Wildlife Habitat	Runoff Filtration
Low	Low	Low	Low	Low	Moderate

Fish and Wildlife Species and Habitats

Samish Bay's marine and nearshore is utilized by threatened or endangered species listed for federal protection according to provisions of the Endangered Species Act (ESA)(NOAA Fisheries 2023a,2023b, USFWS 2023) (Table 2). In addition to the ESA protected species, many other priority species occur in Samish Bay, including numerous fish, shorebirds, waterfowl, and invertebrates.

Table 2. Threatened or Endangered Species Listed for Federal Protection at Clayton Beach.

Species	Total Area		
	Jurisdictional Agency	Federal Listing Status	Designated Critical Habitat in the Clayton Beach Nearshore Restoration Project Area
Bull trout, Coastal/Puget Sound DPS (<i>Salvelinus confluentus</i>)	USFWS	Threatened	Yes (Marine)
Chinook salmon, Puget Sound ESU (<i>Oncorhynchus tshawytscha</i>)	NOAA Fisheries	Threatened	Yes (Marine)
Killer whale, Southern Resident DPS (<i>Orcinus orca</i>)		Endangered	Yes
Marbled murrelet (<i>Brachyramphus marmoratus</i>)	USFWS	Threatened	No

^a NOAA Fisheries 2023a, 2023b, USFWS 2023.

^b The Western DPS of Yellow-billed cuckoo (*Coccyzus americanus*) and the North American wolverine (*Gulo gulo luscus*) are generally mapped for the County by USFWS, however there is no suitable habitat at Clayton Beach for these species.

The marine and nearshore habitat in Samish Bay is located within designated critical habitat for the Coast-Puget Sound Distinct Population Segment (DPS) of bull trout (*Salvelinus confluentus*) and the Puget Sound Evolutionary Significant Unit (ESU) of Chinook salmon (*Oncorhynchus tshawytscha*) (USFWS, 2023, NOAA Fisheries 2023b). Juvenile Chinook, anadromous bull trout, and other salmonids are likely to use the eelgrass beds along marine nearshore for foraging and refugia habitat. Puget Sound steelhead (*O. mykiss*) are not known to extensively rear in estuaries or nearshore habitats and generally out-migrate from natal streams between April to June (NOAA Fisheries 2018). Endangered gray whale and Southern Resident DPS Killer whale have on occasion been documented in Samish Bay (Orca Network 2023).

Forage fish provide significant diet contributions to many economically important fish including juvenile Chinook salmon, Pacific cod, Pacific hake and dogfish and are a major prey for marbled murrelet. Due to the limited extent of available inter-tidal spawning habitat in Puget Sound, forage fish are especially vulnerable to shoreline development and construction activities. Eelgrass beds, such as those along the Clayton Beach shoreline, trap sediment that stabilizes substrate and reduces the force of wave energy, reducing coastal erosion and is important in providing habitat and refuge for many aquatic species, including forage fish.

Spawning habitat for Pacific herring (*Clupea pallasii*) is mapped within Samish Bay (WDFW, 2023a; Figure 14). Pre-spawner herring holding areas are mapped to the northwest of Samish Island and to the east of Eliza Island located approximately 5 miles and 7 miles, respectively, offshore of Clayton Beach. Surf smelt (*Hypomesus pretiosus*) and Pacific sand lance (*Ammodytes hexapterus*) spawning areas are mapped to the south of the Clayton Beach project area.

Most herring stocks in Washington spawn from late January through early April. Herring deposit transparent adhesive eggs on inter-tidal and shallow sub-tidal eelgrass and marine algae. Eggs may be deposited anywhere between the upper limits of high tide to a depth of -40 feet. However, most spawning takes place between 0 and -10 feet in tidal elevation (Penttila, 2007). Mature herring return to their spawning ground in their second or third year and in subsequent years.

Pacific sand lance deposit eggs on a broad range of beach surface substrates from soft, pure sand beaches to beaches armored with gravel up to 3 cm in diameter, although most spawning occurs on the finer grain substrates (Penttila, 2007). Annual spawning typically occurs from November 1 to February 15 at tidal elevations ranging from +/- 5 feet to above the MHHW line. WDFW recently documented sand lance burrowing behavior at Clayton Beach, north of the shoreline armor at about 1 foot (MLLW; WDFW 2024).

Surf smelt spawn year-round within the intertidal area of beaches with a specific mixture of coarse sand and pea gravel. Most spawning areas have gravel ranging in size from 1-7 mm in diameter, otherwise known as "pea-gravel" or "coarse sand." Surf smelt require a specific tidal elevation for successful spawning. They spawn around the highest tide in the afternoon or early evening. Eggs are deposited near the water's edge in water a few inches deep, around the time of the high-water slack. Within Puget Sound, spawning that occurs in the summer months has been most concentrated at a tidal elevation between +7 and the MHHW line.

WDFW documents Dungeness crab (*Cancer magister*) in association with Clayton Beach (WDFW, 2023b). Herrera observed a variety of native and non-native invertebrates within the intertidal zone (Photo 10). Representative species recorded included: Pacific little neck (*Protothaca staminea*) and Pacific gaper horse (*Tresus nuttallii*) clams, heart cockle (*Clinocardium nuttallii*), barnacles (*Balanus* sp.), fringed dogwinkle (*Nucella lamellosa*) and limpet (*Patella* sp.). Non-native species recorded included Pacific oyster (*Crassostrea gigas*), varnish clam (*Nuttalia obscurata*), and Japanese mud snail (*Batillaria attramentaria*). Aggregating sea anemone (*Anthopleura elagantissima*) was also observed to be present.

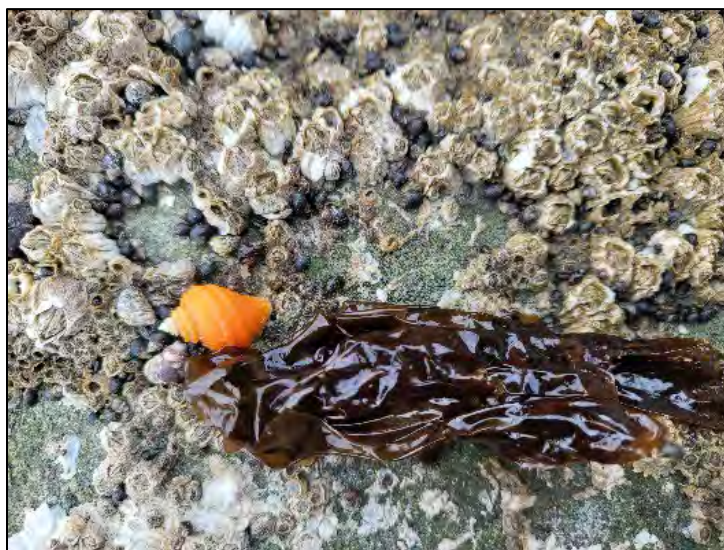
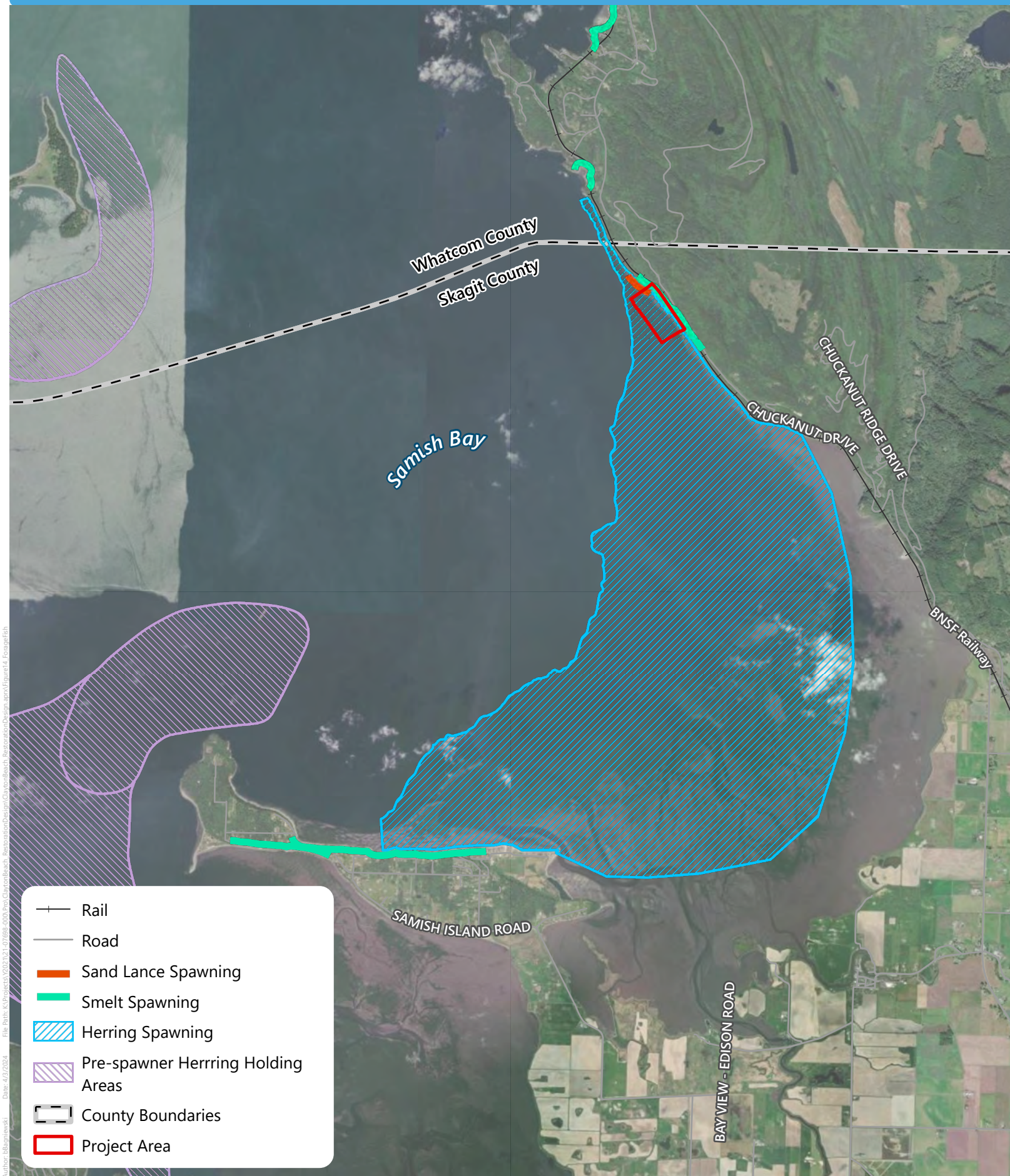


Photo 10. Barnacles, whelks and red algae observed at Clayton Beach (Herrera, April 20, 2022)

Terrestrial Habitat

Larrabee State Park provides habitat for a variety of terrestrial species. Herrera biologists noted visual and auditory observations of several relatively common birds during the April 20, 2022 site visit, including American bald eagle (*Haliaeetus leucocephalus*), belted kingfisher (*Megasceryle alcyon*), seagulls, loon and a woodpecker. Excavations by a red breasted sapsucker (*Sphyrapicus ruber*) were also observed. Columbian black-tailed deer (*Odocoileus hemionus*) are likely to be common to the area.



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Restoration Concepts

Objectives

The Clayton Beach Nearshore Restoration Project proposes to remove fill and debris along approximately 1,200 linear feet of the Samish Bay shoreline with the objectives of improving sediment transport processes and recreational value; restoring forage fish spawning habitats, expanding eelgrass beds, and enabling nearshore habitats to better adapt to sea level rise. Cumulatively, this project will restore over 9 acres of beach, backshore, and riparian habitat to improve spawning habitat for surf smelt and Pacific sand lance, improve public access to Clayton Beach, and provide interpretation of cultural and historical uses and ecosystem dynamics. The combined rock removal and filling of the historical dredge trench will allow for close to 14 acres of additional restoration to eelgrass beds. Failed and unnecessary armor is precluding spawning habitat of surf smelt and sand lance, two critical prey species for salmonids and marine birds. Removal of the rock debris will uncover considerable additional spawning habitat. Without this removal the combined effects of sea level rise on an armored shoreline will lead to the gradual elimination of forage fish spawning habitat over the coming decades, and most might be lost by 2100 (Kruger et al. 2009).

Constraints

Several constraints for project implementation were considered in planning for the restoration at Clayton Beach.

- BNSF Railway infrastructure support
- Potential contaminated sediments from creosote debris
- Cultural resources investigations
- Site access is not available from the uplands, i.e. barge access only

Climate Change and Sea Level Rise

Implications of climate change and sea level rise were explored to understand the long-term impacts and opportunities associated with current land uses and potential restoration alternatives at Clayton Beach. Understanding how conditions at the project site may change aids in development of a more sustainable restoration design and facilitates climate-ready conditions for the beach and for critical rail transport infrastructure.

The existing MHHW and 100-year flood elevations at Clayton Beach are 7.8 feet and 12.9 feet (FEMA 1985; all elevations in NAVD88). The 100-year flood elevation includes wave action. There is a 50 percent chance that relative sea level rise will rise 0.7 feet or greater by 2050 (Miller et al. 2018). The estimated elevations for MHHW and Extreme High Water (EHW) or 100-year flood elevations will exceed 8.5 feet and 13.6 feet respectively. There is a 1 percent probability that the amount of relative sea level rise will

exceed 1.4 feet by 2050. The estimated elevations of MHHW and EHW in 2050 based on this probability are 9.2 feet and 14.3 feet, respectively. These future conditions would exacerbate erosion and contribute to shoreline recession that may eventually cause additional damage to the railroad revetment. Higher water levels would be expected to allow wave energy to reach higher on the beach to erode the backshore or undermine the railroad revetment. Higher water levels and large storms will accelerate sediment transport, which in a sediment supply-limited environment, could reduce the expected duration of beach nourishment material. This means that beach nourishment alternatives that do not include elements to retain nourishment sediment, would likely require periodic maintenance (additional of beach nourishment sediment) over several decades.

Design Alternatives

Three alternative nearshore restoration designs were developed for consideration for the project (Figures 15, 16 and 17). All three designs include the removal of fill, rock debris, crib wall, and creosote-treated piles from the nearshore and restoration of the marine riparian ecotone. The beach would be nourished with a mix of sand and gravel that resembles native beach material from a local reference beach. The upper beach and backshore will include a storm berm intended to help absorb wave energy and protect the landward BNSF rail causeway. The storm berm and landward backshore would be vegetated with salt tolerant plants known to succeed in these environments, such as dune grass (*Leymus mollis*). Restoration of the marine riparian zone will entail removal of several non-native and invasive species and installation of native plants in the uplands.

In all alternatives, rock and suitable fill material that has been removed from the upper beach will be reused to rebuild elevation and eventually fill the dredge trench located directly offshore of the site, following approval from regulatory agencies. Additional sand will need to be imported to complete filling the expansive hole and to restore the natural bathymetry of the sub-tidal, natural wave conditions, and the likely historical spatial extent of eelgrass beds. Filling the dredge hole is a very important element of the restoration and the long-term sustainability of Clayton Beach restoration and the BNSF railway. Wave modeling results revealed that the deep water created by the dredge hole focuses wave dissipation along the toe of the bank, which appears to be a driving force in the erosional hotspot located along the south shore of the beach. The hole also provides an area for larger fish and mammals to prey on migrating juvenile salmonids.

Restoration Alternative 1.

The first proposed restoration alternative is the simplest design, focused on fill and debris removal along with beach nourishment. Rock and fill removal are expected to leave a significantly smaller beach profile, which will be augmented with imported nourishment sediment to increase the breadth of backshore and improve available beach habitat. Overall, the nourishment will build the beach out approximately 5 to 10 feet using a mix of sand and pebble suitable for forage fish spawning (Figure 15). Additional nourishment would be added to the southern end of the project to account for northward transport of sediment over time. In the backshore and uplands, non-native invasive plant species will be removed, and native vegetation installed in its place. As noted above, significant fill removal and regrading will be used to restore a more natural native beach topography.

Restoration Alternative 2.

The second proposed restoration alternative design expands of the action in Alternative 1 with inclusion of two partially buried groin structures to form three pocket beaches along the project shoreline (Figure 16). More extensive beach nourishment would be used to build the beach face farther out with pocket beaches oriented more directly into the prevailing wave direction. This design is intended to emulate the natural processes of a pocket beach, which is swash-aligned, thus oriented to directly face the strongest on-coming waves. Groins will help to retain the (placed) nourishment sediment within the project area, particularly into the future, as sea level rise will lead to increasing sediment transport rates out of the project area. Nourishment would also be placed at a higher elevation where the upper extent will be stabilized with dune vegetation, forming a more natural riparian transition to the uplands. As with Alternative 1, non-native invasive plant species will be removed from the uplands and native vegetation installed in its place.

Restoration Alternative 3.

The third proposed restoration alternative includes more extensive removal of the nearshore fill and associated debris from the uplands between the existing beach and the BNSF railway (Figure 17). The result will be a wider beach and backshore with a more gradual slope to the upland-backshore interface. The backshore portion would be reforested and planted across the marine riparian ecotone, or gradient of upland to dune or backshore vegetation. The elevations and microtopography of the backshore will be wider, higher, and designed to absorb wave energy and protect the landward BNSF causeway. Waterward of the expanded backshore, fill will be excavated from the upper beach and replaced with native beach material via beach nourishment. The existing sandstone outcrops at the northern extent of the project will be augmented with additional sandstone boulders to enhance retention of beach sediment. A buried rock groin would be constructed near the middle of the project. Beach nourishment will be used to form two more stable, pocket beaches. Nourishment sediment would be held in place by the bedrock outcrop and supporting rocks at the northern end of the beach and the central groin. Similar to all of the other restoration alternatives, the relict fill and rock would be removed and used to fill the historical dredge trench back to depths suitable for eelgrass growth.

Comparison of Restoration Alternatives

Each restoration alternative will achieve the main project objectives of enhancing Clayton Beach recreational value and nearshore habitat restoration via rock, debris and fill removal and beach nourishment, while mitigating climate (sea level rise) impacts and erosion to the BNSF railway. Each of the proposed alternatives are more sustainable than the existing beach, which is exhibiting a consistent trend of erosion that is likely to accelerate in the coming decades. Cross-shore groins are proposed to retain beach nourishment material in Alternatives 2 and 3, which results slightly less recovered beach area resulting from rock removal (Table 4). The groins would substantially decrease the loss of nourishment sediment over time, thus reduce the need for maintenance (renourishment) in the future. Each alternative includes fill removal, regrading, and beach nourishment of the entire beach profile. However, a much greater volume of beach nourishment sediment would be imported in Alternatives 2 and 3 (Table 4). Alternative 3 would entail additional disturbance (fill and pile removal) in the uplands to regrade and reslope the uplands into a more stable configuration and further build up the backshore and

storm berm to provide the most sea level rise resilient restoration alternative. As the resulting nearshore topography will be lower gradient uplands that transition to the widest backshore with the larger storm berm, designed to absorb wave energy and protect the toe of the bank and BNSF railway (Table 3 and Table 4).

Table 3. Aerial Extent of Different Restoration Elements.

	Total Area (acres)			
Area	Existing Conditions	Alternative 1	Alternative 2.	Alternative 3.
Rock Cover	1.46	0	0.08	0.07
Intertidal fill	2.05	0	0	0
Low-tide terrace	0	1.35	1.11	0.94
High-tide beach	1.02	1.25	1.89	1.55
Regraded backshore		0	0	1.75

Table 4. Quantity Estimates for Major Project Elements in Each Design Alternative.

	Material Quantity		
Project Element	Alternative 1	Alternative 2.	Alternative 3.
Rock (cy)	5,200	5,200	5,200
Piles	189	189	261
Intertidal fill (cy)	13,800	14,600	13,300
Backshore fill (cy)	0	0	25,800
Beach nourishment (cy)	4,200	7,100	7,500
Backshore soil (cy)	0	0	8,000
Rock groins (cy)	0	440	300

* Assumes 72 additional piles removed during backshore fill removal.

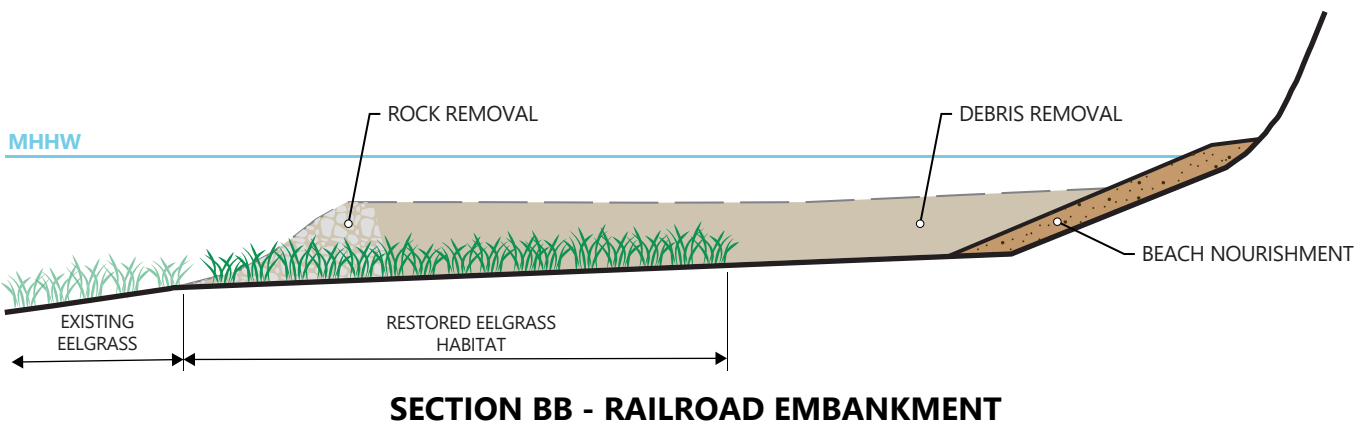
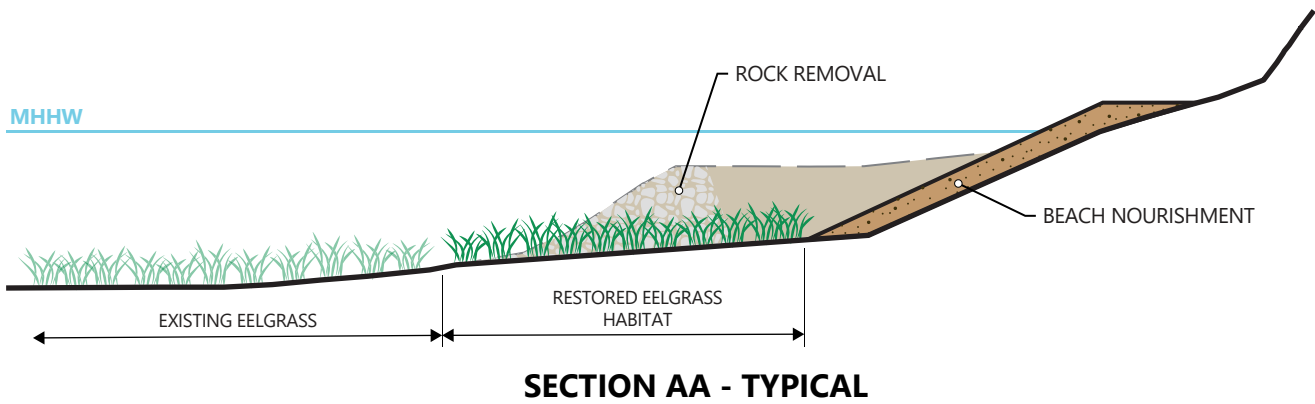
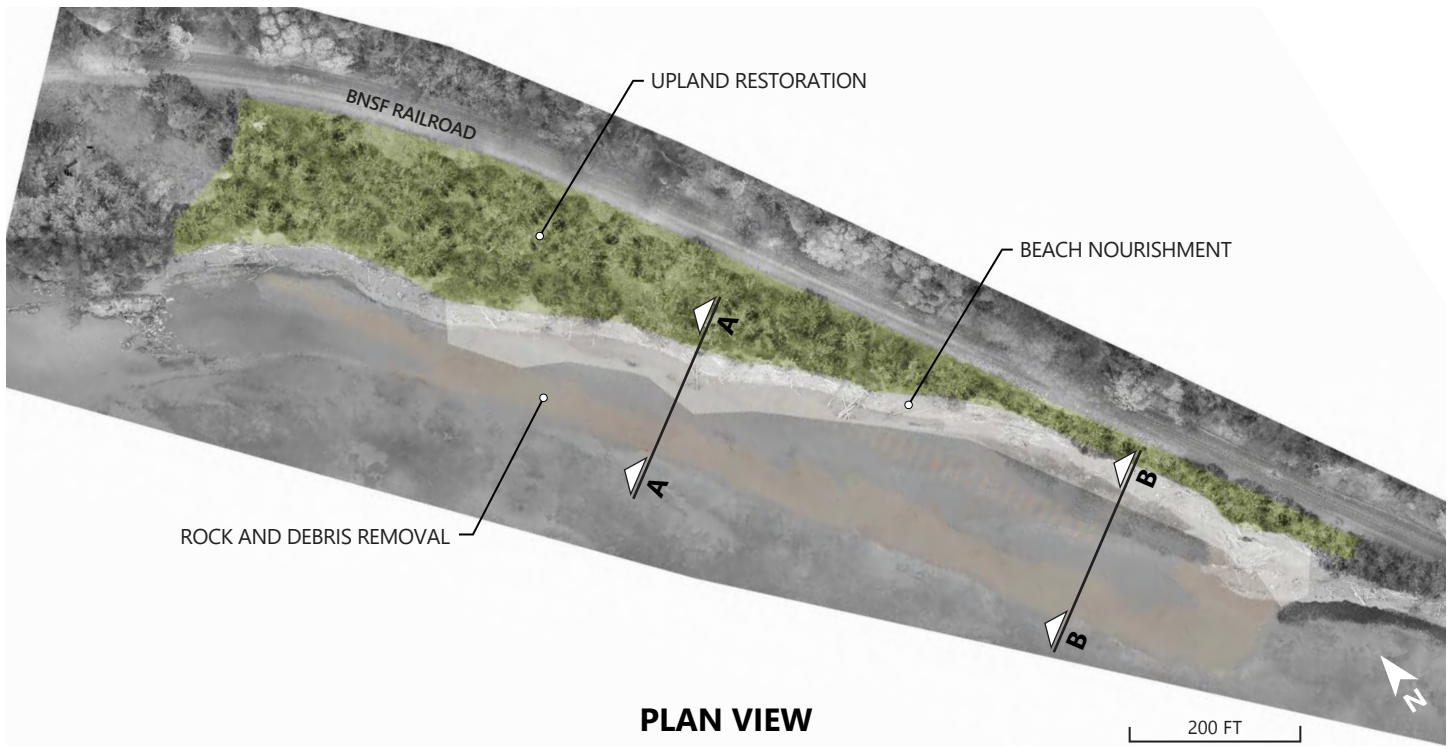
Native Vegetation Restoration

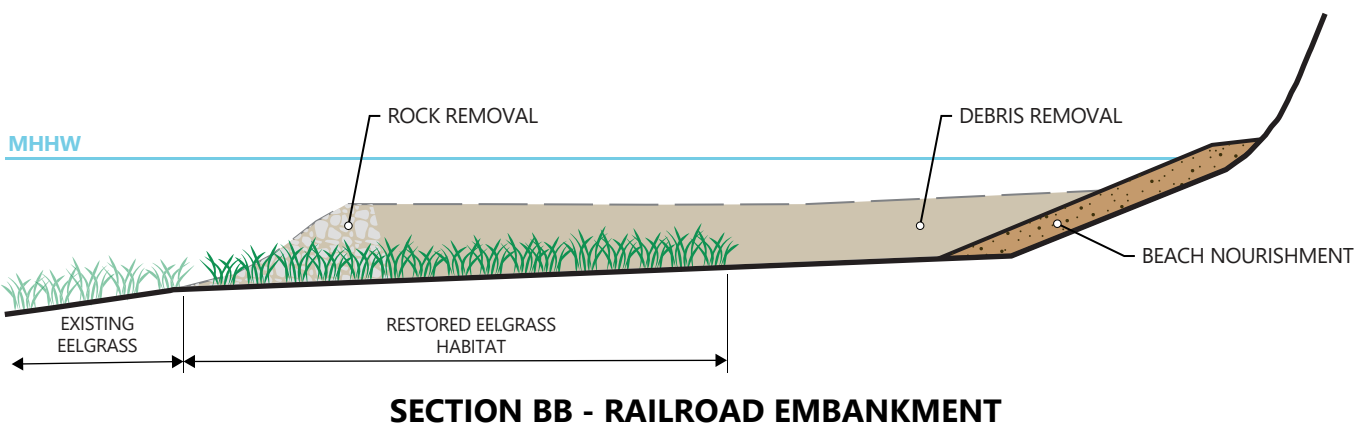
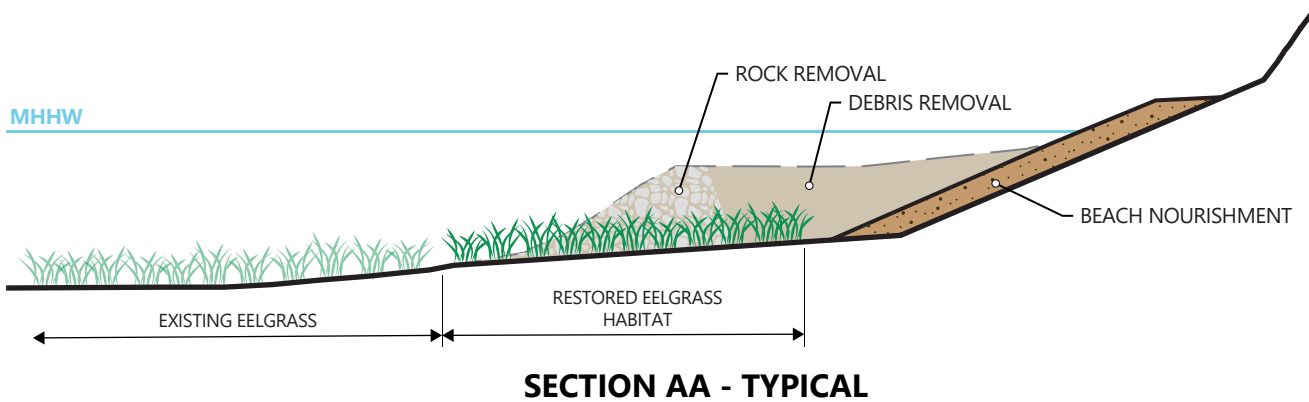
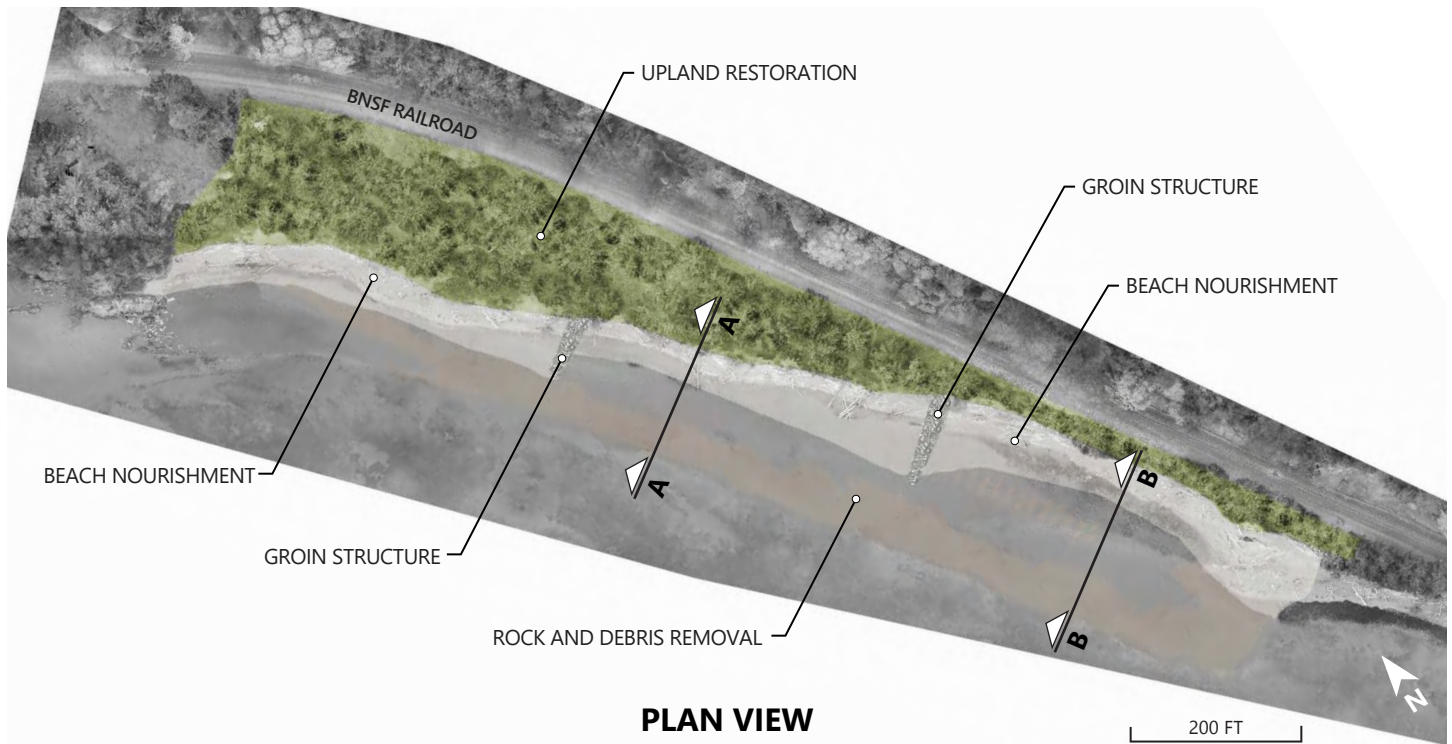
For all restoration alternatives non-native vegetation will be removed from the backshore. Approximately one acre of native vegetation will be installed along the marine shoreline. Vegetation communities represented for installation include upland forest, upland backshore beach berm, salt marsh and palustrine scrub-shrub wetland.

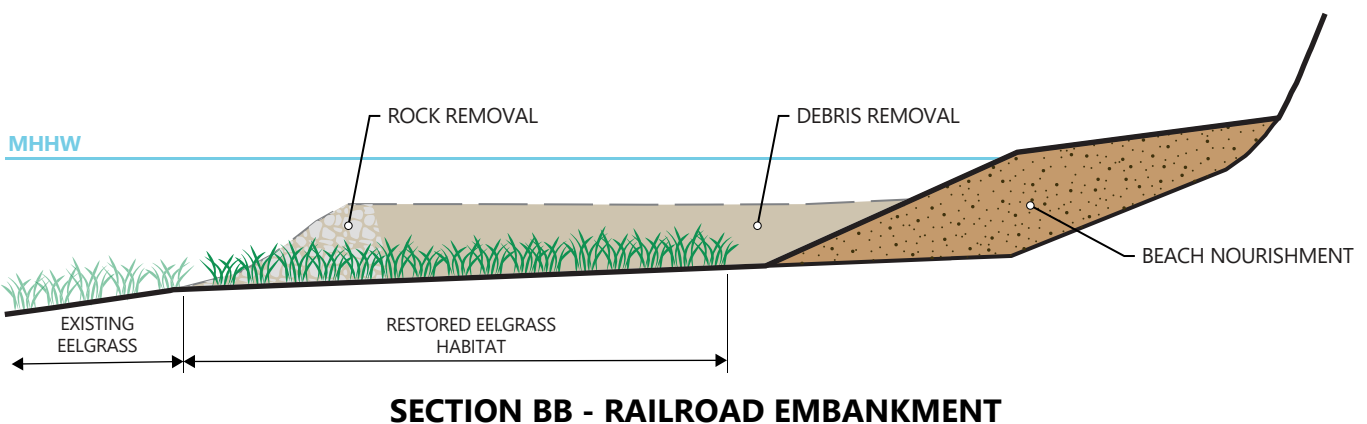
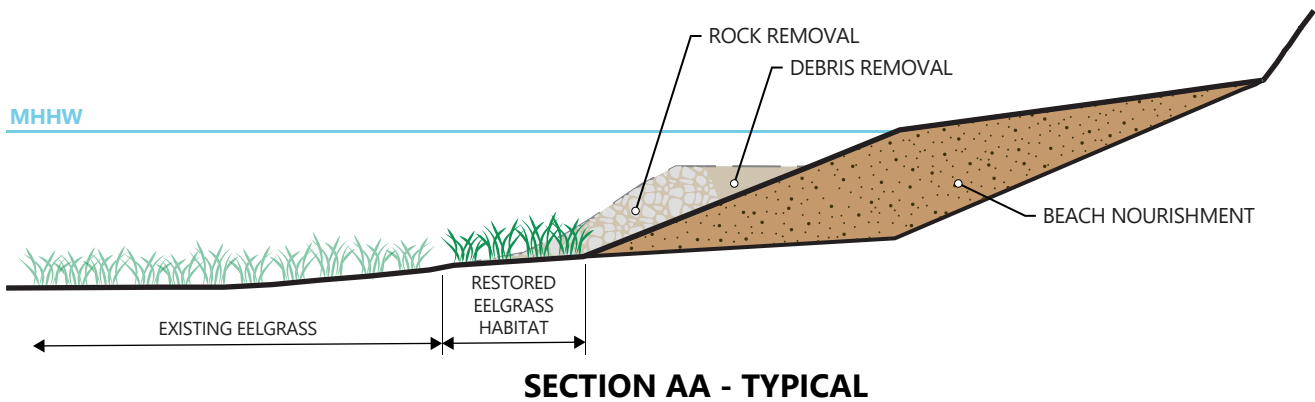
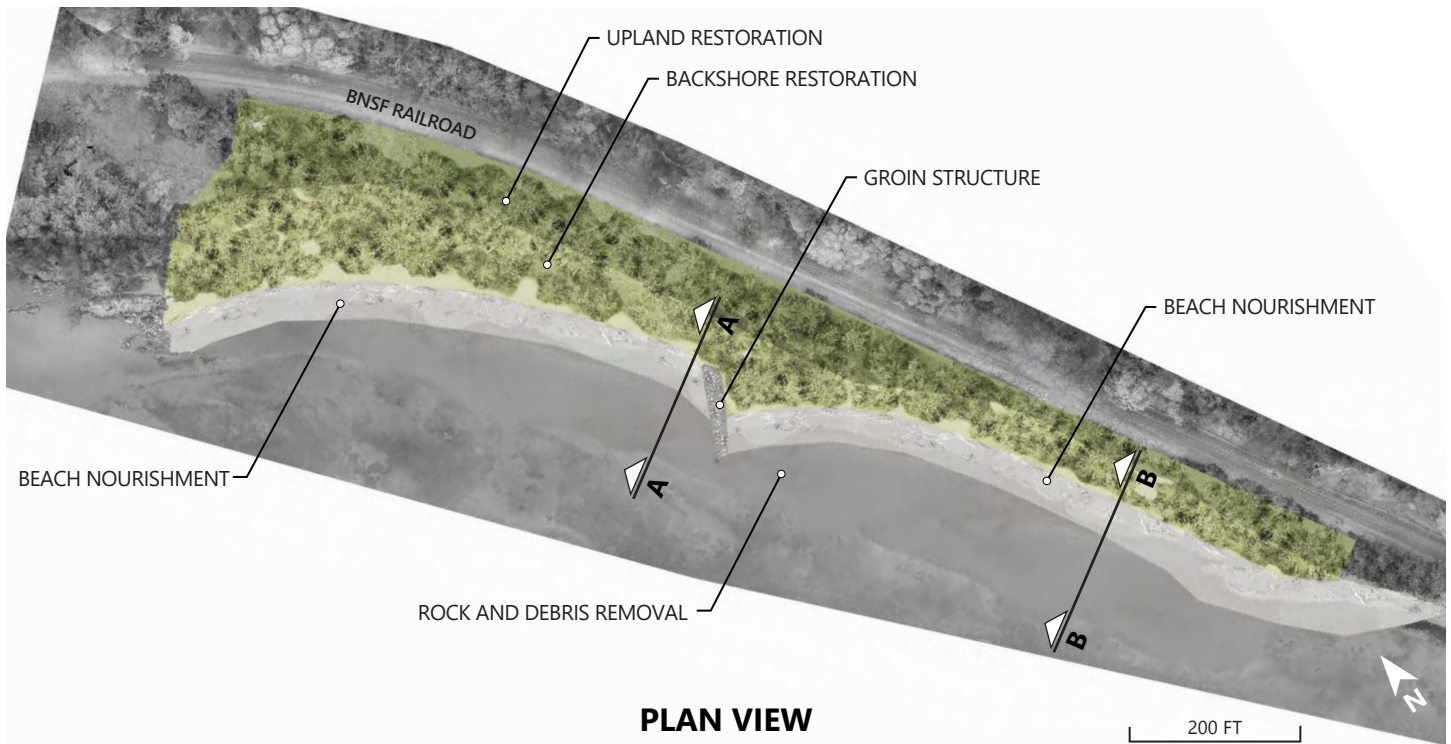
Native plant stock including eelgrass plugs will be sourced from local nurseries.



Photo 11. All three alternative restoration designs will remove artificially placed rocks and regrade the perched beach to more natural conditions conducive to eelgrass growth and forage fish habitat. (Herrera, April 20, 2022).







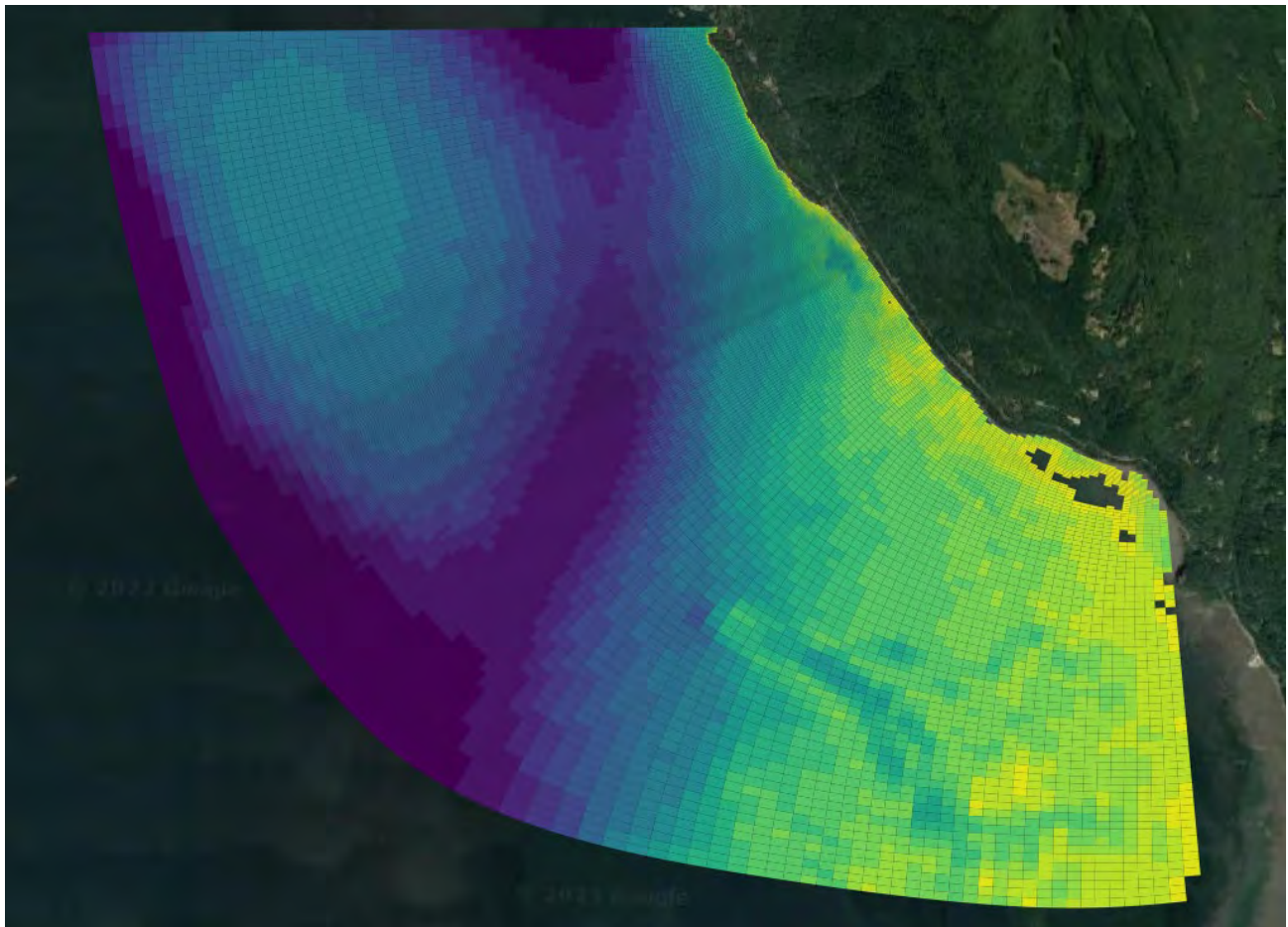
Modeling Outputs of Design Alternatives

The objectives of wave modeling at Clayton Beach was threefold: first, to better understand the complex wave environment along the affected shoreline and the underlying drivers of coastal dynamics; second, to leverage this understanding to inform the design of restoration efforts; and third, to ensure that the proposed restoration designs are robust and effectively mitigate the erosion risk along BNSF. The model used in this application was a Delft3D-WAVE model, part of the extensive Delft3D hydrodynamics modeling software from Deltares. The Delft3D-WAVE model simulates the evolution of random, short-crested wind-generated waves in tidal, estuarine, and lake environments. This report provides analysis of the wave modeling on existing conditions as well as the proposed restoration alternatives.

Model Area

Below is the complete model grid displaying bathymetry for existing conditions at low tide. The model was designed with a curvilinear mesh that extended over large portions of Samish Bay and incorporated a large curved western boundary for the input of boundary conditions.

Figure 18. Model Output for Existing Bathymetry at Low Tide.



Methods

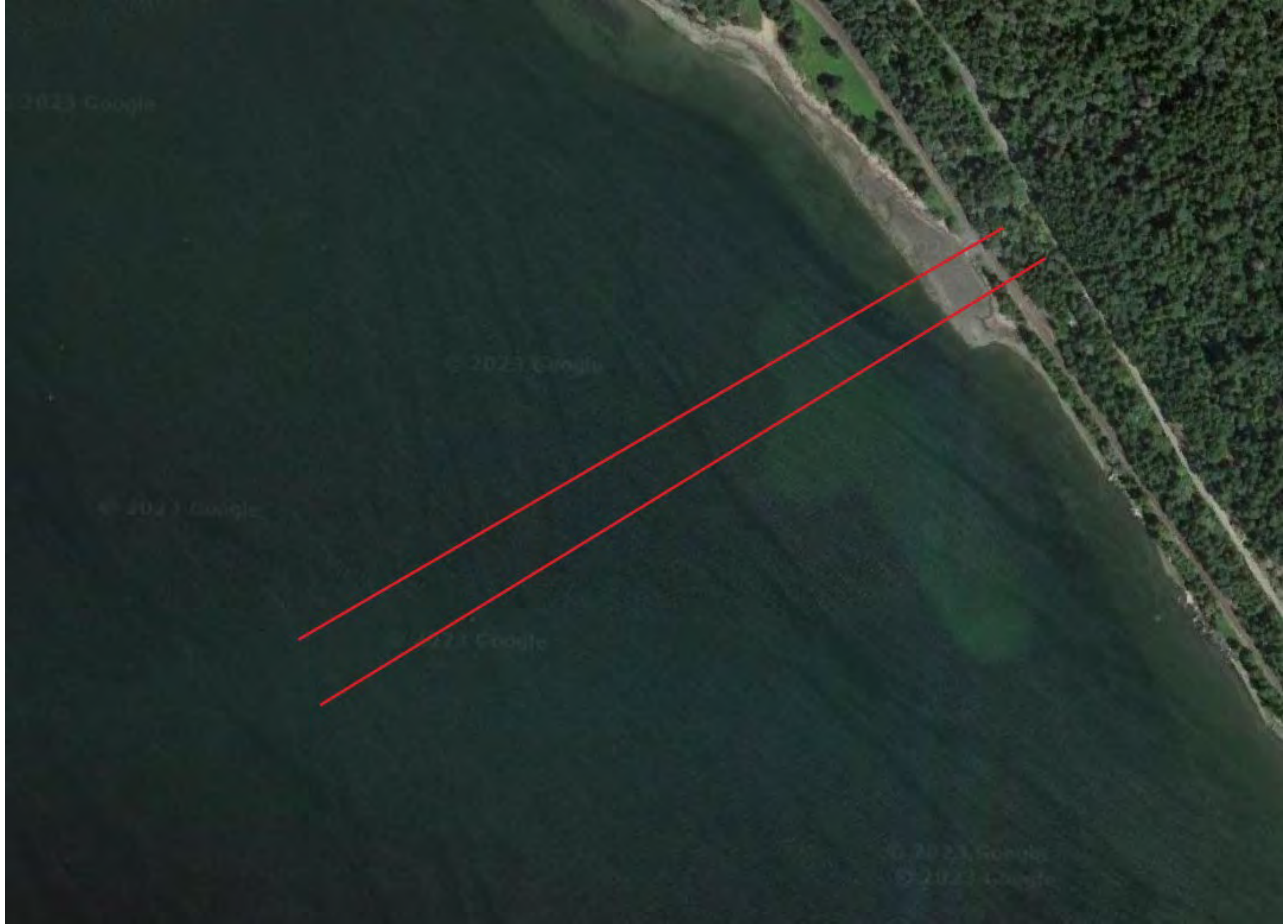
The model was run on three conditions and four surfaces. All conditions were produced using observational data from the NOAA Padilla Bay Farm weather station (NOAA 2024b). Below, Table 5 defines naming conventions for all combinations of model conditions and surfaces. Refer to the Appendix B for more information.

Table 5. Naming Conventions for Model.				
	Model Surfaces			
Model Condition	Existing Dredged Conditions (offshore hole dredged, existing beach surface)	Existing Filled Conditions (Dredged hole filled in, existing beach surface)	Restored Dredged Conditions (offshore hole dredged, alternative beach surface)	Restored Filled Conditions (offshore hold filled, alternative beach surface)
Varying wind direction	Dredged_DirVary	Filled_DirVary	Alt_Dredged_DirVary	Alt_Filled_DirVary
Varying wave height	Dredged_HtVary	Filled_HtVary	Alt_Dredged_HtVary	Alt_Filled_HtVary
Varying tidal depth	Dredged_TideVary	Filled_TideVary	Alt_Dredged_TideVary	Alt_Filled_TideVary

Energy dissipation and significant wave height were selected as variables of interest for this project to isolate wave-induced erosion. The quantified variables characterize erosion risks at locations across the site. As conditions change and affect value outputs from the model, those conditions that display heightened levels of erosion risk can be identified.

The various model conditions were run across the four separate surfaces (dredged, filled, alt dredged, and alt filled) at nine timestamps, and variables of interest were extracted at each timestamp. See Table 5 for more information on surfaces and conditions. Additionally, two transects were drawn across areas of high erosion risk. The northern profile intersects the area of highest erosion and the shoreline armor near the BNSF railway. The southern profile transects an area of high erosion risk near the southeast edge of Clayton Beach (see Figure 19).

Figure 19. Northern and Southern Transect Profiles in the Immediate Vicinity of Clayton Beach.



The northern profile intersects the area of highest erosion and the shoreline armor near the BNSF railway. The southern profile transects an area of high erosion risk near the southeast edge of Clayton Beach.

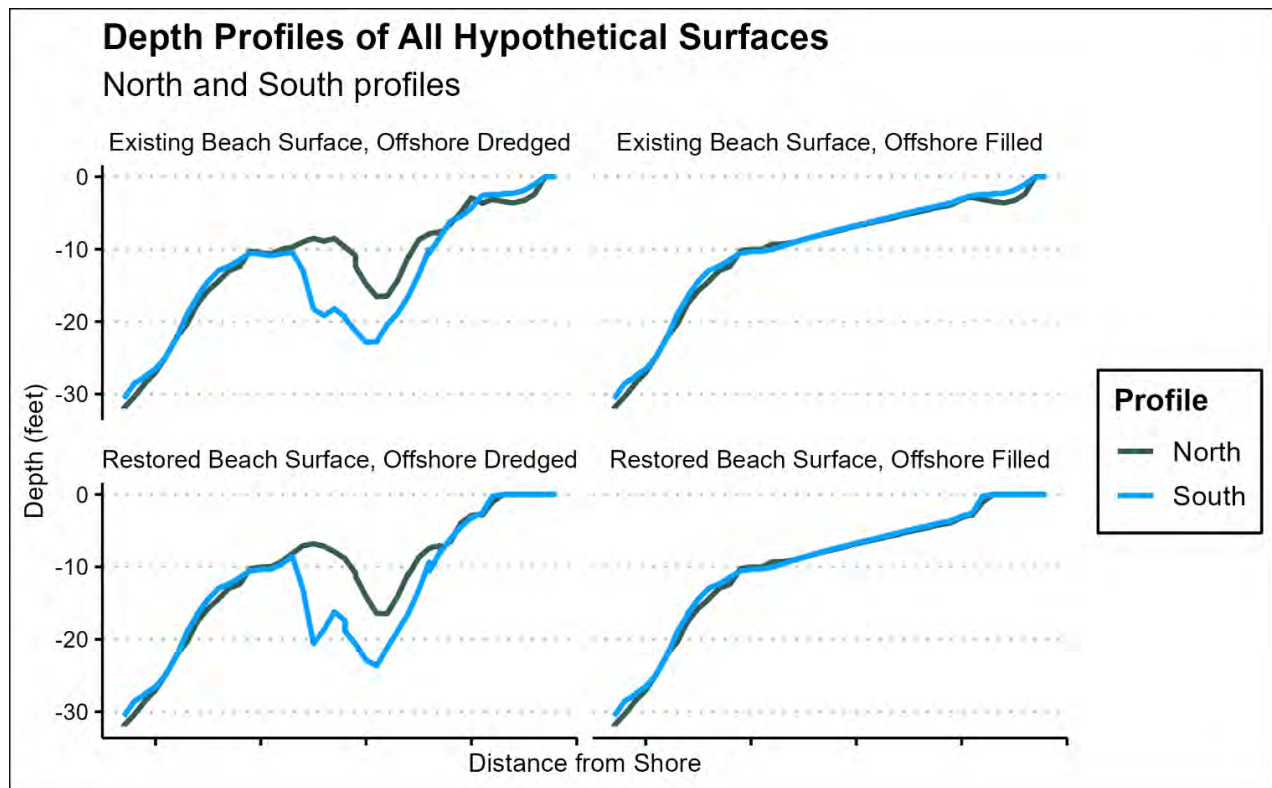
Results

The model conditions were run across the four separate surfaces (dredged, filled, alt dredged, and alt filled) at nine timestamps, and variables of interest were extracted at each timestamp. See Appendix B for more information on surfaces and conditions.

Depth

Below, Figure 20 displays the water depth across all surfaces for both transects. The graphs in the left column show the dredged area, and the dredged area has been interpolated over and “filled” in the graphs in the right column. In the upper row, the bathymetry of the beach reflects the existing slope. In the lower row, the slope has been replaced with a flatter line, reflecting the profile of a nourished and extended beach.

Figure 20. Water Depth at Low Tide for All Conditions, North and South Profile.



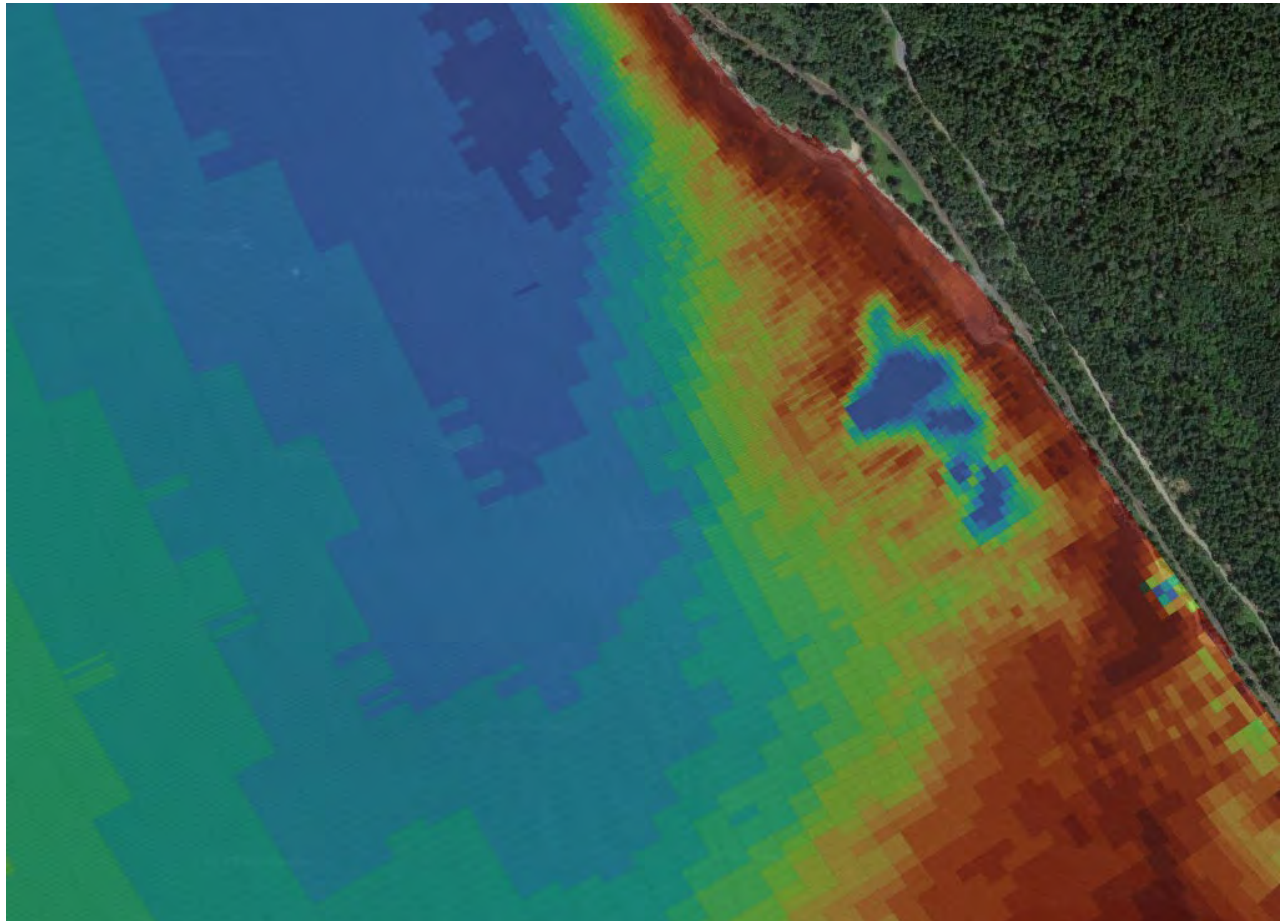
Note the trench depth on the left column, and the restored, extended beach on the bottom row.

Energy Dissipation

Wave energy dissipation is a critical proxy for erosion. As waves break, their kinetic energy is transferred to the shore and increases the risk of erosion, particularly when combined with longshore currents.

Figure 21 displays wave energy dissipation at Clayton Beach over the existing beach surface. As the waves approach shallow water and begin to break, the level of energy dissipation increases. Overall energy dissipation levels rise as waves feel the seafloor with decreasing water depth. The exception to this is the offshore dredged area, which interrupts the energy dissipation as waves cease to interact with the seafloor. When this occurs, the energy dissipation created by breaking waves drops off, delaying the dissipation until further onshore.

Figure 21. Energy Dissipation in the Immediate Vicinity of Clayton Beach at Low Tide on Existing Conditions (model label “Dredged”).



The dark blue colors over the dredged hole demonstrate the effect of the lowered seafloor on the waves, showing that gradual energy dissipation is interrupted over the dredged area.

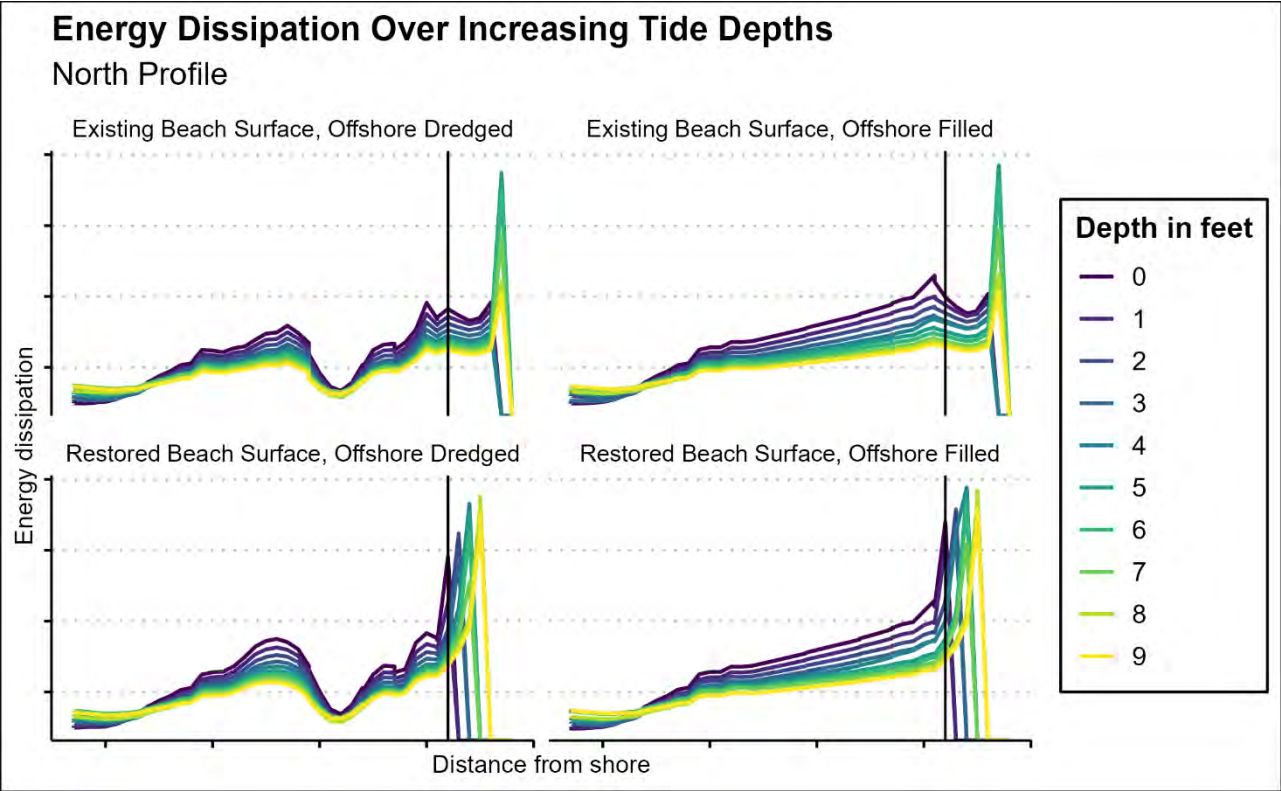
Energy Dissipation Profiles Over Increasing Tidal Depth

Northern profile energy dissipation from varying tidal levels on all conditions

Figure 22 displays the log-normalized energy dissipation at the northern profile over tidal heights of 0 – 9 feet, under constant conditions of 3.83-foot waves approaching from 180 degrees (south). The black vertical line represents the location of the existing rip rap, a stumbling block over which the waves release some energy. The restored beach surface (in the bottom row of plots) does not remove energy dissipation, considering that energy cannot be destroyed, but the nourished beach offsets the energy further offshore, geographically relocating the highest dissipation values away from sensitive onshore structures.

The plots that include the offshore dredged area (present in the left-hand column) demonstrate the interruption in wave energy dissipation caused by the sudden drop in depth. As with the restored shoreline, filling in the dredged area does not remove energy, but distributes it more evenly over the sloping bathymetry on the beach approach. For figure from the southern profile, please see Appendix B.

Figure 22. The Restored, Filled Beach (model label “Alt_Dredged” and “Alt_Filled”, respectively, in the lower left figure) Display Gradual Energy Dissipation Away from Sensitive Structures.

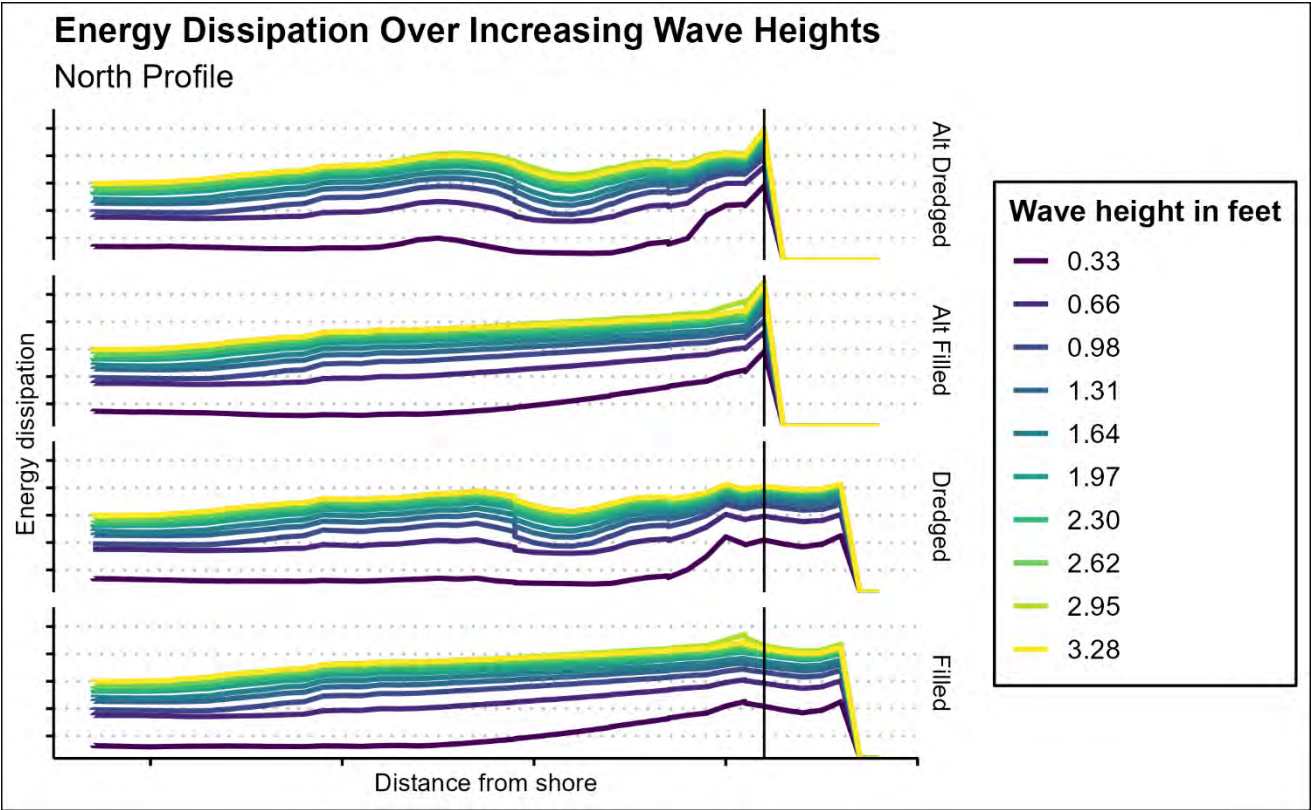


Energy Dissipation Profiles Over Increasing Wave Height

Depth and bathymetry are strong indicators of erosion risk due to their effects on waves, but waves themselves are the primary cause of erosion, especially when combined with other factors. In model conditions that simulated increasing wave height at a consistent approach angle of 180 degrees (south), higher waves resulted in a sharp increase of energy dissipation. The vertical black lines in the Figure 22 and Figure 23 are the location of the existing riprap. For figure from the southern profile, please see Appendix B.

Northern profile energy dissipation from increasing significant wave heights

Figure 23. As Significant Wave Height Increases, Energy Levels Rise Accordingly.



The existing conditions allow for energy dissipation further towards shore, while the restored beach moves this location offshore.

Energy Dissipation at Erosion Hot Spots

At a specific erosion hot spot at Clayton Beach’s southeast corner (Figure 24), energy dissipation can be seen increasing as wave heights increase (Figures 24 and 25). However, restoring the surface suggests lower overall energy dissipation under this condition at this specific location.

Figure 24. Location of a Sensitive Erosional Hotspot Near the Southeast Corner of Clayton Beach, Existing Conditions, Low Tide.

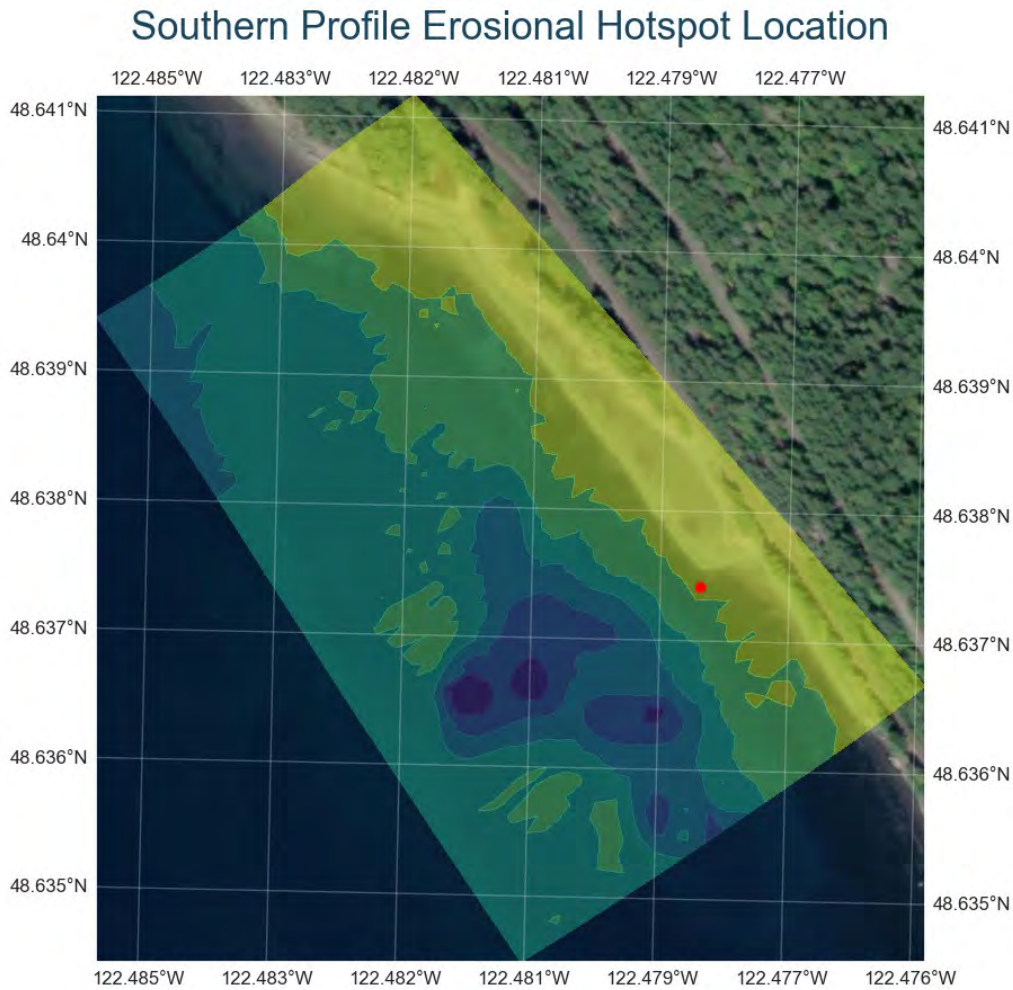


Figure 25. At the Erosion Hot Spot from Figure 24, Overall Energy Dissipation Increases with Wave Height on the Existing Conditions.

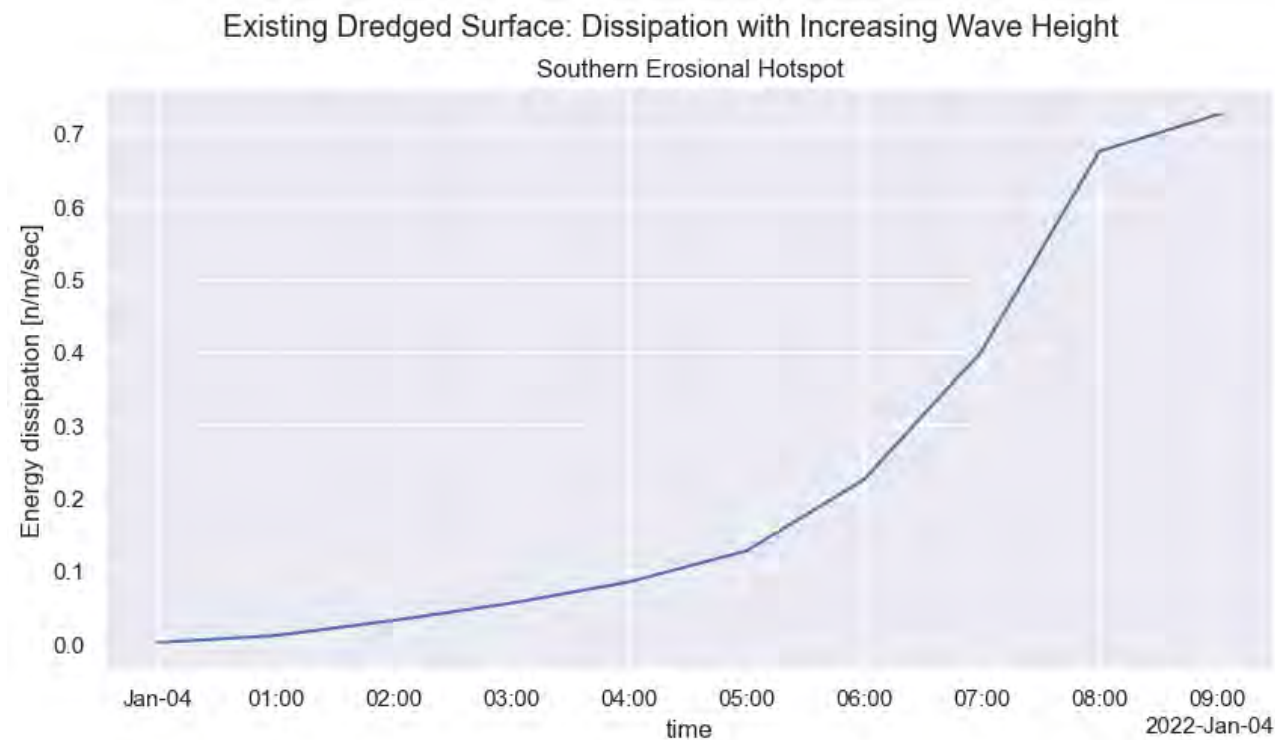
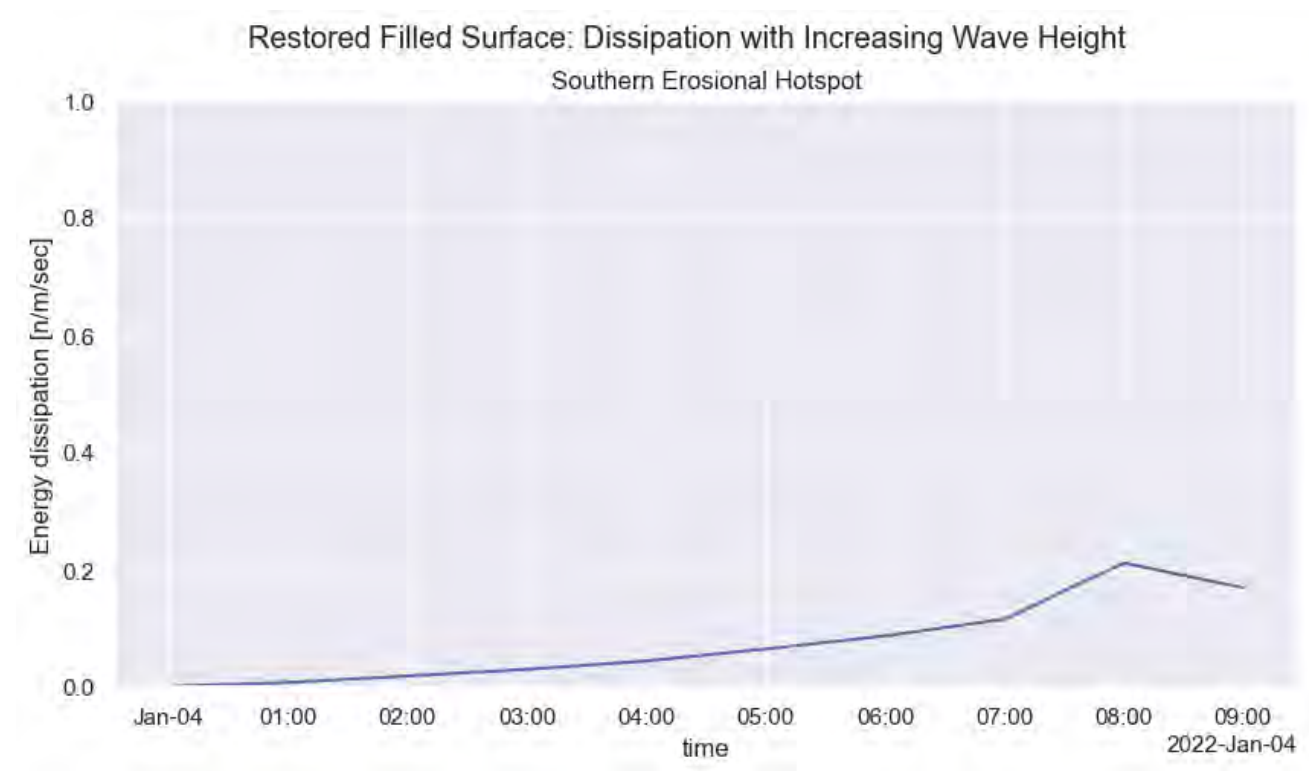


Figure 26. The Restored, Filled Surface (Alt_Filled) Shows Significantly Decreased Overall Energy Dissipation at the Hot Spot.



Significant Wave Height

Significant wave height is a value that traditionally indicates the average height of the highest 33 percent of measured waves. As significant wave height is strongly associated with depth, the dredged trench offshore affects nearshore wave height. In the models run on filled beach surfaces, highest wave heights and the subsequent risk of erosion are shifted offshore when compared with dredged conditions. Figure 27 shows model outputs of low and high wave values on dredged and filled surfaces. When wind and wave values are low overall wave height is low, and waves display increased heights nearer to shore when wind and wave values are high.

Figure 27. Significant Wave Heights at 0.33 Feet Average Wave Height, Existing Conditions (model label "Dredged").



Note the encroachment of higher waves on Clayton Beach.

Figure 28. Significant Wave Height at 3.28 Average Wave Height, Restored and Filled Surface (model label "Alt_Filled").



The restored beach buffers the high waves away from infrastructure.

Conclusion

Modeling was applied to address the erosion challenges at Clayton Beach by examining existing conditions and simulating alternative conditions. The highest risks of shoreline erosion come from combinations of high waves, high water levels, and longshore currents caused by an oblique wave angle approach. The wave models applied to the Clayton Beach site systematically assessed these conditions over existing and proposed surfaces, evaluating which set of conditions resulted high-risk scenarios at sensitive locations. Additionally, the models assessed the efficacy of the proposed restoration surface at mitigating erosion risk by running identical conditions over proposed surfaces (see Table 5 for details). The alternative design surfaces were explored in the context of two relevant variables: energy dissipation and significant wave height. The analysis revealed that the human-induced alterations to the coastal system potentially exacerbate erosion, and the alternative surfaces offer a possible pathway to mitigate the risk of current and future erosion to the adjacent railway.

Across variables associated with erosion, the restored beach relocated the highest values away from the current areas of concerns. For example, the north and south transects extracted from existing conditions showed wave energy dissipation peaking near the railway, while the restored beach moved the energy peaks offshore, closer to the current location of the riprap edging the beach. In the case of a specific erosion hot spot located on the southeast edge of the beach, energy dissipation was significantly lowered by a restored surface when all other conditions remained constant. A second variable of interest, significant wave height, showed similar results to energy dissipation. As wave heights and subsequent erosion risk increased, the highest waves were pushed offshore in the restored beach scenario. Importantly, in the restored condition, the size of waves that present risk to the railway would be significantly reduced compared to current conditions.

A relevant feature for the model was the offshore dredged area. Within the dredged area, the bathymetry deepens. Approaching waves in the model underwent complicated reactions to the abrupt bathymetric change. The natural process of gradual energy dissipation over a constant slope was interrupted: instead, energy dissipation spiked and quickly fell off as the seafloor dropped out from the waves over the dredged area, and then energy dissipation increased closer to the shore. Wave steepness was also affected. Increased wave steepness, the precursor to breaking waves and subsequent energy dissipation, was delayed over the deeper section. Once the shallow bathymetry resumed closer to shore, the process of increased steepness and energy dissipation was pushed closer to sensitive shoreline areas. Two of the model surfaces simulated wave action over a filled trench with varying conditions (model labels "Filled"), and results showed that the filled trench introduced gradual energy dispersion and wave height rather than the rapid local peaks and valleys associated with existing conditions.

The models identified the high-risk scenarios at the site and provided guidance for beach restoration efforts. In conclusion, this modeling exercise has provided a robust foundation for advancing towards the restoration of the beach to a resilient, more natural state.

Conclusions and Next Steps

The objective of this feasibility assessment was to evaluate the existing environmental conditions relevant to proposed nearshore restoration opportunities in consideration of the adjacent BNSF railway, existing Park use, and potential risks to flooding and or damage to cultural or natural resources. This was conducted by first exploring baseline current and historical conditions, including physical conditions and nearshore habitats. The next step included conceptualizing the restored condition and evaluating the benefits, risks, and sustainability of restoration, particularly in the context of sea level rise and climate change. The project conceptual design will provide long term benefits to fish and wildlife and associated habitats.

Based on funding and stakeholder support, the next steps for the project will entail forwarding the preferred conceptual design to 60-, 90- and 100-percent design plans and initiating the permit application process.

All the conceptual designs prepared for the alternative analysis will require environmental permitting reviews by federal, state and local environmental regulatory compliance, as presented in Table 6. For restoration projects, Skagit County will often consider the project's compliance with federal and State permits as applicable for its critical areas report, thus reducing the need the additional documentation. State Parks can lead the State Environmental Policy Act (SEPA) compliance review and determination, which will be required by WDFW for issuing a Hydraulic Project Approval (HPA) for the project. The Section 7 Endangered Species Act (ESA) consultation for federal regulatory permit compliance is anticipated to meet NOAA Fisheries' criteria for expedited review according to the Salish Sea Nearshore Programmatic Opinion.

Restoration at Samish Bay will also require an Essential Fish Habitat (EFH) compliance review for fish species regulated under a federal Fisheries Management Plan (FMP) according to the protective provisions of Magnuson-Stevens Fishery Conservation and Management Act (MSA), as amended by the Sustainable Fisheries Act of 1996 (Public Law 104-267). The Pacific Fisheries Management Council (PFMC) has jurisdiction for commercial fisheries in Washington waters and has designated EFH for the Pacific salmon fishery, Pacific coast groundfish, and coastal pelagic fisheries (PFMC 1998, 2003, 2011, 2016). Pacific salmon EFH includes all freshwater, estuarine, nearshore and tidal submerged marine waters and substrates within Washington State territorial waters that are necessary for Chinook, coho (*O. kisutch*) and pink salmon (*O. gorbuscha*) spawning, breeding, feeding or growth to maturity (PFMC, 2003). Designated EFH for groundfish encompasses all waters from the MHHW elevation in estuaries, and upriver extent of saltwater intrusion in river mouths, and along the coasts of Washington, Oregon, and California seaward to 11,483-foot depth contour (PFMC, 2011). Over 90 species of groundfish, including rockfish (bocaccio, canary, etc.), are managed by the PFMC.

Pelagic species of EFH, including northern anchovy (*Engraulis mordax*), Pacific sardine (*Sardinops sagax*), Pacific chub mackerel (*Scomber japonicas*), jack mackerel (*Trachurus symmetricus*), and market squid

(*Loligo opalescens*), are associated with deeper marine habitats that are not likely to be applicable to the Clayton Beach restoration project.

Table 6. Permitting Needs for Clayton Beach Nearshore Restoration.

Regulatory Agency	Permit/Authorizing & Regulatory Compliance Requirements	Application/Compliance Requirements
US Army Corps of Engineers (USACE)	• Clean Water Act (CWA) Section 404 Authorization • Section 106 Compliance with National Historic Preservation Act • Section 7 of Endangered Species Act Consultation • Section 10 Rivers and Harbors Act (dredging and filling)	• Joint Aquatic Resources Permit (JARPA) Application • Cultural Resources Report • Salish Sea Nearshore Programmatic
Washington State Department of Ecology	• Section 401 Water Quality Certification • Coastal Management Zone (CMZ) Consistency	• Pre-application notification form submitted at least 30 days prior to JARPA submittal
Washington State Parks and Recreation Commission	• State Environmental Policy Act (SEPA) Determination of Non-Significant	• SEPA Checklist Submittal
Washington Department of Natural Resources	• State Owned Aquatic Lands – Use Authorization	• JARPA
Washington Department of Fish and Wildlife (WDFW)	• Hydraulic Project Approval (HPA)	• Aquatic Protection Permitting System (APPS) Joint Aquatic Resource Permit Application (JARPA) submittal
Skagit County – some requirements may be eliminated in recognition that compliance with federal and State permitting is sufficient.	• Shoreline Exemption • (Section 14.26, Shoreline Master Program Guidelines) • Critical Areas Project Review (Chapter 14.24 SCC) • Grading	• Shoreline Exemption Application (Includes JARPA) • Protected Critical Areas (PCA) Site Plan • Master Land Use Permit
Other tideland landowners (BNSF, Puget Sound Energy, Upper Skagit Tribe, Private landowner)	• Use authorization/permissions	• As determined by specific landowner requirements

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Appendix A

Wave Modeling of Current and Future Conditions



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Background

Clayton Beach is located in Larrabee State Park in Samish Bay, Skagit County, Washington. Shoreline modification in the early 20th century culminated in heightened vulnerability to coastal erosion at the site, posing risks to the adjacent BNSF railroad. These modifications included extensive beach fill and hydraulic suction dredging approximately 250 feet offshore, which left a large hole in the existing bathymetry. This heavily altered nearshore environment is currently incurring substantial erosional trends. Numerical modeling of wave conditions was applied to address the erosion threat and restore resilient, sustainable conditions in the area. The primary objective of this modeling initiative was threefold: first, to better understand the complex wave environment along the affected shoreline and the underlying drivers of coastal dynamics; second, to leverage this understanding to inform the design of restoration efforts; and third, to ensure that the proposed restoration designs are robust and effectively mitigate the erosion risk along BNSF. The model used in this study was a Delft3D-WAVE model, part of the extensive Delft3D hydrodynamics modeling software from Deltares. The Delft3D-WAVE model simulates the evolution of random, short-crested wind-generated waves in tidal, estuarine, and lake environments. This report provides analysis of the wave modeling on existing conditions as well as the proposed restoration alternatives.

Nearshore Bathymetry

The nearshore sediment primarily consists of tertiary continental sedimentary rocks, including fluvial sandstone, conglomerate, and mudstone with thick coal seams. Large chunks of bedrock populate the northern section of Clayton Beach, produced by erosion of surrounding sedimentary rock. These sandstone boulders dampen wave energy. The intertidal consists of cobbles mixed with sand from the suction dredging, while the subtidal is finer sand (DNR 2006). Extending into Samish Bay to the south, the bathymetry remains shallow with depths ranging from approximately 1 to 10 feet. At the southern edge of the bay, the mouth of the Samish River is characterized by a large muddy tidal flat, limiting the depth and fetch over which waves can develop from the south. Bellingham Bay, to the north and west, significantly deepens to approximately 100 feet (NOAA 2024a).

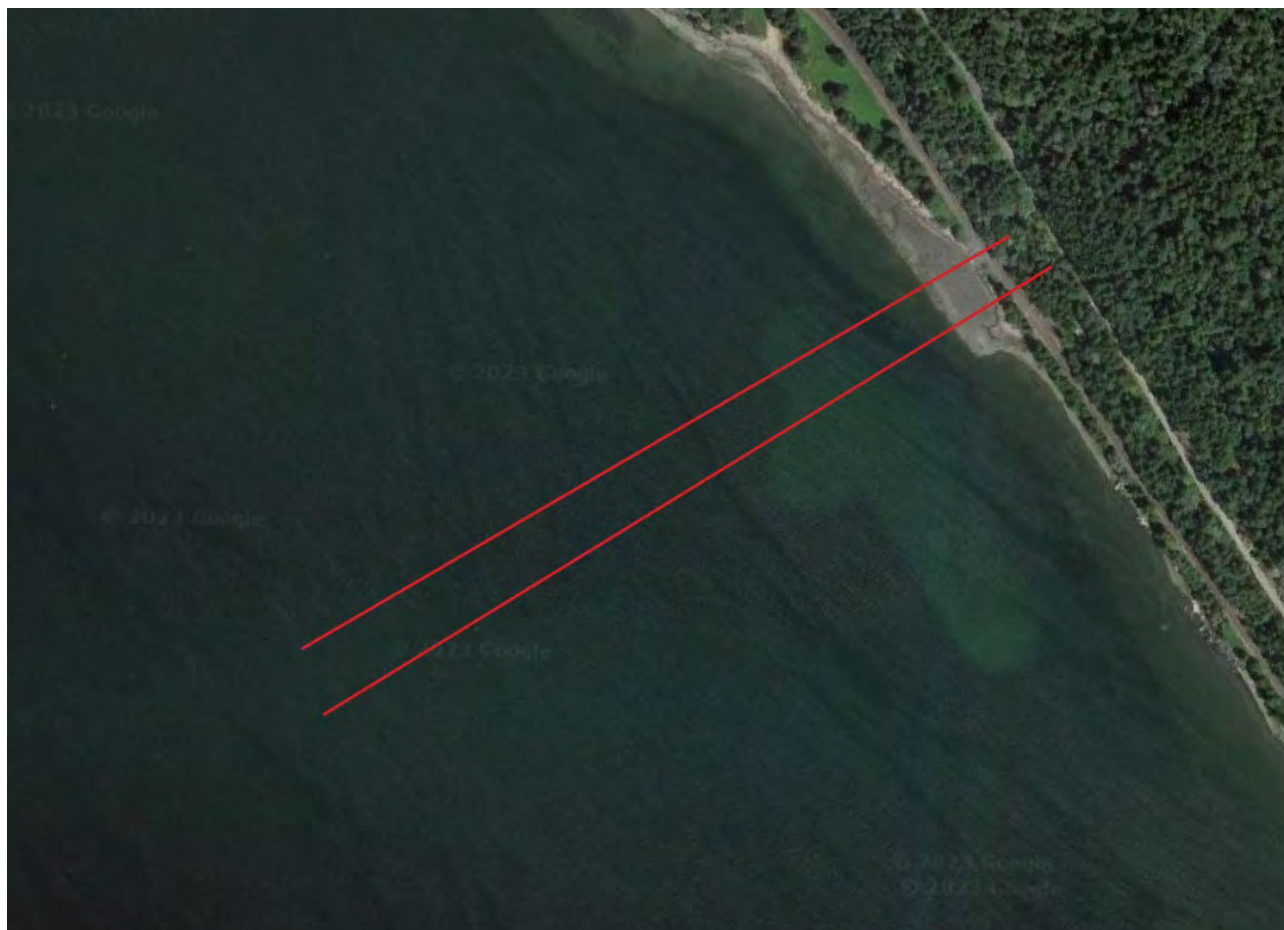
Clayton Beach has been subject to multiple and significant engineering projects to provide shorefront access. The nearshore bathymetry reflects this history of anthropogenic influence. A significant nearshore feature is a dredged trench located approximately 250 feet offshore from the southernmost point of the historical rock armor, where sediment was removed from the subtidal (Figure A-1). The dredged trench covers an area of 300,000 square feet and is approximately 7 feet deeper than the surrounding area (DNR 2023). The natural bathymetry consists of a seaward slope with a water depth of 1.2 feet near the shore and approaching 24 feet of depth 0.5 miles offshore (NOAA 2024a). To highlight the dredged interruption in the natural bathymetry, two profiles were drawn across this dredged area (Figure A-2). These profiles were drawn to intentionally measure wave impacts at this sensitive location, which is adjacent to the critical infrastructure of the BNSF rail causeway.

Figure A-1. Location of the modeling grid.



The model was run over four surfaces: existing conditions and three potential restoration concepts. The three restoration concepts consist of existing beach conditions with the dredged area filled in, a restored beach condition with the offshore area dredged, and a restored beach conditions with the dredged area filled in. Proposed restoration concepts remove the added fill, rock debris, and other anthropogenic additions to the nearshore, and contribute this material to filling in the offshore dredged area along with additional nourishment. Data from the model runs was extracted from cross-trench depth profiles to provide high-resolution data in the most sensitive areas threatened by erosion. Please see Model Conditions and Surfaces, Table A-1, for more details.

Figure A-2. Northern and southern transect profiles in the immediate vicinity of Clayton Beach. The northern profile intersects the area of highest erosion and the shoreline armor near the BNSF railway. The southern profile transects an area of high erosion risk near the southeast edge of Clayton Beach.



Waves and the Nearshore Environment

Clayton Beach has a high-energy wave environment, partially due to its large, approximately 14-mile fetch. This fetch, the distance over water that wind can travel uninterrupted, contributes to the generation of potentially large waves that may approach the beach. The energy and height of waves are influenced by a variety of factors including varying wind directions, tide levels, and wave heights. These

components interact with and amplify each other, resulting in elevated risk of shoreline erosion and the reshaping of the coastal landscape.

Environmental and atmospheric factors can significantly exacerbate shoreline erosion when combined. High tide elevates the overall water level, adding depth over which waves can develop and allowing waves to reach further inland than during times of low water levels. As these heightened waves break upon the shore, they release energy on the beach sediment. When waves approach and break at an oblique angle, longshore currents are generated, which can move sediment along the coast away from its point of origin. Consequently, the combination of deeper water levels at high tide and the angle of wave approach not only elevates the position at which waves impact the coastline but also enhances their ability to transport sediment, reshaping the beach and nearby upland areas over time.

Surface waves are driven by wind. Wind blowing across the surface of the water creates friction, and as energy is transferred from the wind to the water, wave crests are created. The crests align with the wind direction and will remain aligned unless influenced by other factors such as current. In the model for this site, the wind is the driver of waves. As previously discussed, the combination of wave direction with other factors such as wave height and overall levels of energy dissipation can strongly influence erosion. When a longshore current is present, created by waves approaching the shore at an oblique angle, sediment disturbed by energy dissipation are transported away from the original site and cause erosion.

Aggregated wind rose data from nearby buoys indicate that Clayton Beach is primarily subject to winds out of the south. Southerly winds create waves approaching the shore from an oblique angle, heightening the risk of longshore currents that could carry away disturbed sediment. The southeastern waves feel the bottom first and begin to experience refraction, bending toward the shore and creating longshore currents.

Methods

Model Configuration and Setup

The Delft3D-WAVE computation was run as a standalone SWAN model without flow characteristics to isolate the effect of wave energy on the site under various conditions. All models were georeferenced to the NAD83 (HARN)/Washington State N (ft) projection, EPSG: 2926, and the North American Vertical Datum 1988 (NAVD88). Land boundaries were created in QGIS version 3.28.8 Firenze, exported, and formatted using R version 4.3.2 running under Windows 10 x64. Bathymetry was acquired from two sources. NOAA's bathymetric data viewer provided a 1/9 arcsecond (3m) resolution 1956 DEM Global Mosaic combined with a 2006 DEM Global Mosaic for a coverage of approximately 2.2E8 square feet. A point file of 2023 single beam sonar was acquired from the Washington Department of Natural Resources and covered a focused area of approximately 7.9E5 square feet of Clayton beach's nearshore bathymetry. These bathymetries were combined using interpolation from Delft's QUICKIN module, resulting in complete coverage of the area.

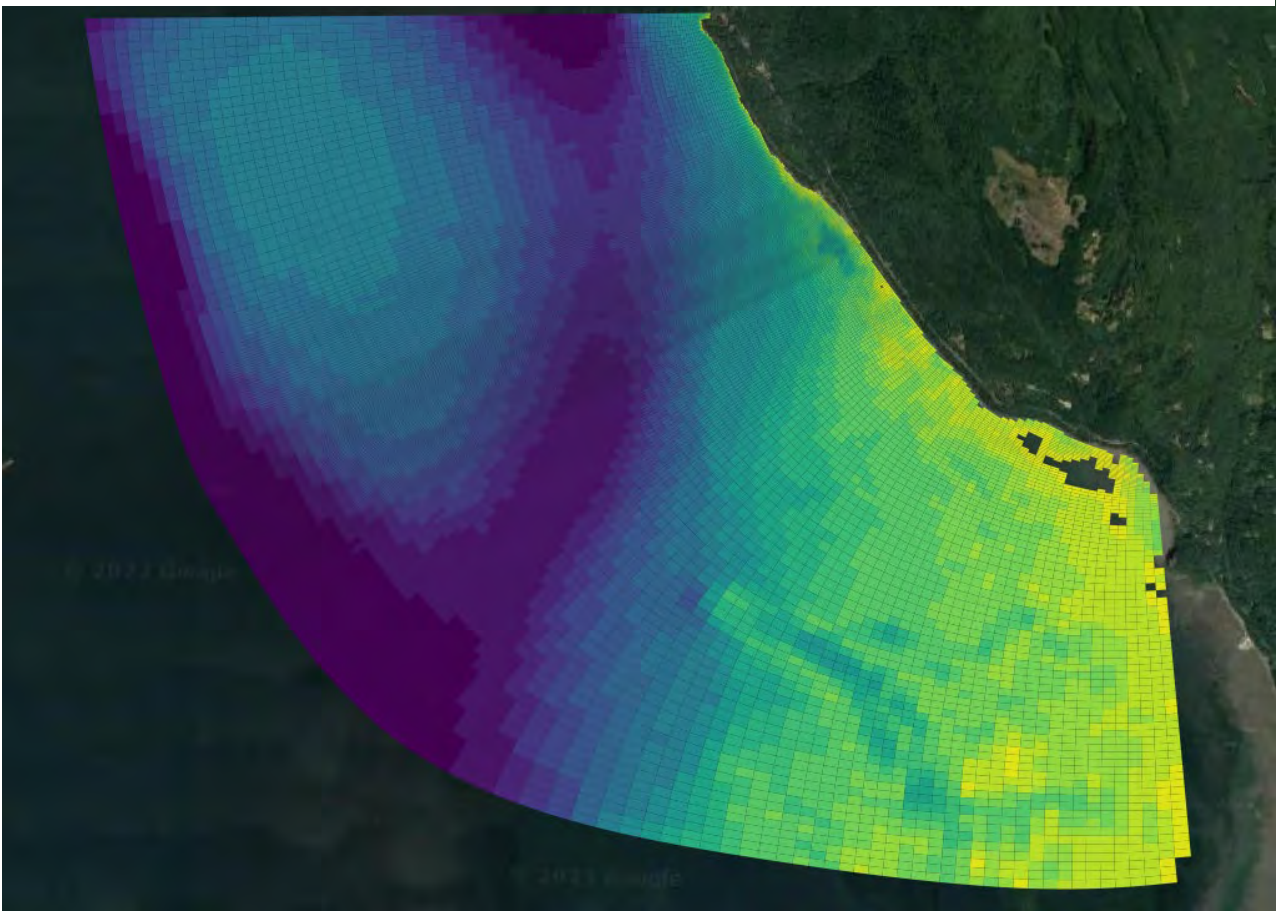
Model computational grids were constructed with curvilinear meshes using Delft3D's RGFRID module that underwent orthogonalization to the lowest possible cosine values, with a maximum of approximately

0.06 outside of areas of interest. The entire computational grid covered an area of approximately 594 million sq ft within Samish Bay. Grids model cell sizes ranged from approximately 400 x 400 ft in deep water to 30 x 30 ft near the area of interest on Clayton beach. The bathymetries were interpolated to the grid using Delft3D’s QUICKIN module, which allowed for depth interpolation across various sources of bathymetry. Due to the high sample resolution available (+4 per grid cell), the depth file was created using grid cell averaging.

Model Area

Below is the complete model grid displaying bathymetry for existing conditions at low tide. The model was designed with a curvilinear mesh that extended over large portions of Bellingham Bay and incorporated a large curved western boundary for the input of boundary conditions.

Figure A-3. Model output for existing, dredged bathymetry at low tide.



Model Conditions and Surfaces

All conditions were produced using observational data from the NOAA Padilla Bay Farm weather station (NOAA 2024b). Below, Table A-1 defines naming conventions for all combinations of model conditions and surfaces. Refer to the Model Definitions section, located below Table A-1, for a detailed description of each model condition.

Table A-1. Naming Conventions for Model.

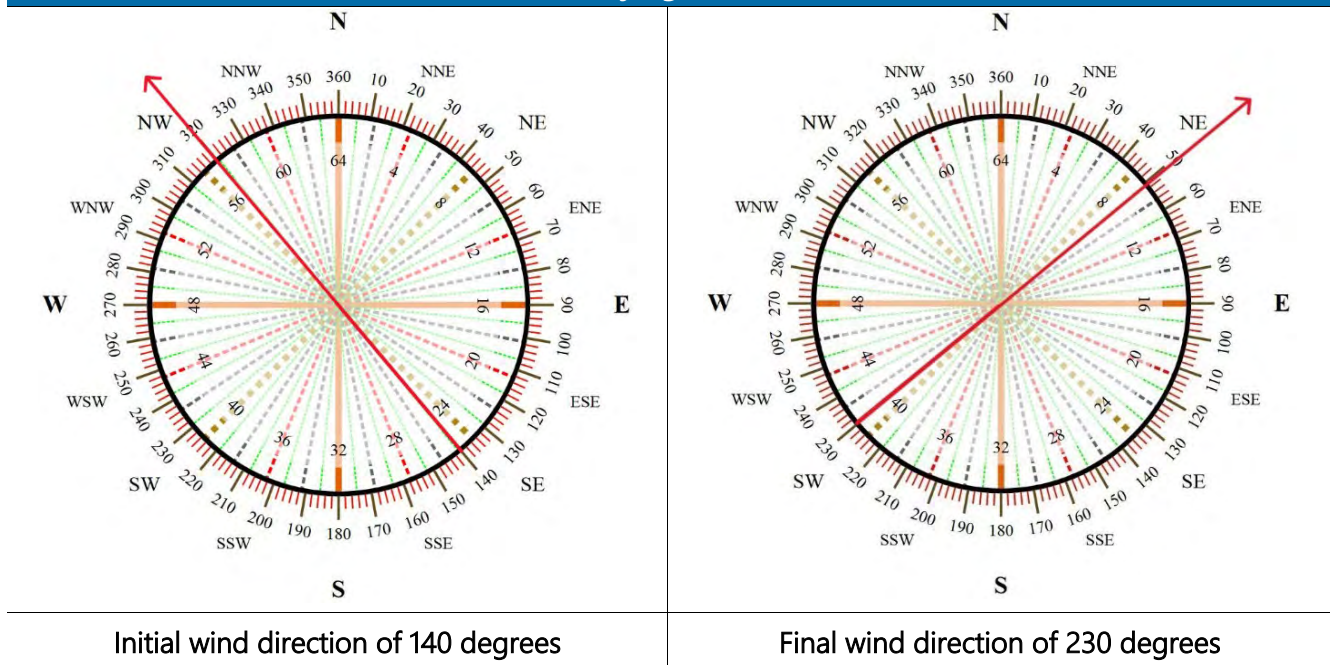
	Model Surfaces			
Model Condition	Existing Dredged Conditions (offshore hole dredged, existing beach surface)	Existing Filled Conditions (Dredged hole filled in, existing beach surface)	Restored Dredged Conditions (offshore hole dredged, alternative beach surface)	Restored Filled Conditions (offshore hold filled, alternative beach surface)
Varying wind direction	Dredged_DirVary	Filled_DirVary	Alt_Dredged_DirVary	Alt_Filled_DirVary
Varying wave height	Dredged_HtVary	Filled_HtVary	Alt_Dredged_HtVary	Alt_Filled_HtVary
Varying tidal depth	Dredged_TideVary	Filled_TideVary	Alt_Dredged_TideVary	Alt_Filled_TideVary

Model Conditions

Varying Wind Direction

This model simulated a steady wind state of approximately 3.8 knots (6.56 feet per second, or 2 meters per second) and a steady wave height of 0.66 feet (0.2 meters): common conditions at the site. The model ran for 9 hours and wave direction increased by 10 degrees each hour (rotating clockwise 10 degrees), isolating the effects of wave direction on the site. The wave direction began at 140 degrees and completed the run at 230 degrees. Refer to Table A-2 for visualization of the initial and final wind directions.

Table A-2. Varying Wind Directions.



Varying Wave Heights

This model simulated a steady wave approach of 180 degrees, the most common wind direction according to the nearby NOAA weather station (NOAA 2024b). Wave heights increased by 0.3 feet (0.1 meters) each hour for the 9-hour model runtime. In this model, tidal height remained constant, isolating the effect of high waves on the shoreline.

Varying Tidal Depths

This model maintained all conditions at default constants except for water depth, which increased by 1 foot (0.3 meters) each hour, beginning at 0 feet (below Mean Lower Low Water) and ending at 9 feet. Wind remained at a steady state of approximately 3.8 knots (6.56 feet per second, or 2 meters per second) and waves remained at a constant height of 3.3 feet (1 meter). A tidal depth of 0 feet indicates low tide.

Post Processing

Variables of Interest

The standalone SWAN model produces multiple output variables for each scenario. The variables of interest for this project were selected to isolate wave-induced erosion and are listed below in Table A-3. The quantified variables characterize erosion risks at locations across the site. As conditions change and affect value outputs from the model, those conditions that display heightened levels of erosion risk can be identified.

Table A-3. Variables of Interest for Model Outputs.			
Variable	Short name	Unit from WAVE model	Description
Depth	depth	Meter (m)	Water depth in meters, not the bottom level.
Significant wave height	hsign	Meter (m)	Commonly referred to as "Seas" in the Marine Forecast, significant wave height is the average of the highest 1/3 (33%) of waves (measured from trough to crest) that occur in a given period. Higher significant wave heights produce more beach erosion.
Wave energy dissipation	dissip	(N/m/sec)	Wave energy dissipation is the energy dissipation per unit time due to the sum of bottom friction and wave breaking. Higher wave energy dissipation at a given location indicates higher risk of erosion in that area, especially if combined with oblique wave approach. As waves transmit energy to the shore, it is imparted to sediment particles, which may be transported away from the site according to wave angle. If high energy dissipation occurs with high waves at high tide, shore normal waves can still cause erosion or damage to shoreline structures through energy transmission, regardless of wave angle.

Results

The various model conditions were run across the four separate surfaces (dredged, filled, alt dredged, and alt filled) at nine timestamps, and variables of interest were extracted at each timestamp. See Table A-1 for more information on surfaces and conditions.

Depth

Below (Figures A-4 – A-7) are renderings of all potential surface bathymetries, pictured at 0 feet of tidal depth. Clayton Beach and the offshore dredged trench are outlined in black. Included are the two profiles placed for extracting model data, drawn in red.

Figure A-4. Existing surface, dredged area included (model label “Dredged”), at low tide. Note that the model extends well over the beach.



Figure A-5. Alternative restored surface, dredged area included (model label "Alt_Dredged"), at low tide. Note that in the restored surface the model edge is pushed seaward, reflecting a raised and nourished beach.



Figure A-6. Existing surface, dredged area filled (model label "Filled"), at low tide. The dredged area no longer displays the deeper bathymetry present in Figures A-4 and A-5. Note that the model extends well over the beach.



Figure A-7. Alternative restored surface, dredged area filled (model label "Alt_Filled"). Note that in the restored surface the model edge is pushed seaward, reflecting a raised and nourished beach.

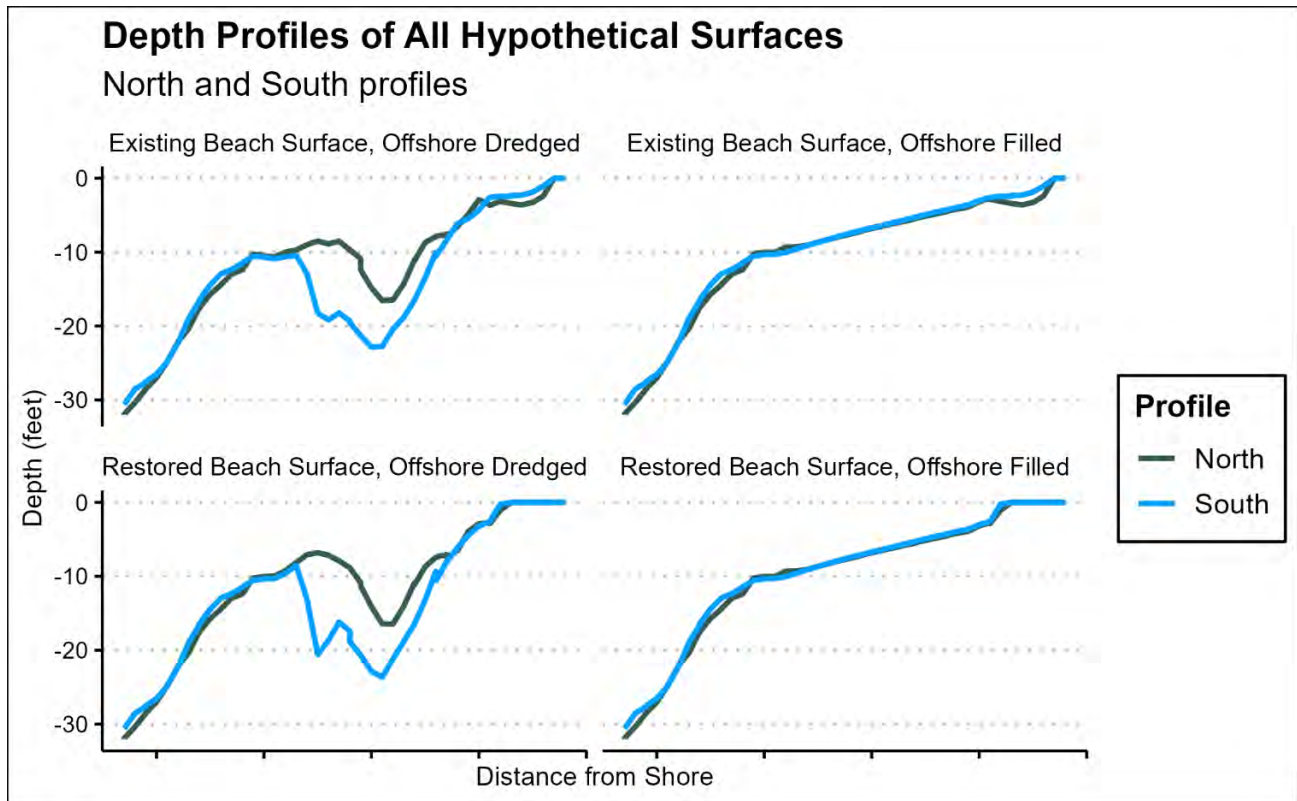


Depth Profiles

Below, Figure A-8 displays the water depth across all surfaces for both transects. The figures are drawn from the data used to produce Figures A-4 – A-7. The graphs in the left column show the dredged area, and the dredged area has been interpolated over and "filled" in the graphs in the right column. In the upper row, the bathymetry of the beach reflects the existing slope. In the lower row, the slope has been replaced with a flatter line, reflecting the profile of a nourished and extended beach.

Wave Steepness and Depth

Figure A-8. Water depth at low tide for all conditions, north and south profile. Note the trench depth on the left column, and the restored, extended beach on the bottom row.



Water depth is an important factor in wave behavior. As wind-driven waves approach the shore, friction between the sea floor and the water causes the base of the wave to slow while the upper sections of the wave continue to travel at the same speed. This results in increasingly steep wave angles, causing waves to eventually break and dispel their energy, imparting it to the shore. The presence of the offshore dredged section at Clayton beach affects the bathymetry and the resulting wave action.

Figures A-9 and A-10 demonstrate wave steepness as waves approach the beach at a consistent angle of 180 degrees (from the south) at a constant wave height of approximately 3.3 feet (1 m). The water depth is modeled at low tide, where waves would most strongly feel the sea floor. As wave steepness increases, the dark red colors lighten.

Figure A-9. In existing conditions at low tide (model label "Dredged"), the wave steepness remains lower over the dredged area, as the bottom drops out and does not exert friction on the waves. The breaking of the wave is "delayed" over the dredged area, instead breaking closer to the beach. The waves increase in steepness on the southwest corner of the beach, indicating wave breakage. Elsewhere along the beach, the waves increase in steepness further offshore, as the seafloor rises and exerts friction on the waves further away from the beach.

Wave steepness, existing conditions, tidal depth of 0 feet

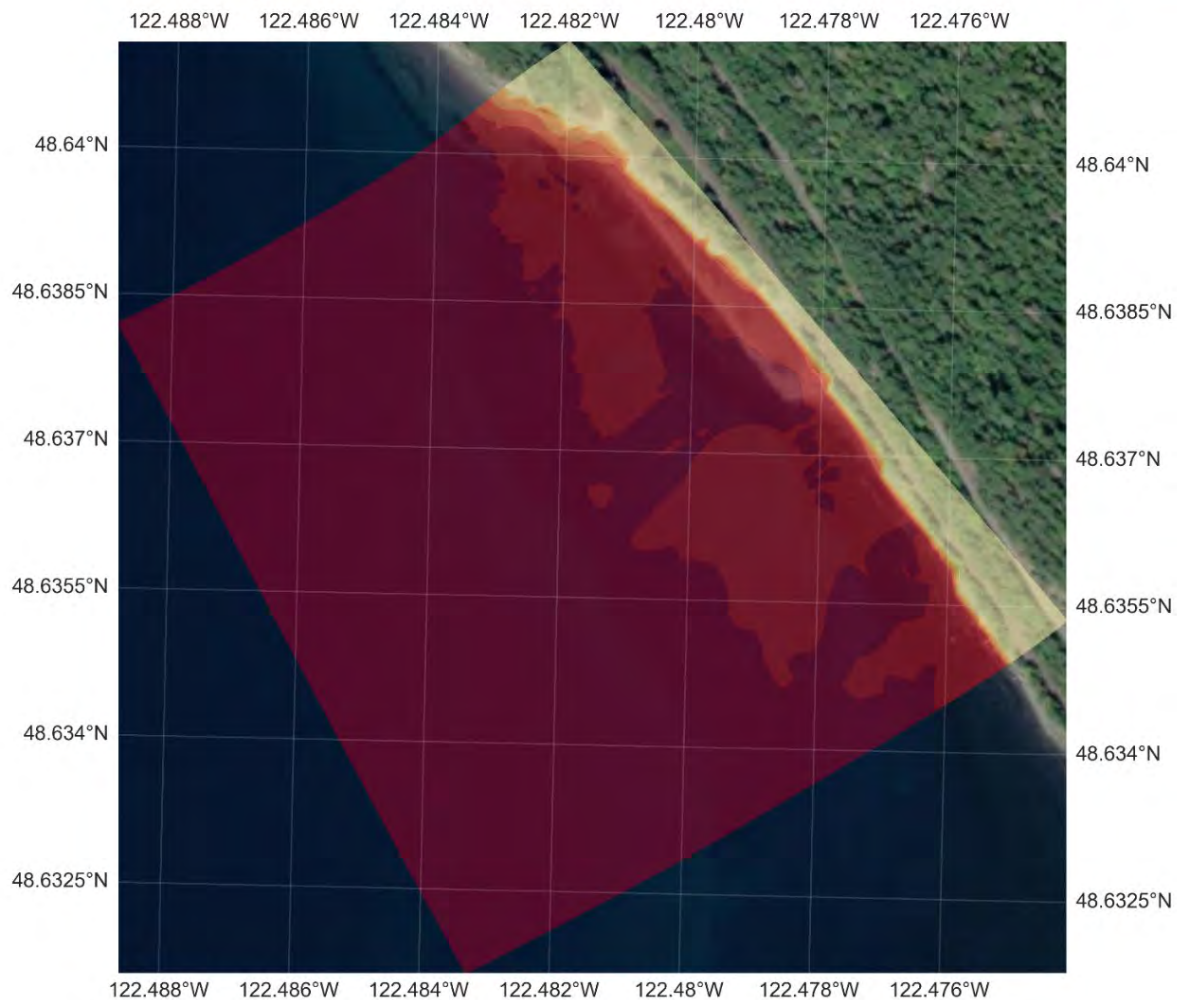
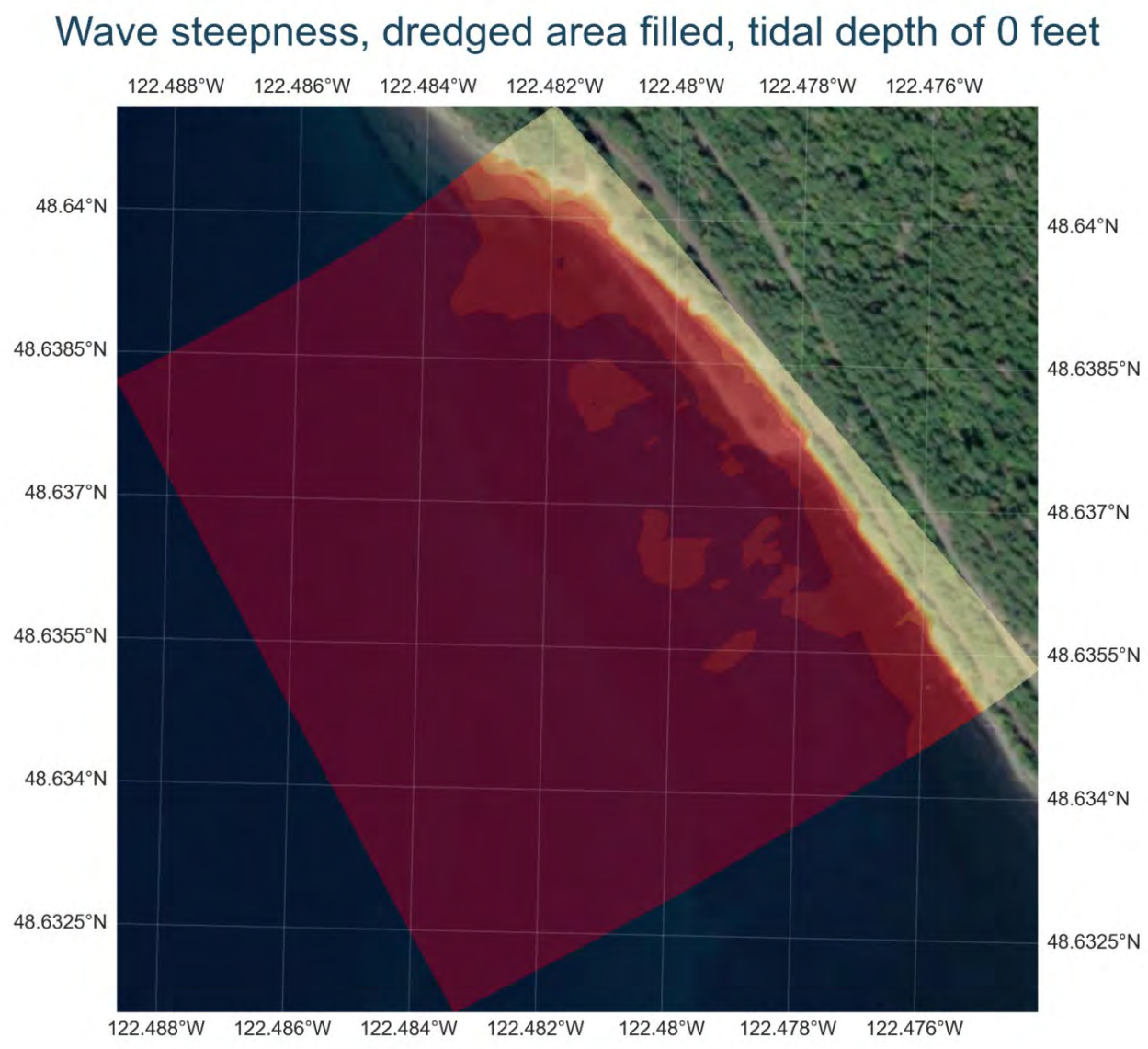


Figure A-10. When the dredged area is filled in (model label "Filled"), waves feel the bottom further offshore and increase in steepness away from the beach. Wave steepness is more evenly distributed across the beach.



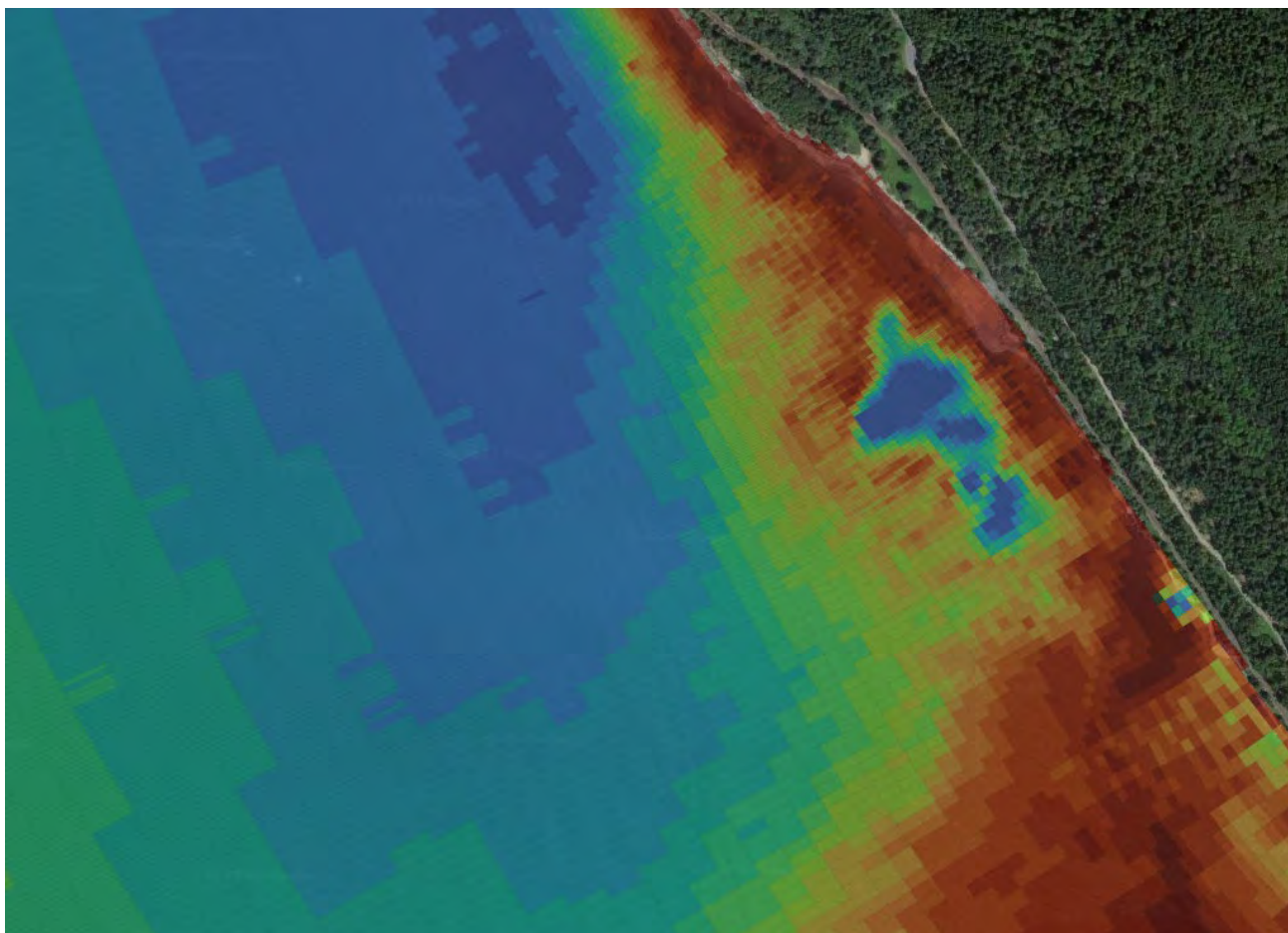
Energy Dissipation

Wave energy dissipation is a critical proxy for erosion. As waves break, their kinetic energy is transferred to the shore and increases the risk of erosion, particularly when combined with longshore currents.

Energy Dissipation Model Output

Figure A-11 displays wave energy dissipation at Clayton Beach over the existing beach surface. As the waves approach shallow water and begin to break, the level of energy dissipation increases. Overall energy dissipation levels rise as waves feel the seafloor with decreasing water depth. The exception to this is the offshore dredged area, which interrupts the energy dissipation as waves lose touch with the seafloor. When this occurs, the energy dissipation created by breaking waves drops off, delaying the dissipation.

Figure A-11. Energy dissipation in the immediate vicinity of Clayton Beach at low tide on existing conditions (model label "Dredged"). The dark blue colors over the dredged hole demonstrate the effect of the lowered seafloor on the waves, showing that gradual energy dissipation is interrupted over the dredged area.



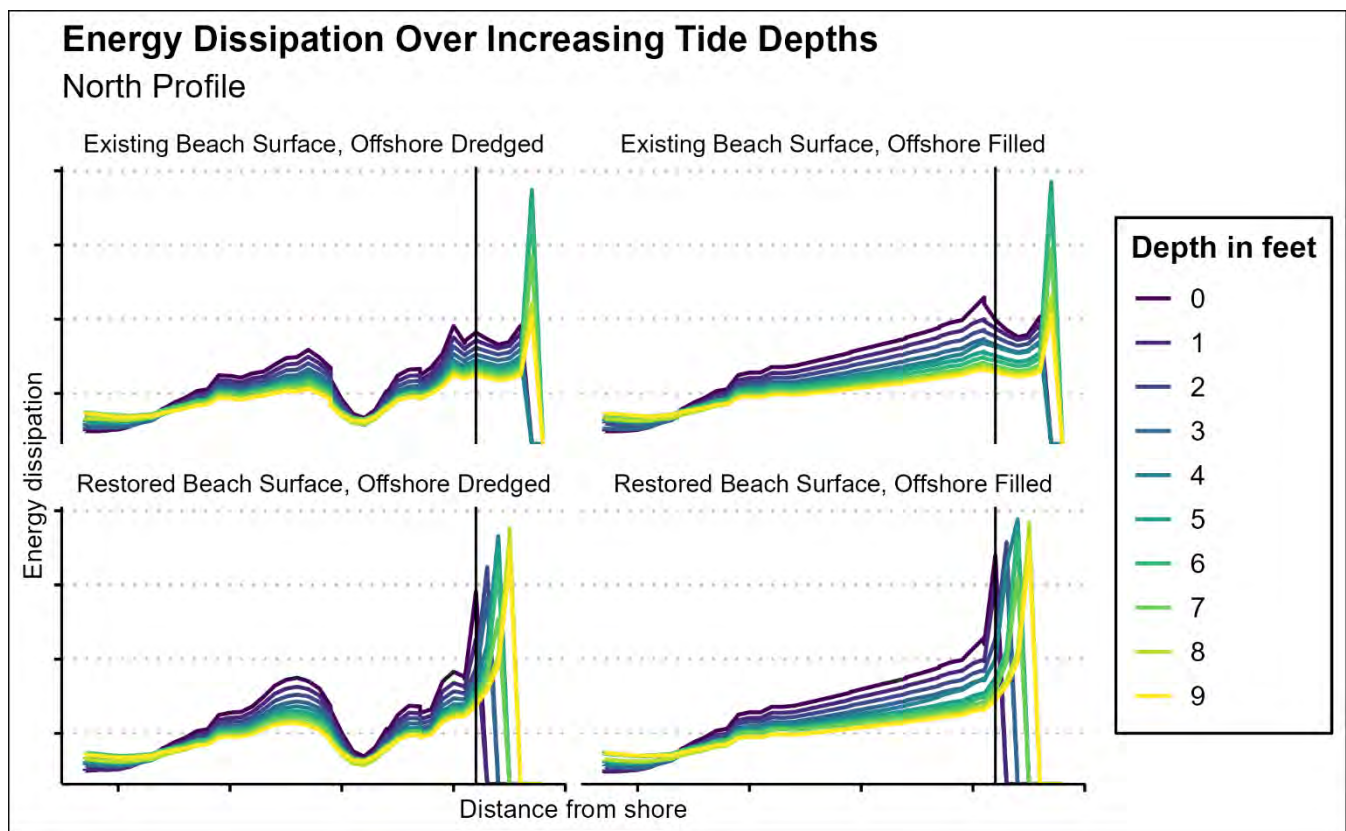
Energy Dissipation Profiles Over Increasing Tidal Depth

Northern profile energy dissipation from varying tidal levels on all conditions

Figure A-12 displays the log-normalized energy dissipation at the northern profile over tidal heights of 0 – 9 feet, under constant conditions of 3.83-foot waves approaching from 180 degrees (south). The black vertical line represents the location of the existing rip rap, a stumbling block over which the waves release some energy. The restored beach surface (in the bottom row of plots) does not remove energy dissipation, considering that energy cannot be destroyed, but the nourished beach offsets the energy further offshore, geographically relocating the highest dissipation values away from sensitive onshore structures.

The plots that include the offshore dredged area (present in the left-hand column) demonstrate the interruption in wave energy dissipation caused by the sudden drop in depth. As with the restored shoreline, filling in the dredged area does not remove energy, but distributes it evenly over the sloping bathymetry on the beach approach.

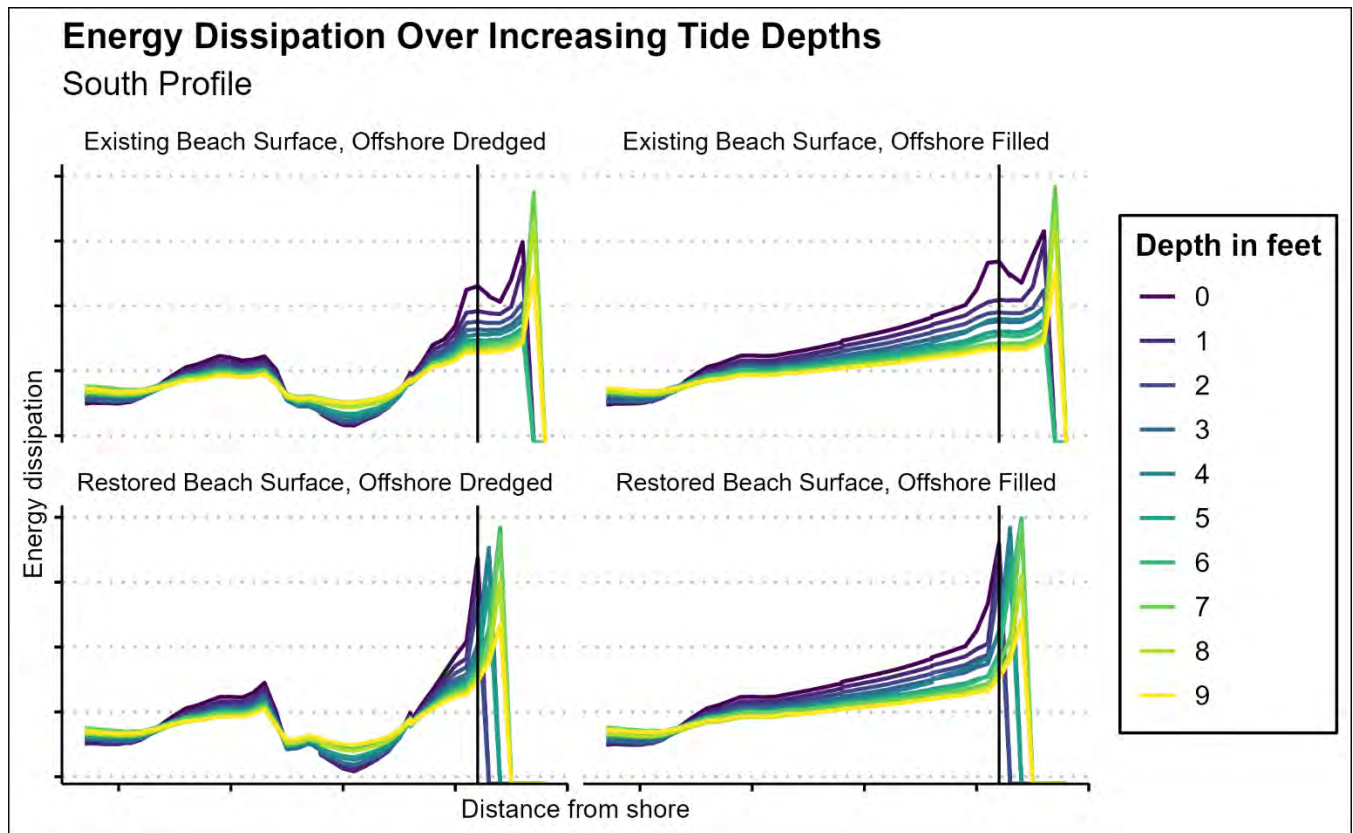
Figure A-12. The restored, filled beach (model label “Alt_Dredged” and “Alt_Filled”, respectively, in the lower left figure) display gradual energy dissipation away from sensitive structures.



Southern profile energy dissipation from varying tidal levels on all conditions

The southern profile transects across a deeper section of the dredged area, and the subsequent effect on the bathymetry on waves is more pronounced. However, the overall effect is similar: the highest peaks of energy dissipation are relocated offshore on the nourished surface and energy dissipation is more evenly spread over the filled dredged area (Figure A-13).

Figure A-13. As with the north profile, restored beach conditions (model label "Alt_Dredged" and "Alt_Filled") show the peak energy dissipation located closer to the current riprap, rather than near onshore structures.

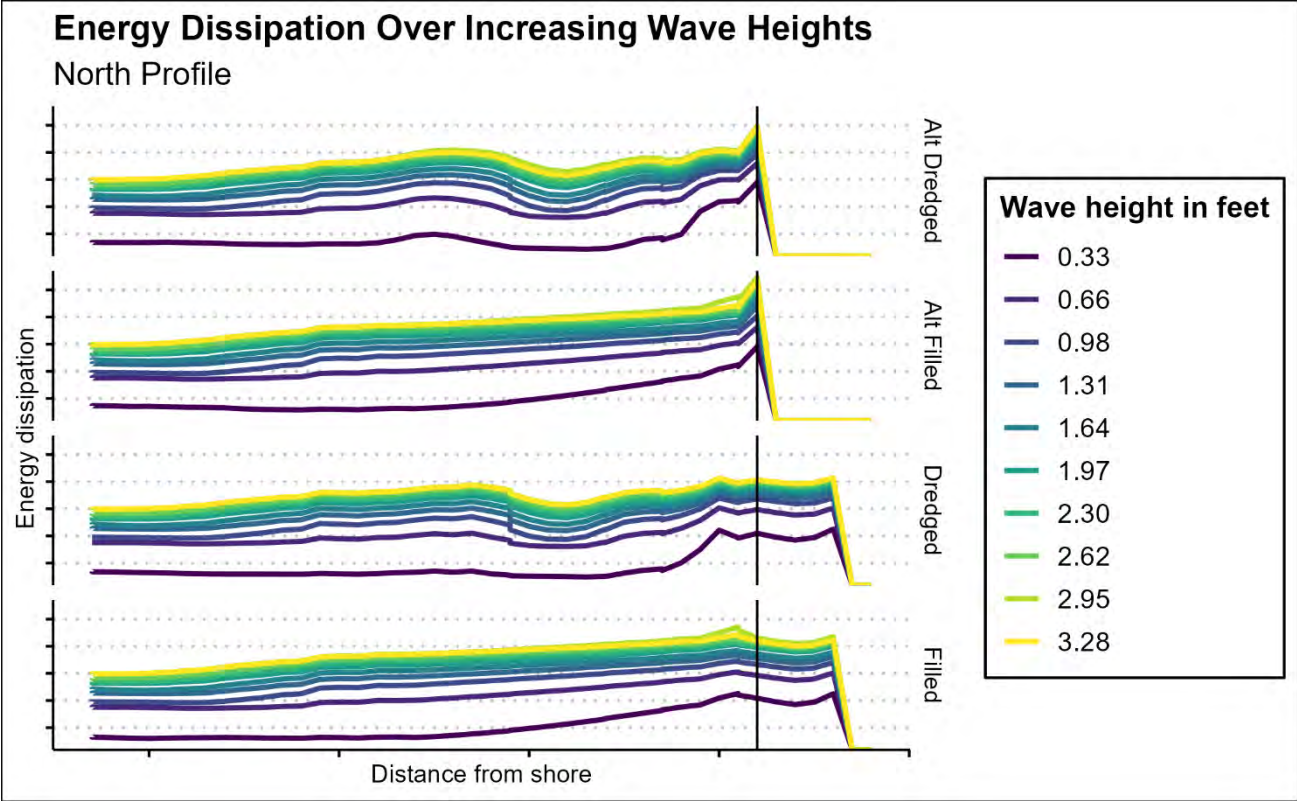


Energy Dissipation Profiles Over Increasing Wave Height

Depth and bathymetry are strong indicators of erosion risk due to their effects on waves, but waves themselves are the primary cause of erosion, especially when combined with other factors. In model conditions that simulated increasing wave height at a consistent approach angle of 180 degrees (south), higher waves resulted in a sharp increase of energy dissipation. The vertical black lines in the Figures A-14 and A-15 are the location of the existing riprap.

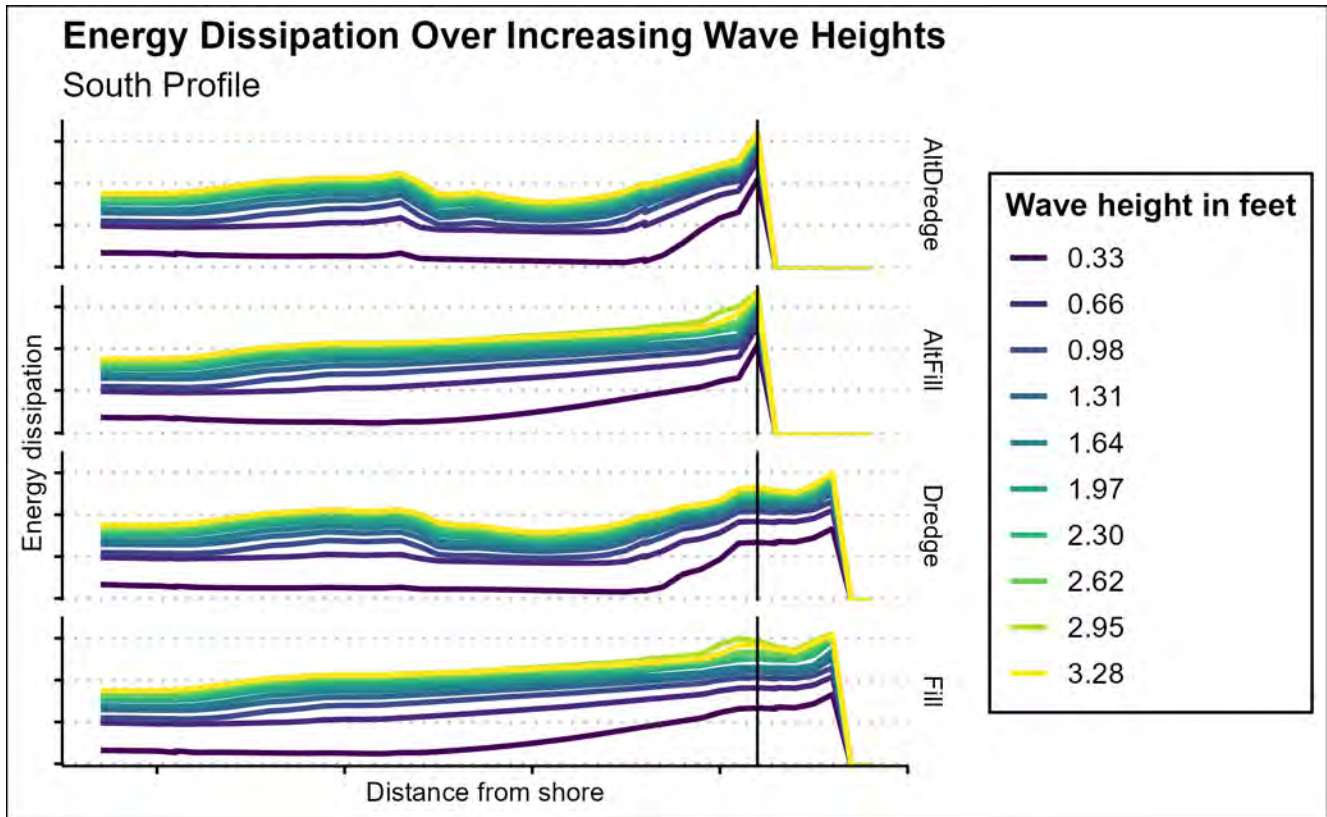
Northern profile energy dissipation from increasing significant wave heights

Figure A-14. As significant wave height increases, energy levels rise accordingly. The existing conditions allow for energy dissipation further towards shore, while the restored beach moves this location offshore.



Southern profile energy dissipation from increasing significant wave heights

Figure A-15. The southern profile indicates similar trends to those displayed in the northern profile, depicted in Figure A-14.



Energy Dissipation at Erosion Hot Spots

At a specific erosion hot spot on Clayton Beach’s southeast corner (Figure A-16), energy dissipation can be seen increasing as wave heights increase (Figures A-17 and A-18). However, restoring the surface suggests lower overall energy dissipation under this condition at this specific location.

Figure A-16. Location of a sensitive erosion hotspot near the southeast corner of Clayton Beach, existing conditions, low tide.

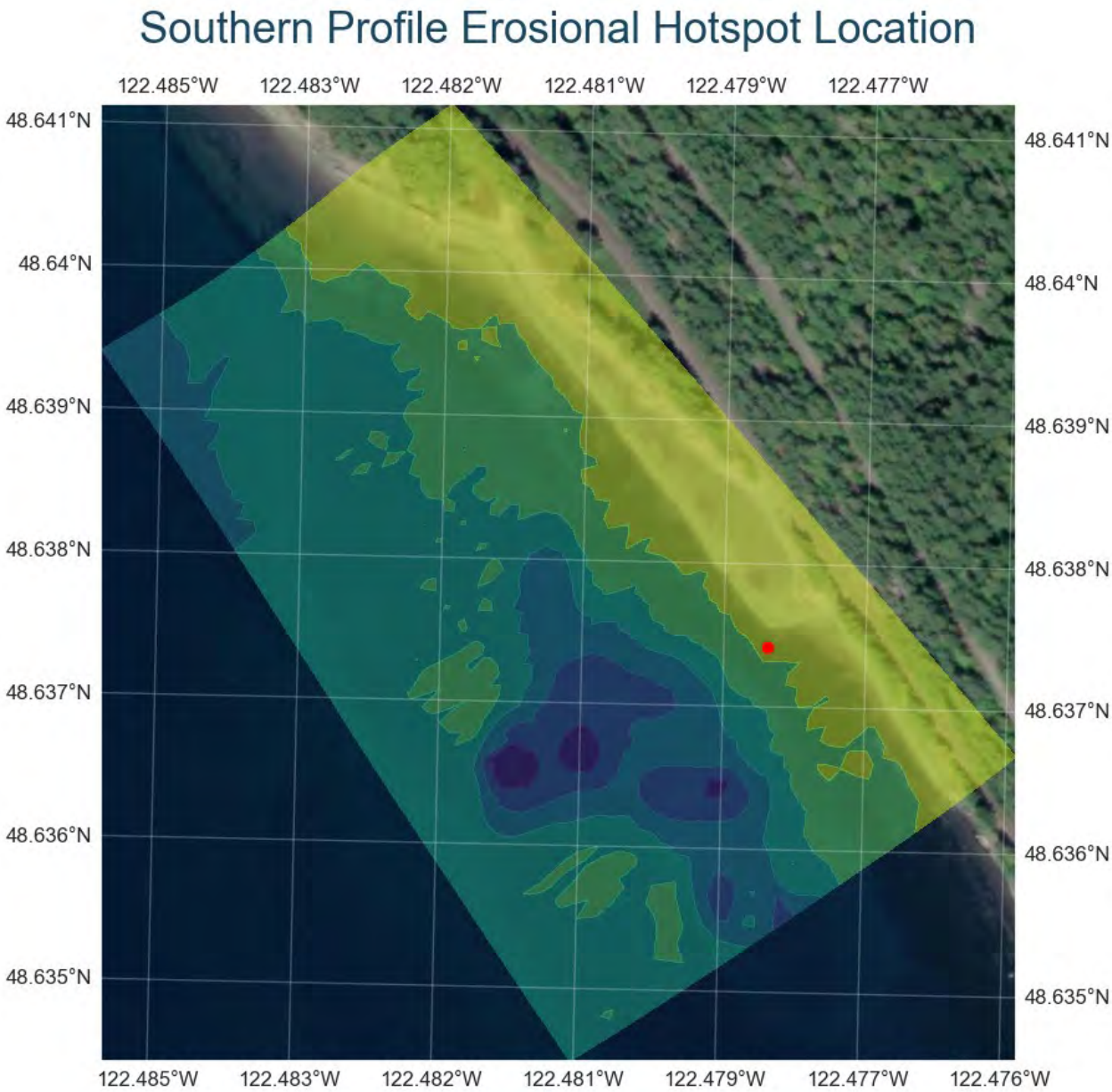


Figure A-17. At the erosion hot spot from Figure A-16, overall energy dissipation increases with wave height on the existing conditions.

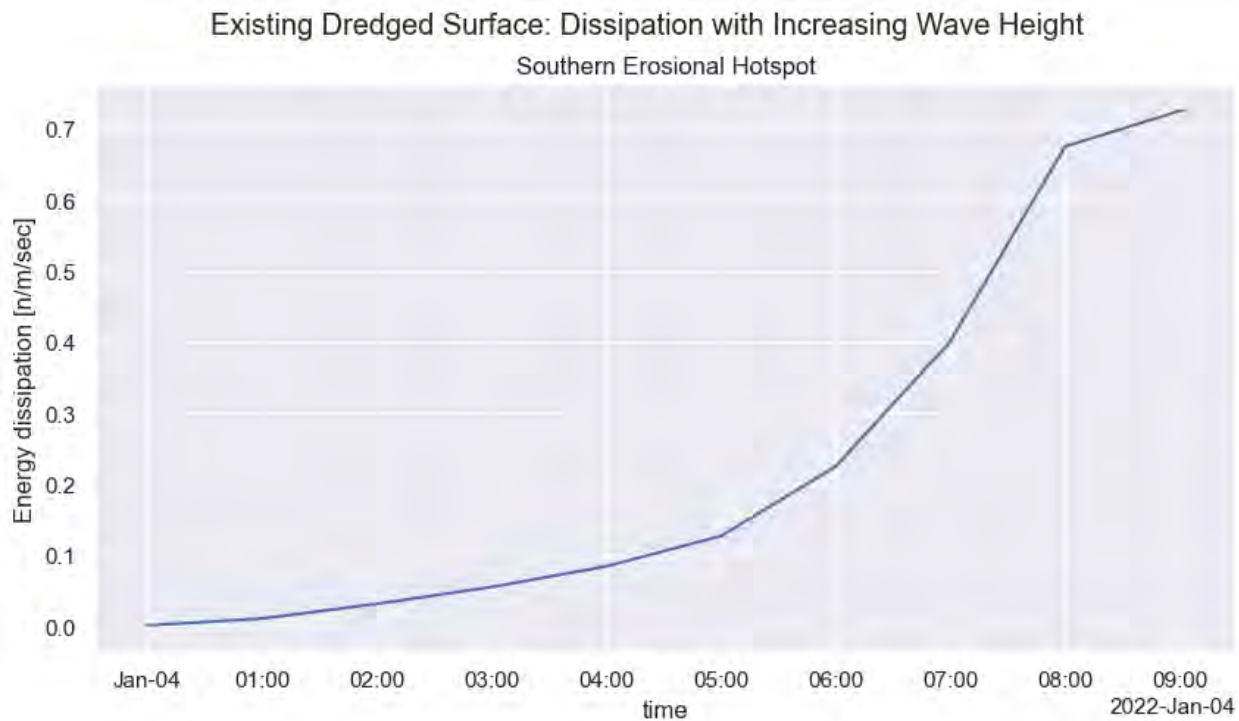
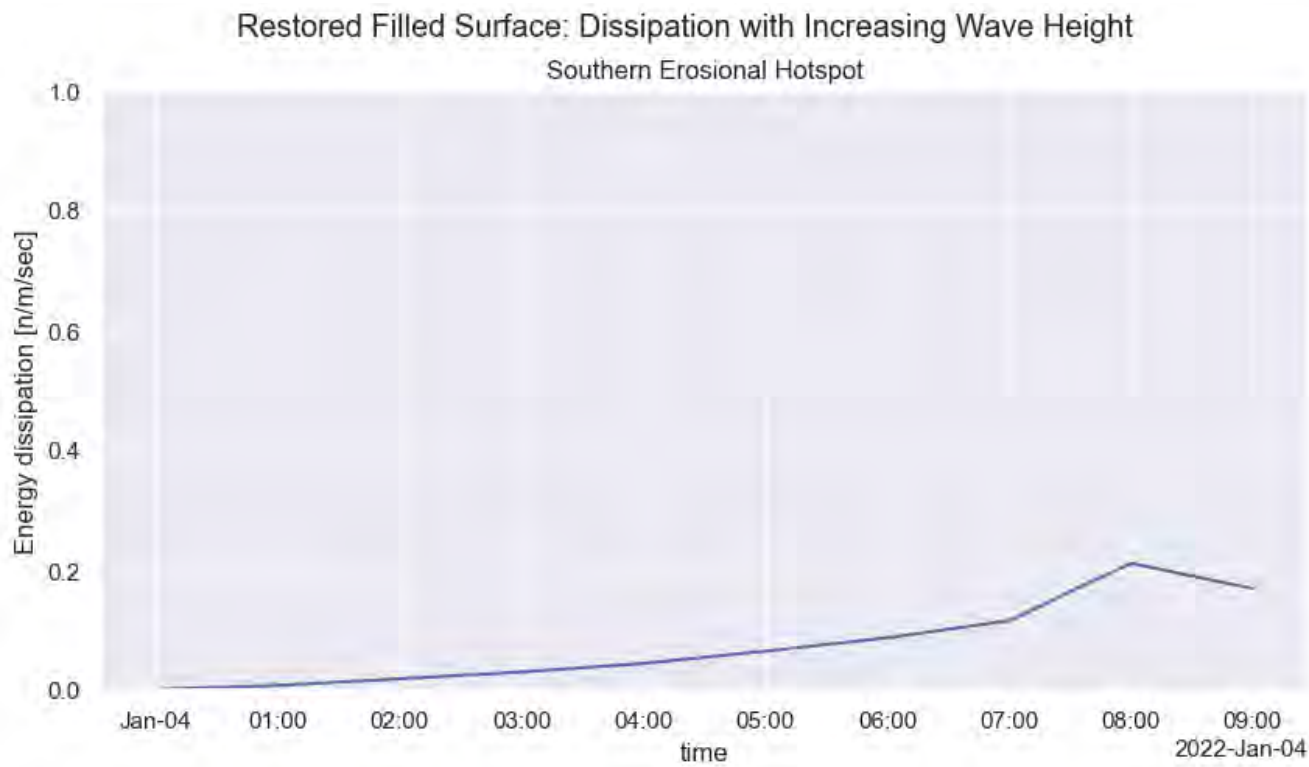


Figure A-18. The restored, filled surface (Alt_Filled) shows significantly decreased overall energy dissipation at the hot spot.



Significant Wave Height

Significant wave height is a value that traditionally indicates the average height of the highest 33 percent of measured waves. As significant wave height is strongly associated with depth, the dredged trench offshore affects nearshore wave height. In the models run on filled beach surfaces, highest wave heights and the subsequent risk of erosion are shifted offshore when compared with dredged conditions. Figures A-19 – A-22 show model outputs of low and high wave values on dredged and filled surfaces. When wind and wave values are low overall wave height is low, and waves display increased heights nearer to shore when wind and wave values are high.

Figure A-19. Significant wave heights at 0.33 feet average wave height, existing conditions (model label “Dredged”). Note the encroachment of higher waves on Clayton Beach.



Figure A-20. Significant wave height at 3.28 feet average wave height, existing conditions (model label "Dredged"). Note the extended reach of significant waves into the nearshore area at Clayton Beach, particularly over the dredged trench.

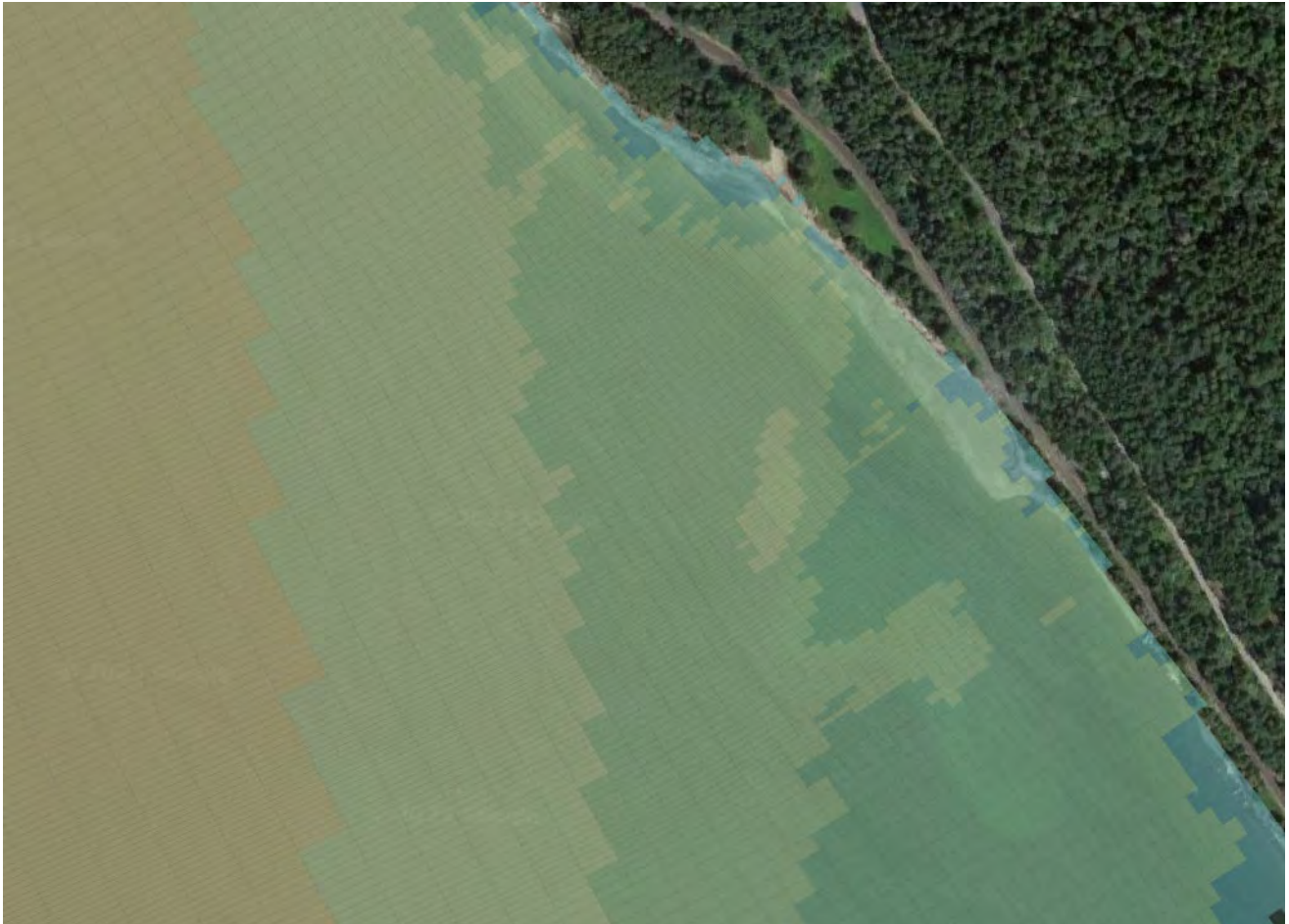


Figure A-21. Significant wave height at 0.33 average wave height, restored and filled conditions (model label "Alt_Filled"). High significant wave heights have been shifted offshore.



Figure A-22. Significant wave height at 3.28 average wave height, restored and filled surface (model label "Alt2_Filled"). The restored beach buffers the high waves away from infrastructure.



Conclusion

The modeling objectives of this report were to address the erosion challenges at Clayton Beach by examining existing conditions and simulating alternative conditions. The highest risks of shoreline erosion come from combinations of high waves, high water levels, and longshore currents caused by an oblique wave angle approach. The WAVE models applied to the Clayton Beach site systematically assessed these conditions over existing and proposed surfaces, evaluating which set of conditions resulted high-risk scenarios at sensitive locations. Additionally, the models assessed the effectiveness of the proposed restoration surface at mitigating erosion risk by running identical conditions over proposed surfaces (see Table A-1 for details). The alternative design surfaces were explored in the context of two relevant variables: energy dissipation and significant wave height. The analysis revealed that the human-induced alterations to the coastal system potentially exacerbate erosion, and the alternative surfaces offer a possible pathway to mitigate the risk of erosion to the adjacent railway.

Across variables associated with erosion, the restored beach relocated the highest values away from the current areas of concerns. For example, the north and south transects extracted from existing conditions

showed wave energy dissipation peaking near the railway, while the restored beach moved the energy peaks offshore, closer to the current location of the riprap edging the beach. In the case of a specific erosion hot spot located on the southeast edge of the beach, energy dissipation was significantly lowered by a restored surface when all other conditions remained constant. A second variable of interest, significant wave height, showed similar results to energy dissipation. As wave heights and subsequent erosion risk increased, the highest waves were pushed offshore in the restored beach scenario. Importantly, in the restored condition the size of waves that present risk to the railway would be significantly reduced compared to current conditions.

A relevant feature for the model was the offshore dredged area. Within the dredged area, the bathymetry deepens. Approaching waves in the model underwent complicated reactions to the abrupt bathymetric change. The natural process of gradual energy dissipation over a constant low approach was interrupted: instead, energy dissipation spiked and quickly fell off as the seafloor dropped out from the waves over the dredged area, and then energy dissipation returned closer to the shore. Wave steepness was also affected. Increased wave steepness, the precursor to breaking waves and subsequent energy dissipation, was delayed over the deeper section. Once the shallow bathymetry resumed closer to shore, that process of increased steepness and energy dissipation was pushed closer to sensitive shoreline areas. Two of the model surfaces simulated wave action over a filled trench with varying conditions (model labels "Filled"), and results showed that the filled trench introduced gradual energy dispersion and wave height rather than the rapid local peaks and valleys associated with existing conditions.

The models identified the high-risk scenarios at the site and provided guidance for beach restoration efforts. In conclusion, this modeling exercise has provided a robust foundation for advancing towards the restoration of the beach to a resilient, more natural state.

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Appendix B

Clayton Beach Eelgrass and Dredge Hole Investigation



Clayton Beach Eelgrass and Dredge Hole Investigation

A Nearshore Habitat Survey for the Northwest Straits Foundation

Washington Department of Natural Resources
NWSF Contract No. 2023-09-DNR
DNR Contract #93-105096

January 17, 2024



WASHINGTON STATE DEPARTMENT OF
NATURAL RESOURCES

Cover Photo: Clayton Beach looking North (Photo from Washington Trails Association).

Clayton Beach Eelgrass and Dredge Hole Investigation

A Nearshore Habitat Survey for the Northwest Straits Foundation

January 17, 2024

Aquatic Assessment and Monitoring Team
Aquatic Resources Division



WASHINGTON STATE DEPARTMENT OF
NATURAL RESOURCES

Contents

Executive Summary	1
1 Introduction.....	2
1.1 Background and Project Description.....	2
1.2 Specific Study Objectives	5
2 Methods.....	7
2.1 Mapping Vegetation and Bathymetry.....	7
3 Results.....	17
3.1 Total Area Surveyed	17
3.2 Bathymetry	18
3.3 Eelgrass Bed Distribution – General Trends	20
3.4 Dredge Hole Volume Estimate.....	30
4 Conclusion	32
5 References	34

Executive Summary

The Northwest Straits Foundation (NWSF) and partners are currently assessing the feasibility of removing 1,300 linear ft. of armoring rock (riprap) and remnant wooding pilings from the nearshore at Clayton Beach in Skagit County, WA. In the absence of a riprap wall, eelgrass at the site is expected to move landward and fill a portion of the unvegetated intertidal at Clayton Beach. Eelgrass is an important canopy forming vegetation that countless native species rely upon for food and shelter.

In addition to the current shoreline restoration, another restoration opportunity exists just offshore from Clayton Beach. An unvegetated dredge hole, created when fill was excavated from the shallow intertidal and utilized in the construction of an interurban electric trolley at Clayton Beach (now part of Larrabee State Park in Skagit County, WA) remains as a large depression in the seafloor. While the electric trolley is long since gone, this hole remains a permanent feature of the nearshore. Due to its depth, 13.9 acres of native eelgrass that would have naturally existed in the space is absent. DNR is working with the Northwest Straits Foundation (NWSF), the Whatcom and Skagit County Marine Resource Committees (MRC), and Washington State Parks (WSP), to explore restoring the native eelgrass in this dredge hole.

In August of 2023, DNR's Aquatic Assessment and Monitoring Team surveyed a large area offshore the Clayton Beach nearshore restoration zone to understand the current distribution of native eelgrass adjacent to the current restoration zone, as well as the total volume of the unvegetated dredge hole. In total, 33 acres of the Clayton Beach nearshore were mapped with a multibeam sonar for bathymetry and eelgrass bed morphology. Sixty five acres were mapped with a single beam sonar for eelgrass canopy height and percent cover.

The Washington State Department of Natural Resources (DNR) manages 2.6 million acres of state-owned aquatic lands for the benefit of current and future citizens of Washington State. In addition to the protection of certain habitats and native species, DNR seeks to increase the opportunities for the utilization of renewable resources as well as to generate income from the use of aquatic lands when consistent with other goals.

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1 Introduction

1.1 Background and Project Description

Nine miles south of the city of Bellingham WA., Larrabee State Park is a treasured recreational access point of the Chuckanut Range shoreline. Every year, tens of thousands of visitors come to the park to explore 8,100 ft of saltwater shoreline pitted with Chuckanut Sandstone features. In addition to views of the San Juan Islands and Padilla Bay, the nearshore zone provides critical habitat to countless species of important marine organisms such as forage fish, salmon, and feeding grounds for migrating seabirds.

Eelgrass, a vegetation that provides important structured habitat to these species grows abundantly along the Larrabee State Park shoreline and is especially prevalent at its southernmost portion known as Clayton Beach. Clayton Beach abuts the second largest eelgrass meadow on North America's Pacific Coast, known as Padilla Bay. Seagrasses such as the native eelgrass (*Zostera marina*) are known to increase the climate resiliency of a shoreline by capturing carbon, filtering nutrients from the water, producing oxygen, and helping to protect the coastline from floods and storm surge (Pew Charitable Trust 2023).

The Northwest Straits Foundation (NWSF) and partners are currently assessing the feasibility of removing 1,300 linear ft. of armoring rock (riprap) and remnant wooding pilings from the nearshore at Clayton Beach (Figure 1). This restoration targets the removal of structure placed at the site in the early 1900's which historically supported an electric trolley for commuter transport from Bellingham to Mt. Vernon WA. This route was known as the Bellingham and Skagit Interurban railway and operated from 1912 to 1928 (Figure 2).

The removal of riprap/pilings and re-contouring of the beach is expected to improve sediment transport processes and allow for a landward increase in the shallow edge of eelgrass back to its natural extent, which is likely impacted by rock armoring at the site (Figure 1). By itself, this restoration aims to restore nine acres of nearshore habitat, improve public access, and allow for adaptation of the shallow boundary of the eelgrass bed in the face of sea level rise (PMEP 2023).

On top of this restoration of the nearshore, another opportunity to restore an additional 13.9 acres of seagrass habitat exists only 250 ft. seaward of the existing Clayton Beach restoration zone. A large unvegetated dredge hole (hereafter called the "divot") was created in the early 1900s when sediment was excavated to support the interurban trolley trestle. This divot is currently too deep to naturally support eelgrass and is thought to exist as a bare vegetation-less hole in the subtidal. Based on sparse data from DNR's Nearshore Habitat Program, eelgrass is abundant around the periphery of the divot – indicating an exciting restoration opportunity (WADNR 2023). Restoration of this divot will involve filling it with suitable substrate and replanting with native eelgrass.

To this point, a dedicated boat based sonar survey has not been carried out to understand baseline subtidal eelgrass cover surrounding the restoration zone and divot at Clayton Beach. To further understand this distribution, the Northwest Straits Foundation contracted with the Washington State Department of Natural Resource's Aquatic Assessment and Monitoring Team (AAMT) to map the bathymetry and distribution of eelgrass at Clayton Beach.



Figure 1. Clayton Beach, 2023. Photograph taken from Larrabee State Park, looking South. Photo: Pacific Marine and Estuarine Fish Habitat Partnership.



Figure 2. Clayton Beach 1912 Trolley Trestle Construction. Photograph taken from the south, looking north. Photo from Western Washington University Heritage Resources Archive.

1.2 Specific Study Objectives

As a project partner, DNR was contracted to map the area around the Clayton Beach rip rap and piling removal project as well as surrounding the divot. Mapping was completed to delineate the following:

1. The current extent of eelgrass around the Clayton Beach nearshore restoration site to provide a baseline map of conditions which will provide a reference to determine how riprap and piling removal supports eelgrass reintroduction.
2. The current extent of eelgrass surrounding the unvegetated dredge hole or “divot”.
3. Seafloor surface morphology (or bathymetry) surrounding the nearshore restoration zone. This information will reveal how future riprap and piling restoration changes alongshore geomorphologic processes and slope profiles.
4. Bathymetry of the divot. This information will reveal the true area of the divot and the total volume of material required to fill it.

2 Methods

From August 7th to the 8th, 2023 approximately 3,380 ft. (1000 meters) of shoreline mapping for vegetation and bathymetry was carried out during two different hydrographic surveys at Clayton Beach. Both single beam and multi beam sonar were utilized to collected data that reveals the total vegetative cover as well as bathymetry of the divot and offshore of the restoration zone.

Features of each type of sonar are presented in Table 1.

Table 1. Capabilities of both single beam and multibeam sonar.

Data Type	Single Beam Sonar	Multi Beam Sonar
Eelgrass Bed Distribution (Top Down Map)_	Low resolution based on transect interval. Faster to collect.	High resolution full coverage. Slower to collect in shallow zones.
Eelgrass Percent Cover	Built in calculation.	Not capable without custom model.
Eelgrass Canopy Height	Built in calculation.	Not capable with highly vegetated sites.
Bathymetry	Low resolution. Differentiates vegetation canopy from sediment in highly vegetated sites.	High resolution, high accuracy. Full coverage. Does not differentiate vegetation canopy from sediment in highly vegetated sites.

2.1 Mapping Vegetation and Bathymetry

2.1.1 Site Description and Project Planning

The intended survey area included the riprap restoration zone, and as far to any side as impacts from restoration were expected based on predominant south to north drift cell flow (Figure 3). This area spanned 3,000 ft of nearshore at a width of 1,000 ft. and included both the unvegetated dredge hole and riprap restoration zones (Figure 3). Approximately 2000 ft of this shoreline was within Larrabee State Park (Figure 3).

Surveys were intended to extend as shallow as safely possible, and as close to the riprap shoreline to provide a thorough baseline of current shoreline conditions. The majority of this area resulted in operations within 9 ft of water or less (MLLW).

A systematic survey with a gridded design was implemented to cover the target area, which included transects spaced 65 ft. (20 meters) apart for single beam sonar. A smaller area was targeted for multibeam sonar collection which included the divot as well as zones shallower than it (Figure 3).

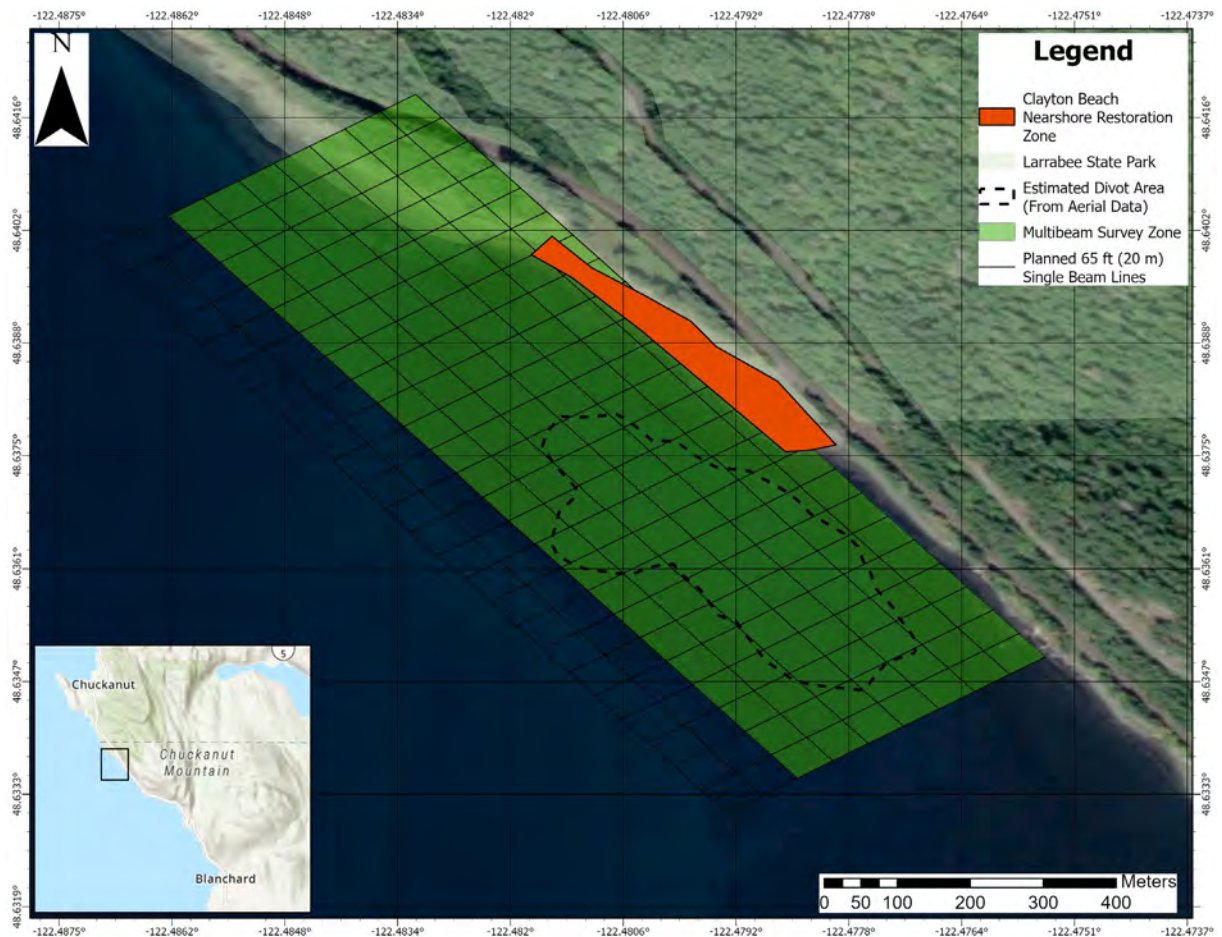


Figure 3. Approximate multibeam collection footprint at Clayton Beach, Skagit County, WA. Planned single beam transects are indicated by the hashed polygon.

2.1.2 Field Collection – Single Beam Sonar

The DNR Aquatic Assessment and Monitoring Team (AAMT) staff utilize a BioSonics DTX single beam transducer onboard AAMT's 21-foot research vessel to accurately and efficiently collect eelgrass percent cover and canopy height as well as bathymetric data (Gumusay et al., 2019).

The BioSonics DTX system is a proven and accurate platform for aquatic vegetation delineation and mapping (Gumusay et al., 2019; Stevens 2019). It emits a 420 kHz sound pulse with a width of 6 degrees, collects a sound signal reflected from the surrounding environment, and converts the signal into electrical energy. A BioSonics surface unit is used in tandem to interpret the incoming electrical signal, associate each ping to positional GPS in an interface for users to observe incoming data, adjust settings, and store raw data as digital files.

The transducer head (Figure 4A) is mounted on an aluminum pivot arm off the starboard side of the vessel and when vertically deployed sits approximately 0.39 m beneath the water's surface (Figure 4B). This pole and mounting bracket have been designed to reduce vibration and to maintain a level position while collecting data thereby minimizing distortion in backscatter readings. A Trimble Pro 6H GPS is mounted on the top of this pole and directly overhead the sonar transducer (Figure 4D). The GPS feeds position data (accurate up to 10cm) to both the Biosonics surface unit as well as a tethered towable camera.

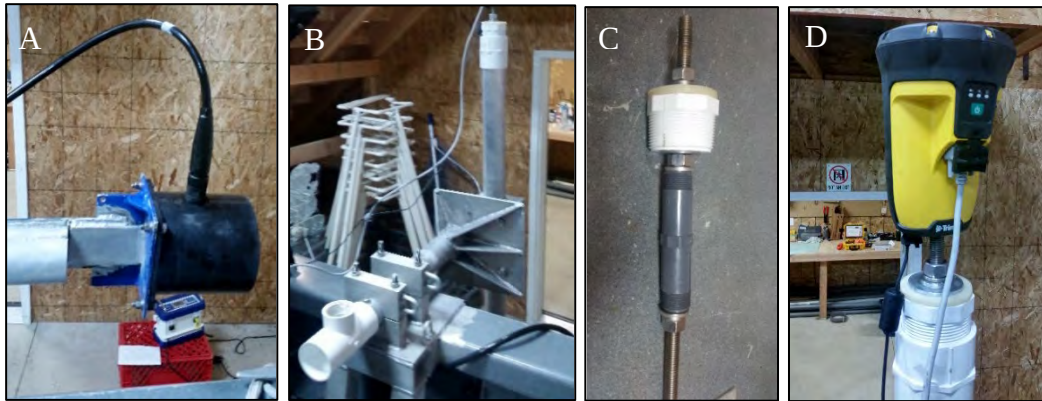


Figure 4. A) Single Beam Sonar transducer with deck cable connected. B) SBS mount in survey positions. C) GPS mount. D) GPS with RS232 and micro-USB cables attached.

Settings

A sound pulse ping rate is set at a standard of 10 pings per second and the duration for each pulse is set to 0.1 millisecond. These values have been found to be best when collecting data for eelgrass delineation (Stevens 2019). The maximum depth at which data is collected varies per site but averages 15 m - Eelgrass rarely grows beneath 12m in Puget Sound. Data is collected at a rate equal to the ping rate, 10 data points per second.

Video

BioSonics software interprets a unique sound return for eelgrass; however, there are anomalous features that may be misinterpreted as eelgrass when post-processing (Sabot et al., 2002; Shuai Xu, 2019). To verify eelgrass presence, we collect underwater video along 10% of the transects surveyed. For these transects, video can be collected while the sonar is also running by towing a SeaViewer Sea-Drop 950 video camera weighted and suspended by line off the port side of the boat. In real-time, a SeaViewer Sea-Trak GPS overlay displays time and GPS locations onto the video image (Figure 6). Video data is recorded digitally on an SD card with a SeaViewer DVR-SD.

The towed camera is housed within a PVC enclosure which orients it at a 45 degree angle to the bottom, protects the camera from potential damage, and allows the camera to track straight with the use of fins and weights (Figure 5). To maintain a constant field of view, the camera is held about 1 m from the benthos.

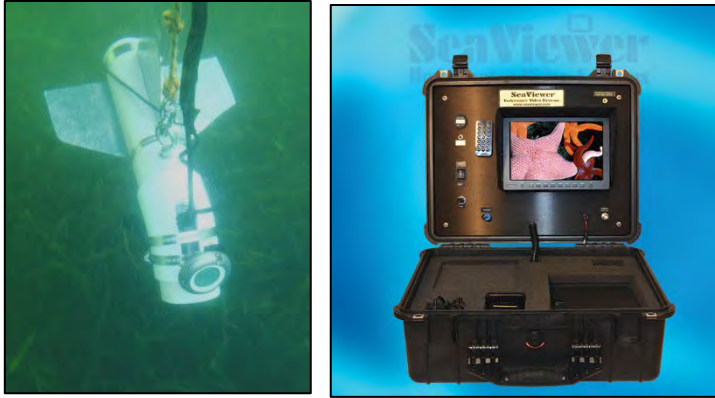


Figure 5. Left: Seaviewer Camera. Right: Seaviewer Surface Unit and Recorder Interface.



Figure 6. View of real-time video collection and attributes.

Post-processing

BioSonics data is processed for each transect using BioSonics Visual Aquatic software. This software allows a trained technician to correct inaccuracies in bottom detection and eelgrass delineation after algorithms within Visual Aquatic have been applied. These algorithms are a starting point at providing a rough classification of seafloor bathymetry and eelgrass presence or absence by sonar ping (BioSonics 2023). Eelgrass presence is determined by a unique backscatter or “bearding” pattern in the data (Figure 7). This pattern is caused by the structure of seagrass and is unique from other functional groups of marine vegetation (Shuai Xu, 2019).

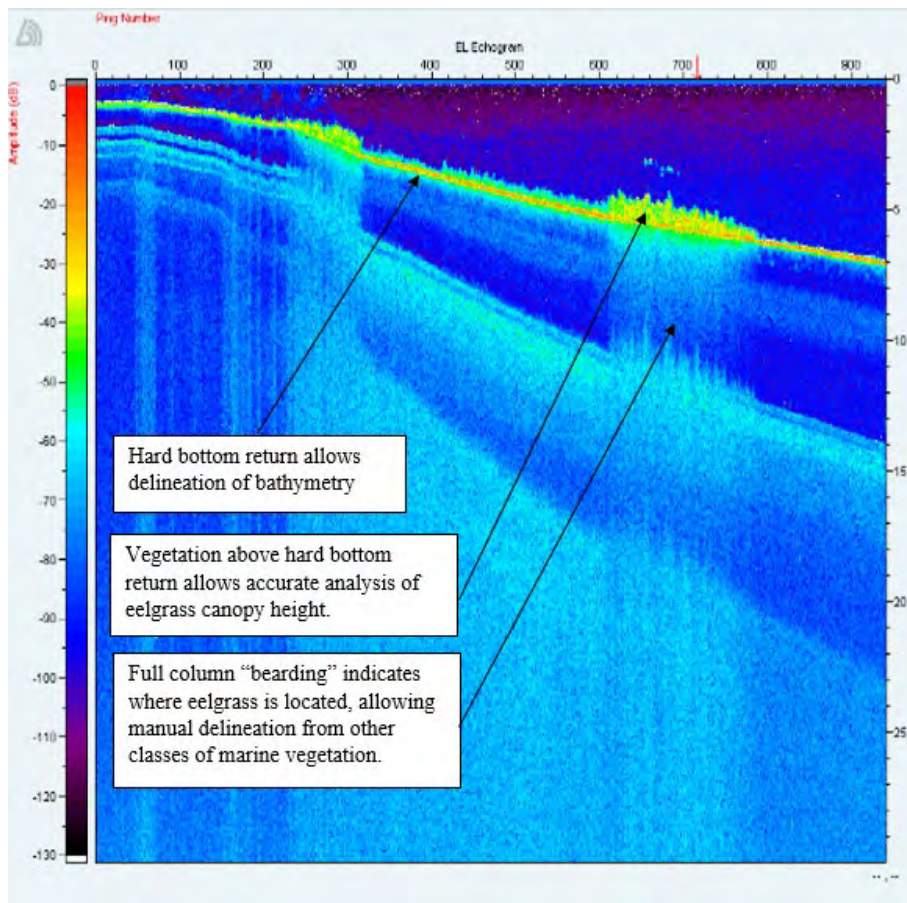


Figure 7. Image showing the distinction in the backscatter pattern unique to eelgrass.

Processed transect files are exported to a CSV format and combined into one complete dataset for further post-processing and analysis. These exported CSV files include attributes for the date, time, location (latitude, longitude), percent eelgrass cover, eelgrass canopy height, and substrate depth. Eelgrass cover for each ping is represented with a one (present) or a zero (absent), and percent cover is calculated by averaging eelgrass presence and absence over 10 pings.

GPS data collected with a Trimble Pro 6H antennae is differentially corrected with Trimble GPS Pathfinder Office (TPO). This software utilizes a network of base stations to increase accuracy of locational data by removing errors caused by various factors (e.g., cloud cover). Accuracy for data collected with the Trimble Pro 6H can be as resolute as 10 cm after post-processing.

Raw bathymetry is imported from the processed Visual Aquatic CSV and corrected for an offset to adjust for the distance between the top of the water line and the bottom of the transducer (measured before each survey). It is then transformed to Mean Lower Low Water (MLLW) vertical datum using tidal data from T-bone tides and a custom R version 4.2.2 script (University of South Carolina 2020, R Core Team 2023). A raster surface of bathymetry is created with the kriging tool in ArcGIS from corrected single beam point depths.

Video data is reviewed by a trained analyst into one-second segments. Presence and absence of marine vegetation classes (kelps, red algae, green algae, seagrass, and sargassum) as well as bottom type are determined. BioSonics data for the same transects are compared to results from processed video for quality control and to tune BioSonics edits.

2.1.3 Field Collection – Multi Beam Sonar

In addition to single beam sonar data, a multi beam was used to further establish a volume estimate of the divot and the distribution of eelgrass around it.

The bathymetry of non-vegetated surfaces is much more accurate with a multibeam sonar than a single beam, and it provides full coverage. For this reason, the multibeam was employed to target the intricacies in divot bathymetry. Additionally, it was also used to understand where eelgrass exists as it provides full coverage rather than transect data. While this “full picture” view does not provide an estimate of canopy height or percent cover, it is good supplement to the data collected with the single beam.

An R2sonic 2020 multibeam sonar and an integrated Applanix navigation system was utilized for bathymetry. The R2Sonic 2020 model is a small and light flat array multibeam unit that combines the transmitter and receiver into a single instrument. Position, heading, pitch, yaw, and roll are recorded with an Applanix Inertial Motion Unit (IMU) and Trimble GNSS positioning system. Using Applanix’s POS PAC software (Applanix Corporation 2021) DNR scientists collect raw motion and heading data in the field, process these observations in the office, and recalculate the entire survey’s data for high-accuracy three dimensional spatial locations.

Data was collected at a 400 kHz frequency, with a beam width of 130 degrees. At least fifty percent data overlap was collected between tracks. The survey was planned and carried out with QINSY software by QPS Maritime Software Solutions. Full water column sound speed measurements are collected with a Sontek CastAway CTD every two hours. The CastAway rapidly measures density, pressure, salinity, conductivity, and temperature and calibrates sound speed with the multi beam’s surface sensor.



Figure 8. R2Sonic 2020 multibeam (bottom, grey), Applanix IMU (top, black), and mount (blue)

Data Processing

Bathymetric surfaces were cleaned and processed with QPS QIMERA software. A corrected position and motion file was created with Applanix PosPac software and applied to raw bathymetric files. From these raw files, a dynamic surface was created by which point surface data anomalies were edited by hand.

Once manual edits were applied, a final dynamic surface was exported as a two band 0.25 m² resolution raster (hereafter referred to as Bathymetric Attributed Grid (BAG)). Band 1 in the BAG contains elevation data in the NAVD88 (m) vertical datum averaged from a cloud point surface. Band 2 contains CUBE uncertainty data for every band 1 cell calculated as the standard deviation of the accepted soundings that contributed to the selected surface hypothesis.

Bathymetric estimates in survey datum NAVD88 (m) were converted to MLLW (ft.) using NOAA's Vdatum tool (NOAA 2023).

The corrected BAG surface is interpolated to fill small voids in coverage using the elevation void fill function in ArcGIS Pro (creating a BAG_evf layer). Using the Benthic Terrain Modeler (BTM) package in ArcPro, the "roughness" of the Clayton BAG surface was defined using rugosity and slope. Rougher zones were extracted using a supervised classification in ArcPro and exported to a single feature class to provide a multibeam generated representation of eelgrass in the cove.

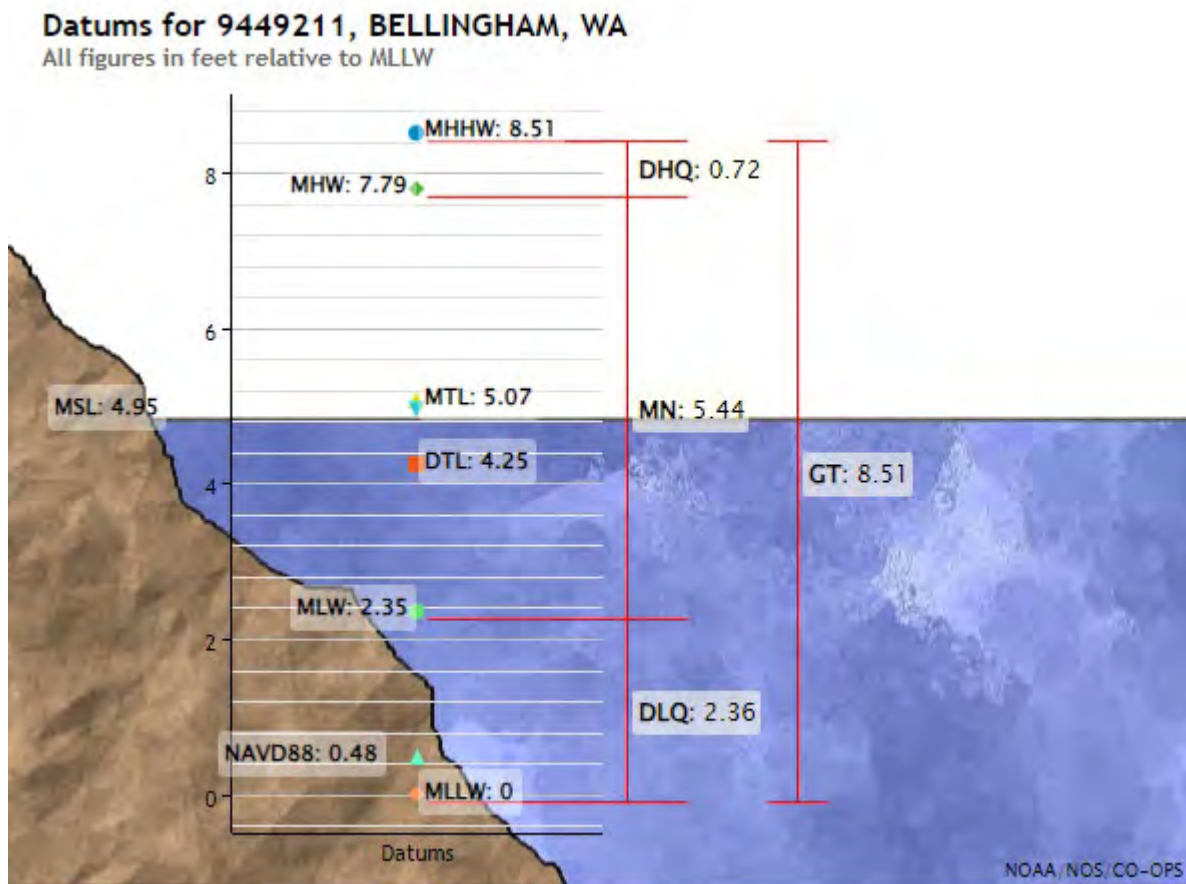


Figure 9. Datum Benchmarks for Bellingham Bay showing the difference between NAVD88 (m) and MLLW (ft.).

2.1.4 Eelgrass Bed Shape Delineation

Eelgrass bed area and size is established from multibeam data. First, a slope surface is created from the BAG with the Bathymetric Terrain Modeling (BTM) toolbox in ESRI ArcPro. Slope is the gradient, or rate of maximum change in z-value from each cell of a surface raster in degree units, and assumes that the depth or elevation units of the surface raster are the same as the x and y units (Walbridge et al. 2018).

Next, an unsupervised classification was carried out on this slope surface using the “Iso Cluster Unsupervised Classification” tool for 5 classes. The resulting classes define certain portions of the BAG that are covered in eelgrass. By comparing processed single beam data to this surface, we determine which of 5 classes include eelgrass.

The “make raster” tool is then utilized to combine eelgrass classes and remove all others. All artifacts of surveying are cleaned by hand from this surface, and the “dissolve” tool combines all separate polygons into the same feature.

2.1.5 Divot Volume Analysis

To calculate the total volume of the divot, a series of interpolations and raster masking operations were carried out. Two masks were required – the first (mask 1) was a mask of only the unvegetated area of the divot. The second (mask 2) included all area covered by multibeam data minus the unvegetated portion of the divot.

To produce mask 1 (divot extract mask) all unvegetated portions of the divot were isolated and extracted from the original BAG interpolation. The first step in this process included erasing the multibeam eelgrass layer created in the previous section from an original BAG_evf layer using the erase function. The resulting raster was converted into a polygon using the raster to polygon tool. This polygon was then edited by hand to extract the unvegetated portion of the divot, thereby producing a mask of unvegetated area of the divot, and restoration opportunity. This mask was used to extract cells of the divot using the extract by mask function.

For mask 2 (divot minus mask), a total survey mask was created with the raster to polygon tool which represented the entire multi beam sonar surveyed area (Clayton multibeam mask). The clip tool was then used to clip out the divot extract mask from the Clayton multibeam mask.

Using the extract by mask tool, both mask 1 and mask 2 were used to extract cells of the original BAG_evf raster, resulting in a raster surface without the divot included, and a raster surface with only the bathymetry of the divot. Next, the raster surface missing the divot was interpolated to establish an estimate of the natural seafloor slope prior to divot excavation.

Finally, the Cut Fill tool was used to calculate the total volume between a Clayton Beach nearshore without a divot, and the current divot bathymetry. An error estimate for this volume

calculation was produced by following a similar cut-fill process with the cube uncertainty surface.

3 Results

3.1 Total Area Surveyed

On August 7th, 2023, sixty-five acres of the nearshore were mapped by single beam sonar. The next day, on August 8th, an additional 33 acres were mapped by multi beam. Coverage for both surveys extended approximately 3000 ft along the shoreline (Figure 10).

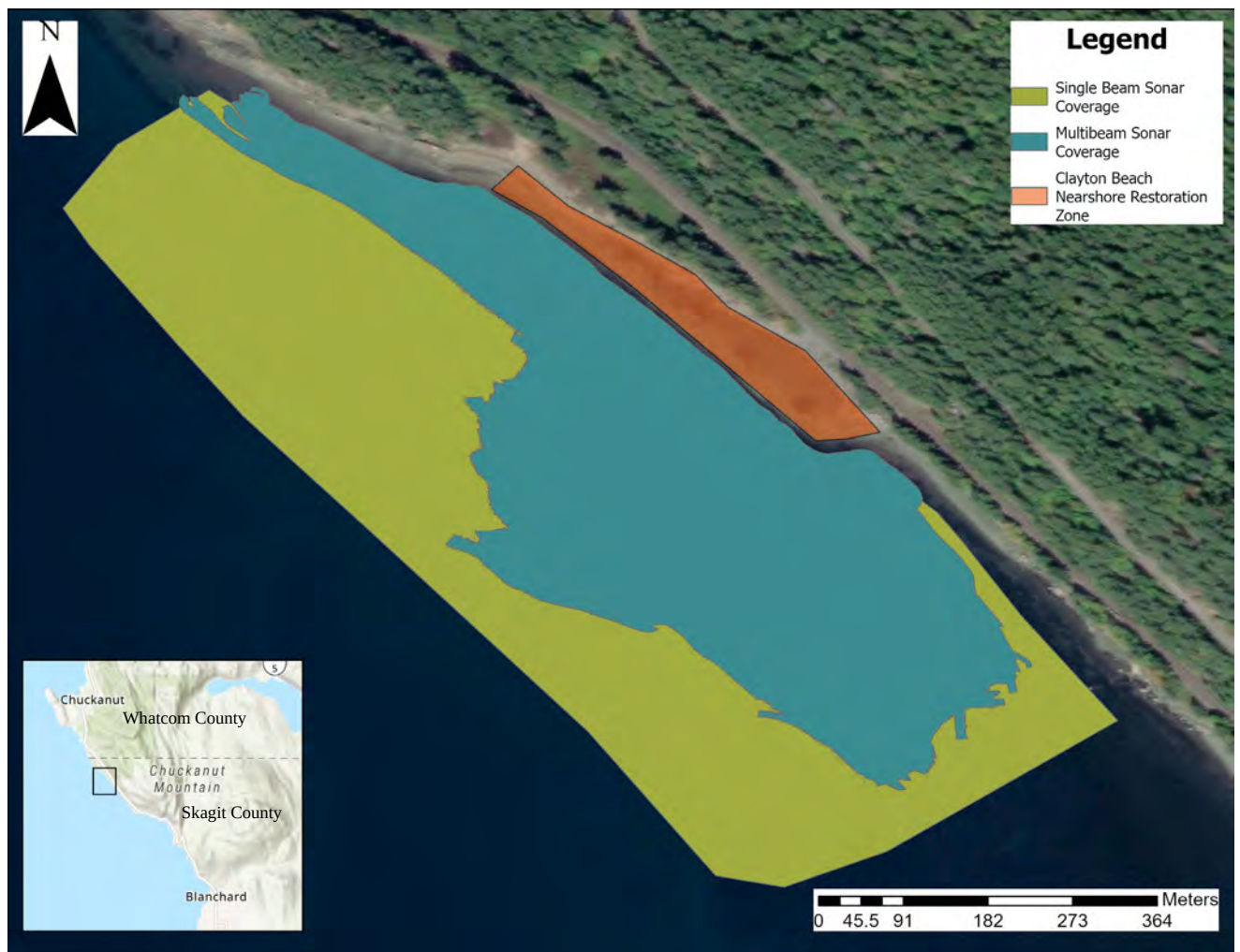


Figure 10. Survey footprints for both types of sonar applied to map the bathymetry and subtidal habitat at Clayton Beach and the offshore divot.

3.2 Bathymetry

Bathymetry from single beam depths was interpolated and is represented in (Figure 11). This surface has a low resolution of approximately 20 m², however, it indicates that in general, the sites' surface slopes steeper north of the nearshore restoration zone than it does southeast of it. To the north, the bathymetry falls from 0 ft MLLW to -8 ft. MLLW in 300 ft, is flat for 330 ft, then steeply descends out of frame (Figure 11). South of the divot, the seafloor appears to slope offshore at a shallower angle for 450 ft, falling from 0 ft. to -8ft. MLLW across that distance. The seafloor then flattens and remains at a constant depth of -9 to -10 ft. MLLW (Figure 11).

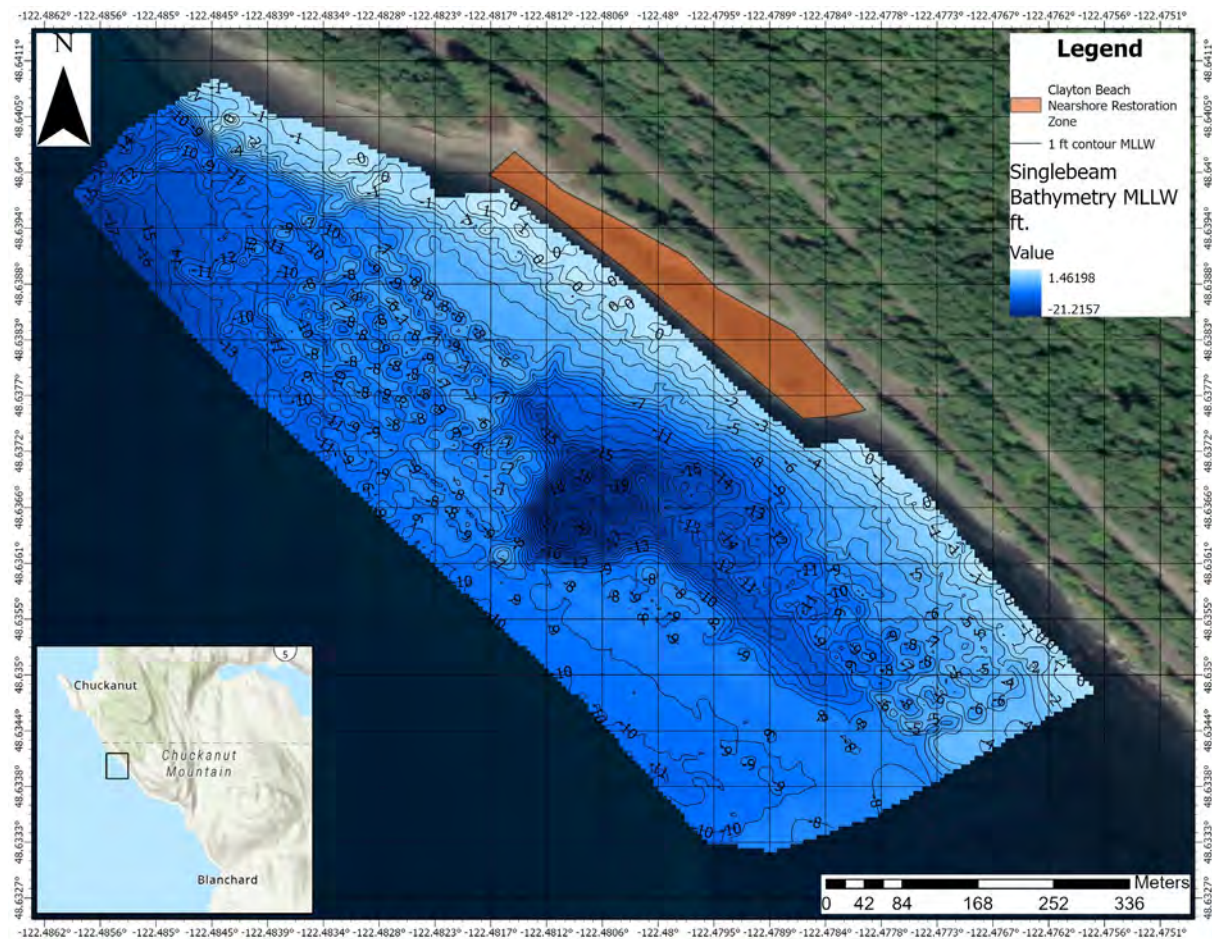


Figure 11. Bathymetric surface interpolated from single beam sonar data at Clayton Beach, Skagit County, WA.

3.2.1 Bathymetry – Nearshore Restoration Zone

The surface of the seafloor just offshore from the Clayton Beach riprap wall (at 0ft MLLW) follows a shallow slope of 0.9 degrees between the -2 and 0 ft. MLLW contour. This surface slope is more gradual than the seafloor just south of the Nearshore Restoration Zone, which slopes steeper at 1.1 degrees (Figure 11). This slope can be attributed as an influence from

the unvegetated dredge hole, as past this and at the edge of where data was collected, the slope returns to a shallower form (Figure 11).

3.2.2 Dredge Hole Bathymetry

Figure 12 is a surface that has been produced from multibeam sonar data. This surface accurately displays the shape and depth of the unvegetated dredge hole which is obvious as a deep depression south of the Clayton Beach nearshore restoration zone. At a resolution of 0.25 m², this surface gives a more accurate value of depth where vegetation is sparse or absent compared to the interpolation from single beam data in Figure 11. Where eelgrass was dense however, the multibeam sonar is unable to detect the true bottom depth.

Zones that are bare have a standard deviation of only 1 – 2 cm, whereas locations with eelgrass have up to 70 cm of error. In these zones, the single beam generated bathymetry surface can be used as a replacement for seafloor depth. Both bathymetric surfaces corroborate the maximum depth of the divot as -20 ft. MLLW and show that it is deepest at its northwest extent, becoming gradually shallower as one moves to the southeast. It appears to be completely void of any rock, boulder, or large feature.

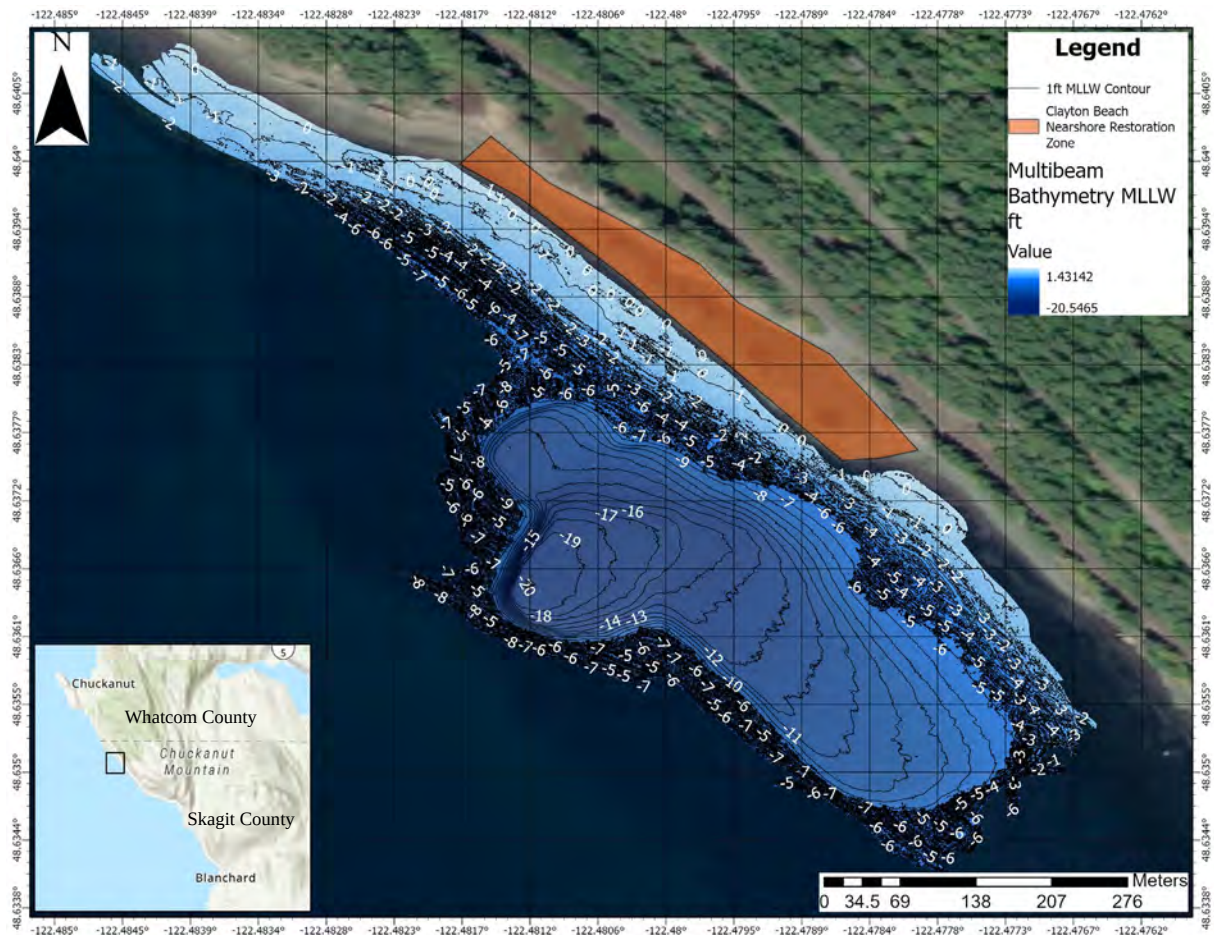


Figure 12. Bathymetry collected and produced by multibeam sonar at Clayton Beach, Skagit County, WA

3.3 Eelgrass Bed Distribution – General Trends

A dense eelgrass bed was found at depths between -1 and -10 ft. MLLW at Clayton Beach. In general, the percent cover of eelgrass is high in any zone we surveyed deeper than -1 ft. MLLW. Shallower than this, there are isolated locations where only 1- 25% cover (shoots present/m²) are found. These reductions in percent cover exist in only in localized pockets, and for the most part percent cover remains high with a mean of 60 ± 37 (SD) % cover (Figure 15).

Eelgrass canopy height is consistently long with a mean of 110 ± 21 cm (SD) up to -3 ft. MLLW (Figure 14). Shallower than this depth band, canopy height is shorter and more inconsistent– measured from 1 to 50 cm, with a mean of 31 ± 25 cm (SD) (Figure 14). The deep edge periphery of the bed at Clayton Beach is made up of shorter, less dense plants that are less than 50cm in length (Figure 14).

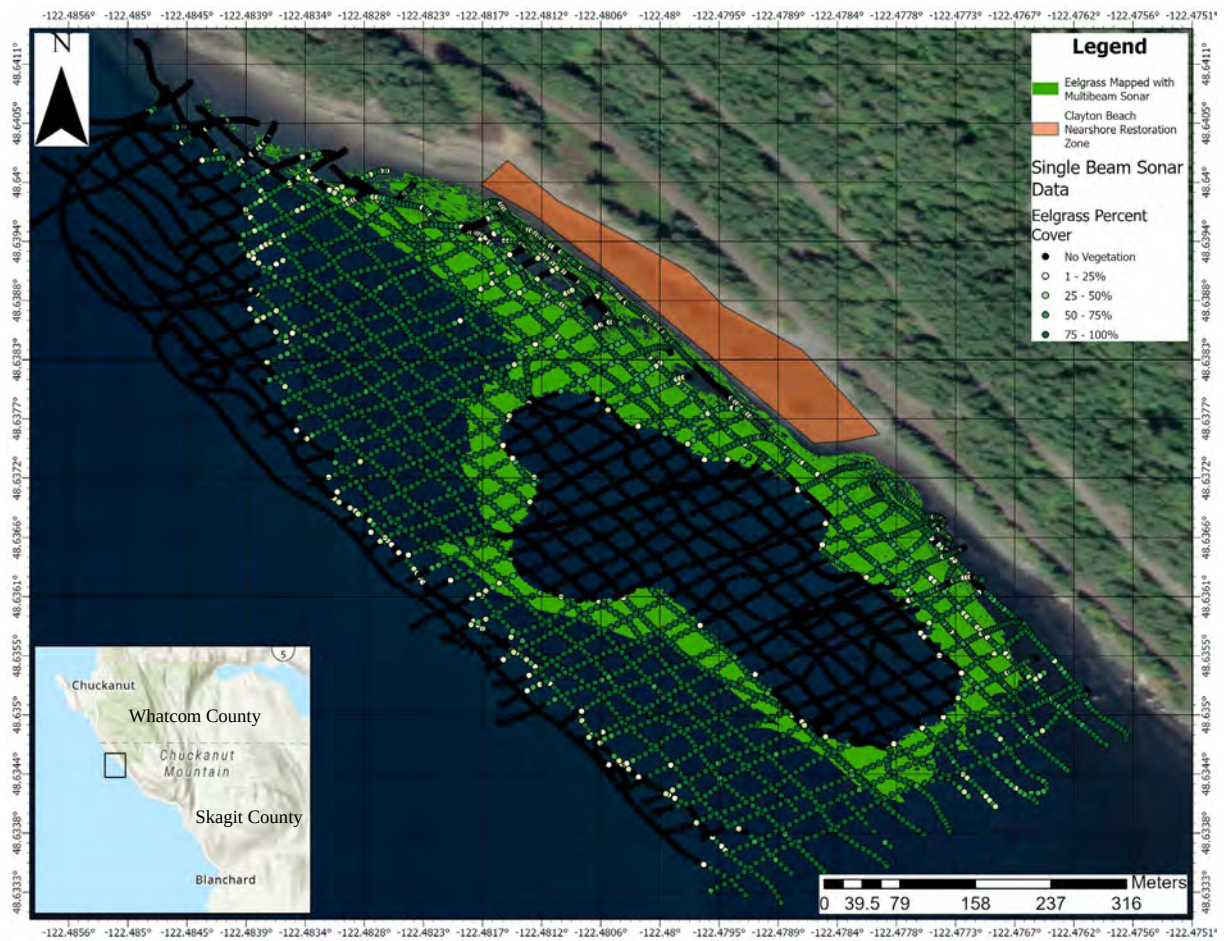


Figure 13. Eelgrass percent cover per m² from single beam sonar survey at Clayton Beach, Skagit County, WA.

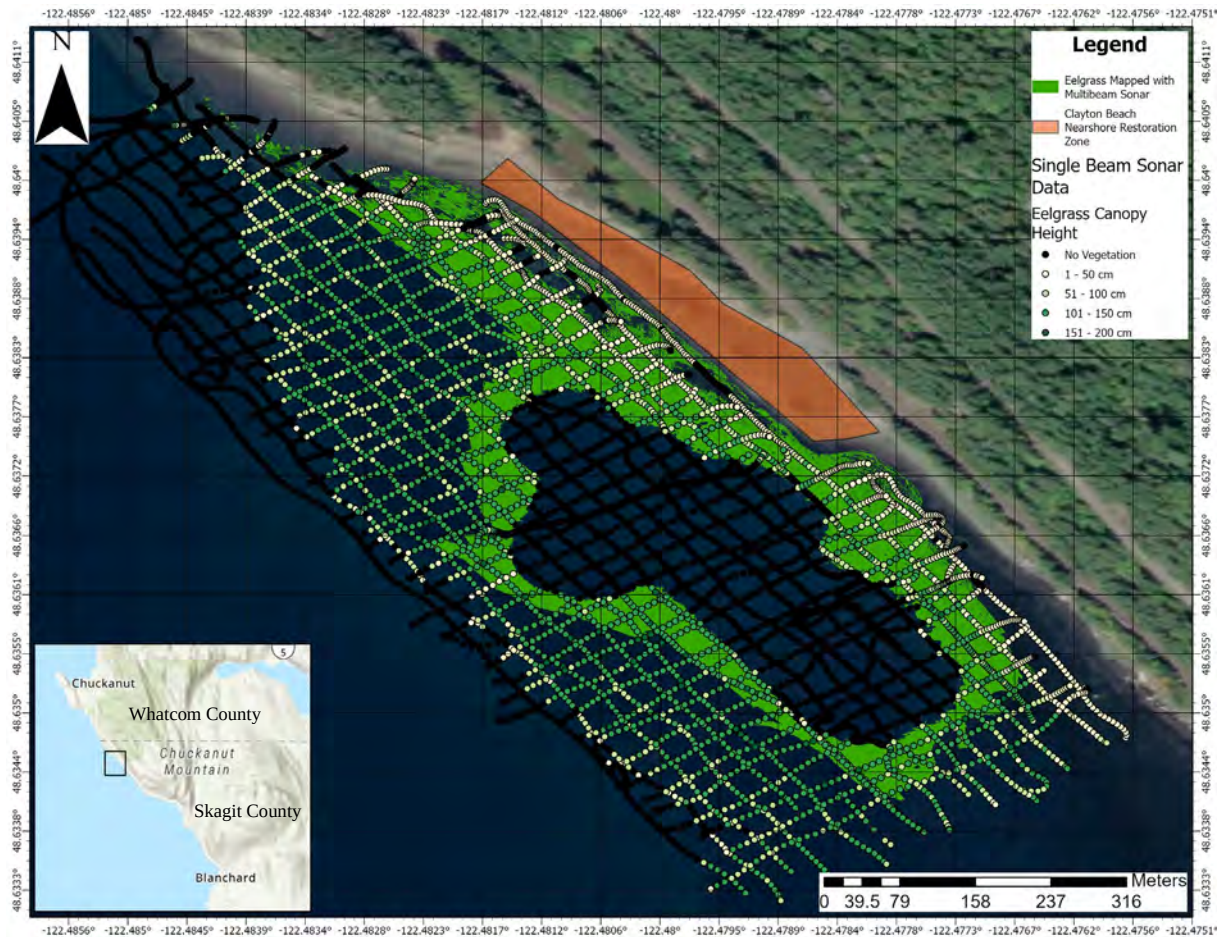


Figure 14. Eelgrass blade length from single beam sonar survey at Clayton Beach, Skagit County, WA.

3.3.1 Clayton Beach Restoration

Closer to the restoration zone, Eelgrass is patchily distributed within a buffer of approximately 130 ft. from the riprap wall, where large unvegetated patches are present and obvious in both multibeam and single beam data (Figure 17). These unvegetated patches sum to approximately .68 acres of unvegetated bed-land. The eelgrass offshore from armoring and out to approximately -1 ft. MLLW has an average percent cover of 55.4 ± 36.6 (SD). The patchy framework extends to this point (-1 MLLW ft), and deeper than this (dredge hole excluded) it becomes a more continuous bed.

Due to hazards along the shoreline, we did not extend our multibeam survey as close to shore than we did in zones with riprap armoring. This makes a comparison of the unarmored shoreline's eelgrass bed morphology difficult. Data from the single beam sonar however indicates that eelgrass in the unarmored section of our survey (hashed box Figure 17) extends shallower than -1 ft. MLLW without the large voids that are seen offshore from the armored trestle. (Figure 16). Above -1 ft. MLLW, the eelgrass in this unarmored section is also more dense (average percent cover equal to 83.4 ± 23 (SD)).

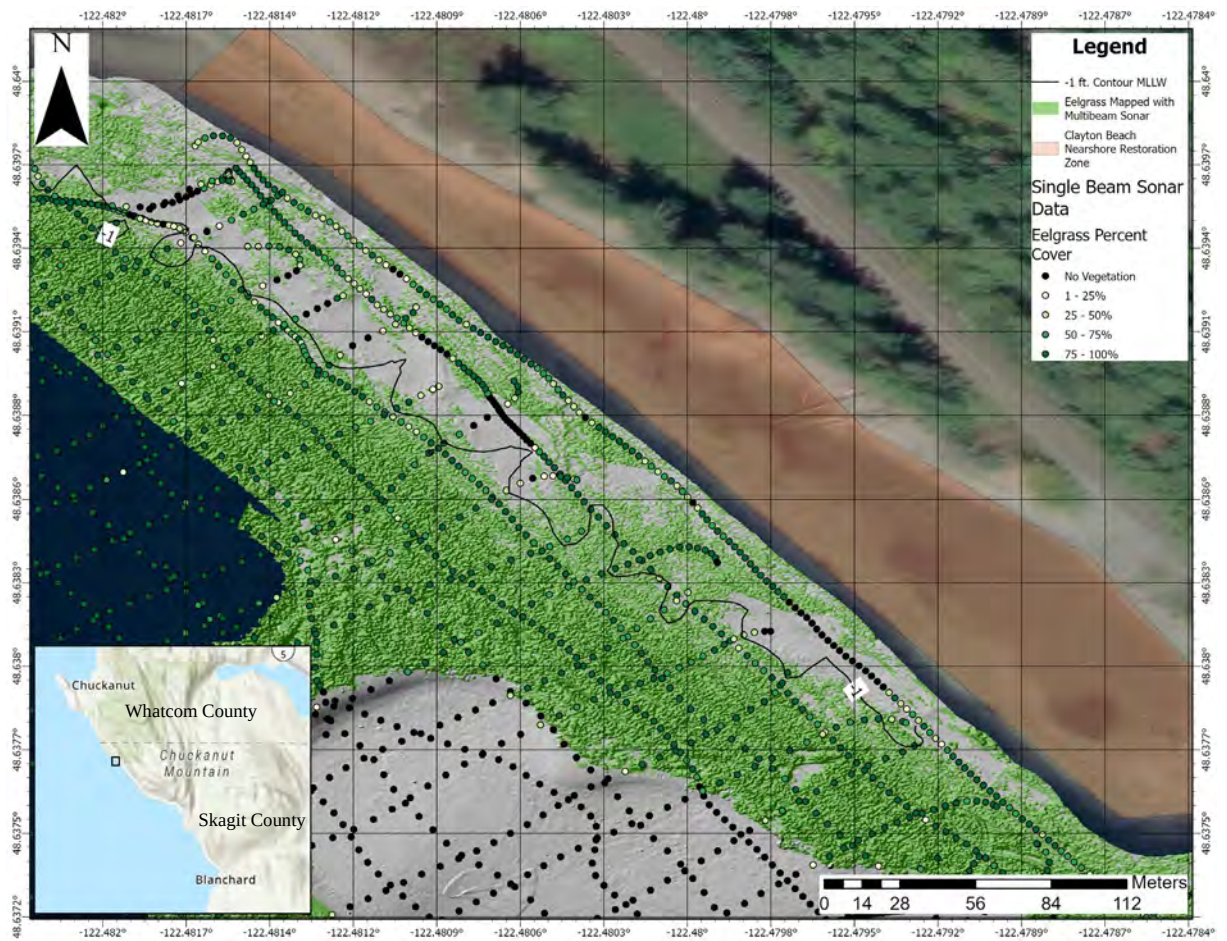


Figure 15. Eelgrass distribution offshore the Clayton Beach restoration zone.

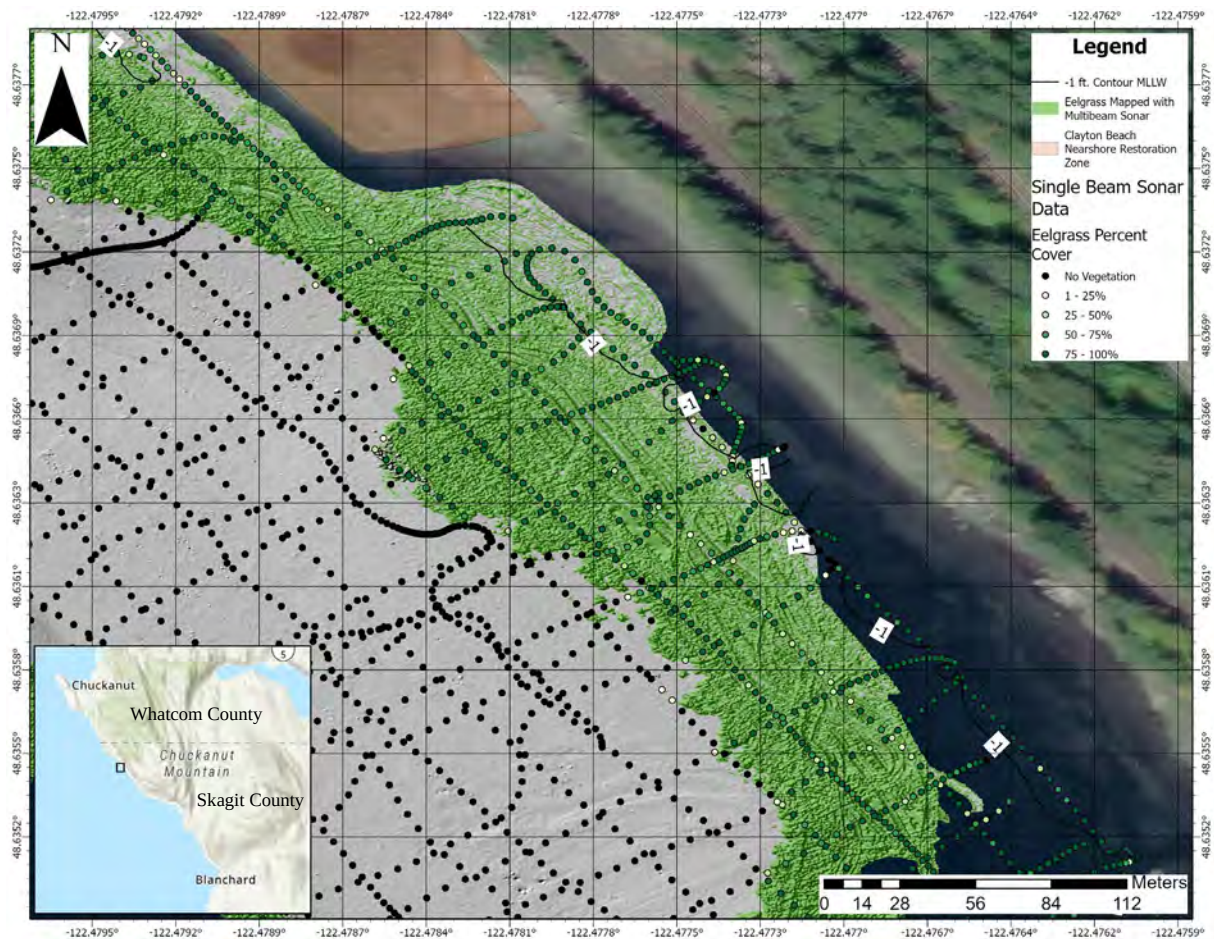


Figure 16. Eelgrass distribution south of restoration zone offshore unarmored shoreline.

3.3.2 Dredge Hole

The dredge hole yields 13.9 acres of unvegetated bed-lands, surrounded by dense eelgrass on all sides (Figure 17). Figure 18 A – D are cross sections of the divot taken from multibeam data. Eelgrass canopy appears obvious in these images as a “spiked” surface after moving from a smooth non – vegetated divot. Apparent in these cross sections is that eelgrass grows to different depths at different locations along the edge of the divot. In some locations (shallow southeast edge), it ceases to grow at approximately -5 or -6 ft. MLLW, whereas in other locations (western deep edge), eelgrass ceases to grow at the -9 ft. interface. These images corroborate previous figures and show that the divot is more steeply excavated on its west side compared to the east side (Figure 17).

Video used to “truth” single beam and multi beam sonar identified a thin algal mat inside the dredge hole (which appeared to be decomposing at the time of this late summer survey). It is likely that the dredge hole acts as a sink for seasonal decomposition during the summer, accumulating algae and detritus (Figure 20 and Figure 21).

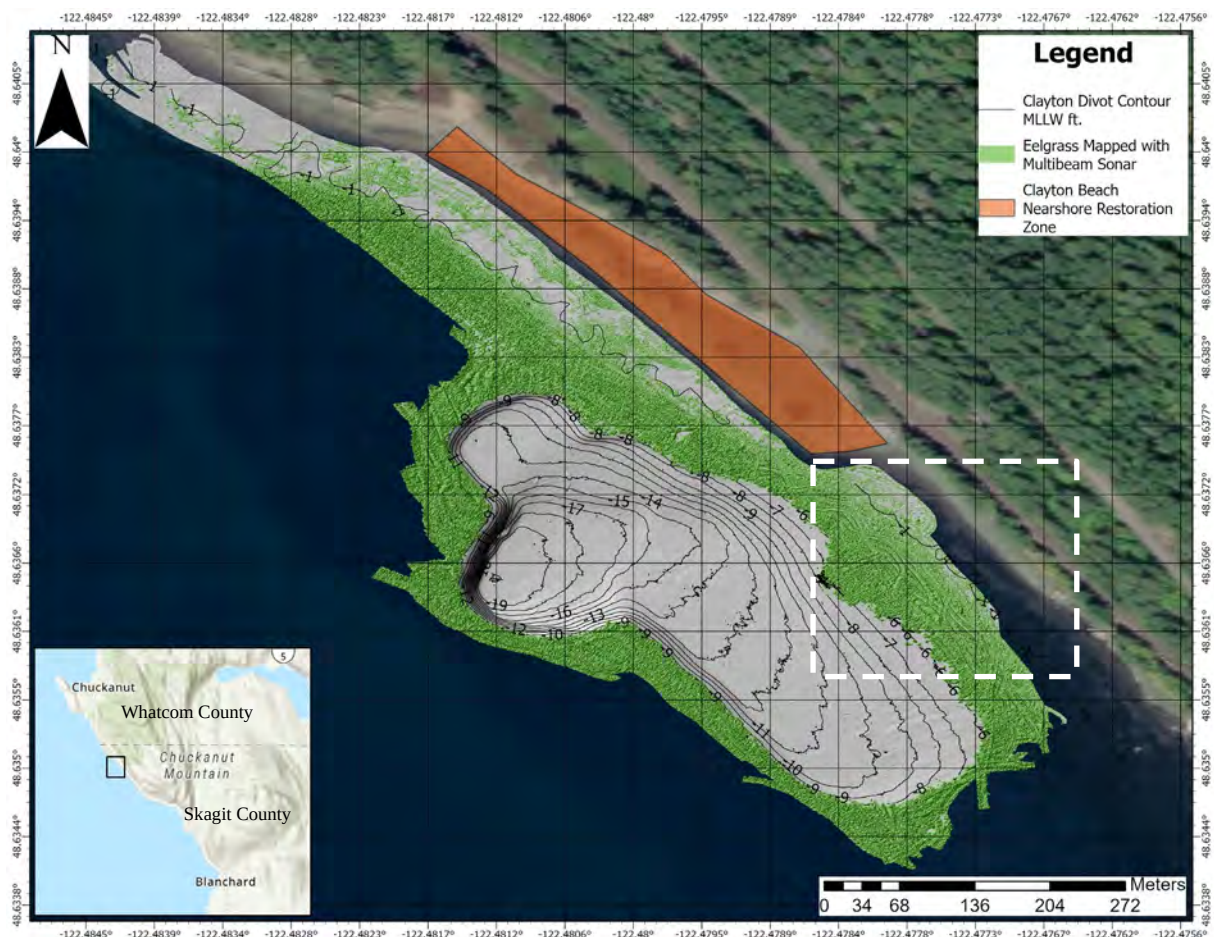
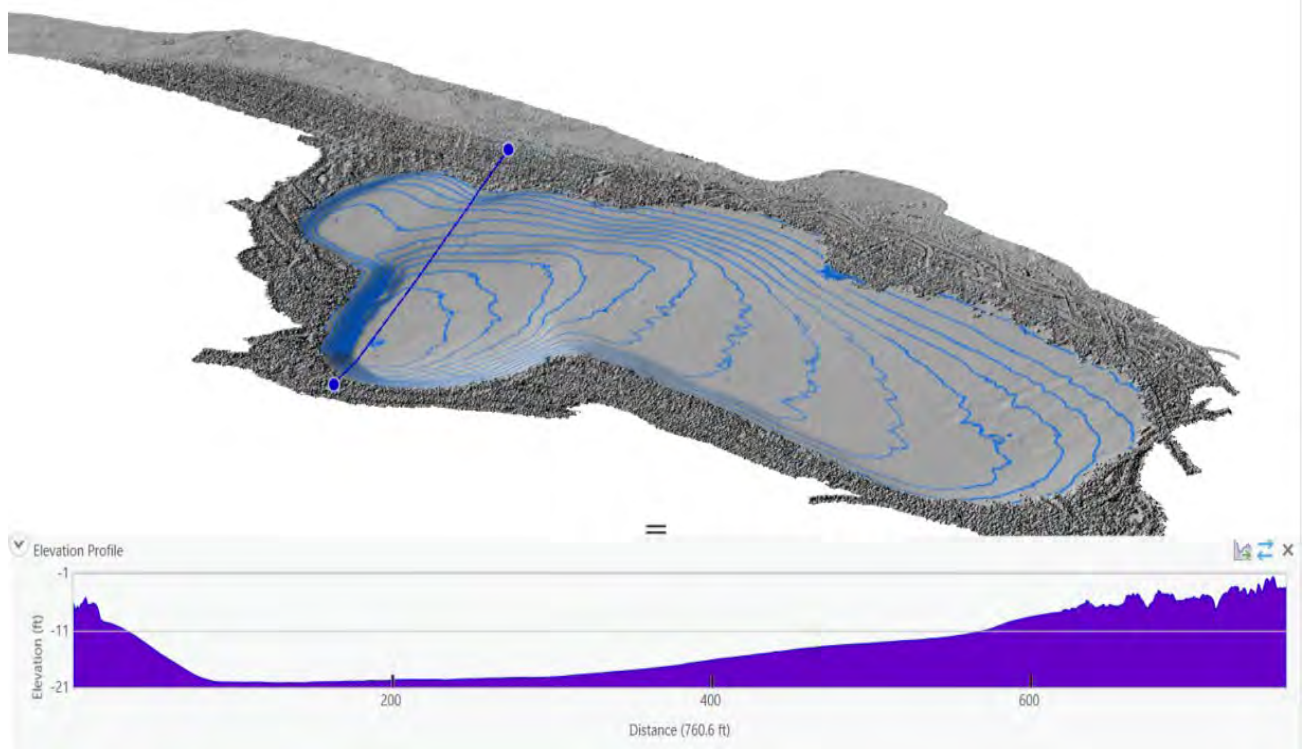
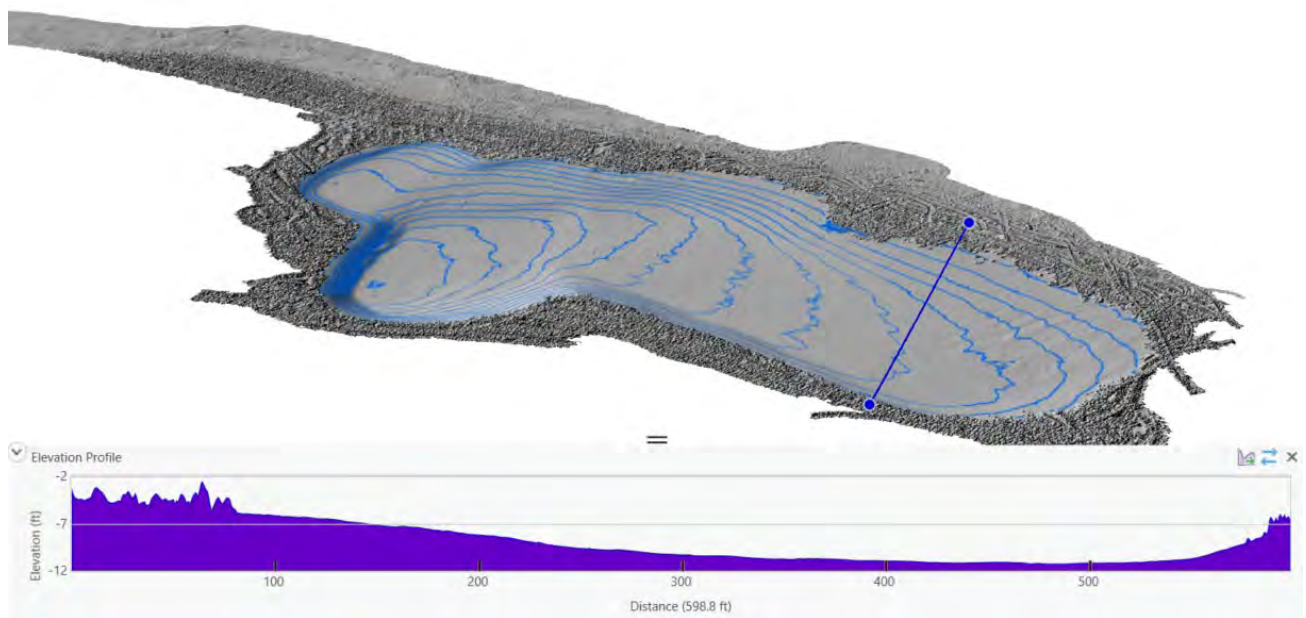


Figure 17. Bathymetry of the dredge hole and surrounding eelgrass at Clayton Beach, Skagit County, WA. Patchy eelgrass bed exists shallower of -1 ft. MLLW, whereas the eelgrass bed grows more continuous to a depth of approximately -10 ft (MLLW). The hashed white box indicates a section of the survey that was completed in front of unarmored shoreline.

A.



B.



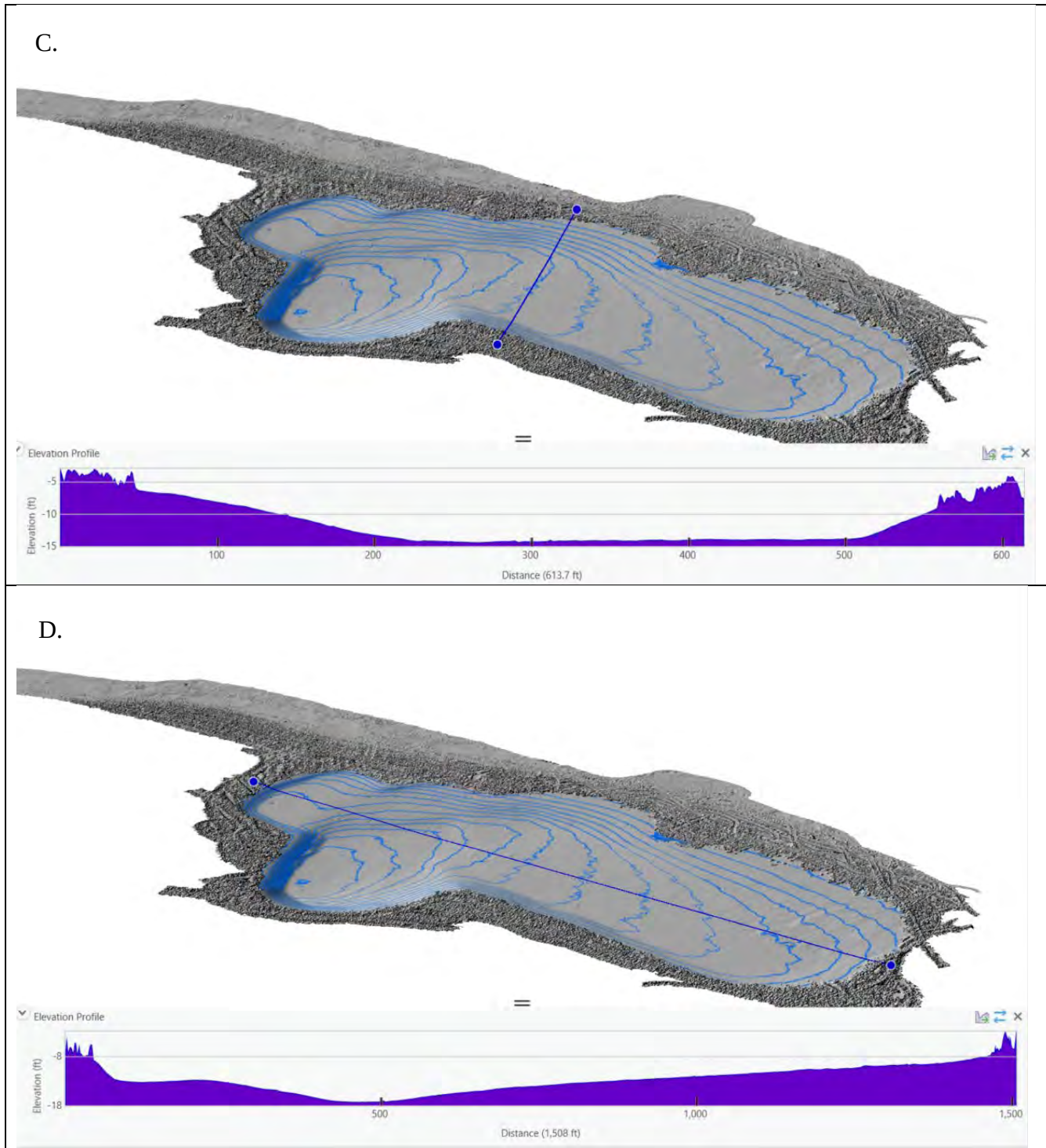


Figure 18. Cross Sections of the divot offshore from Clayton Beach, Skagit County, WA.



Figure 19. Dense eelgrass (*Zostera marina*) at Clayton Beach.



Figure 20. Video from within the Clayton Beach dredge hole, Skagit County, WA.



Figure 21. Video from within the Clayton Beach Divot, Skagit County, WA.

3.4 Dredge Hole Volume Estimate

Two raster surfaces were used to calculate the total volume of the divot. The first was an unaltered 0.25 m² resolution raster of bathymetry for all unvegetated portions of the divot (Figure 22A). The second was an interpolated surface that estimated a natural slope profile as if the divot did not exist (Figure 22B).

The volume between these two surfaces was calculated as 236,435 ± 5,859 m³. This is the total quantity of fill needed to bring the seafloor up to a suitable height for eelgrass restoration. For reference – this equates to roughly 8,700 full size school busses needed to fill the hole.

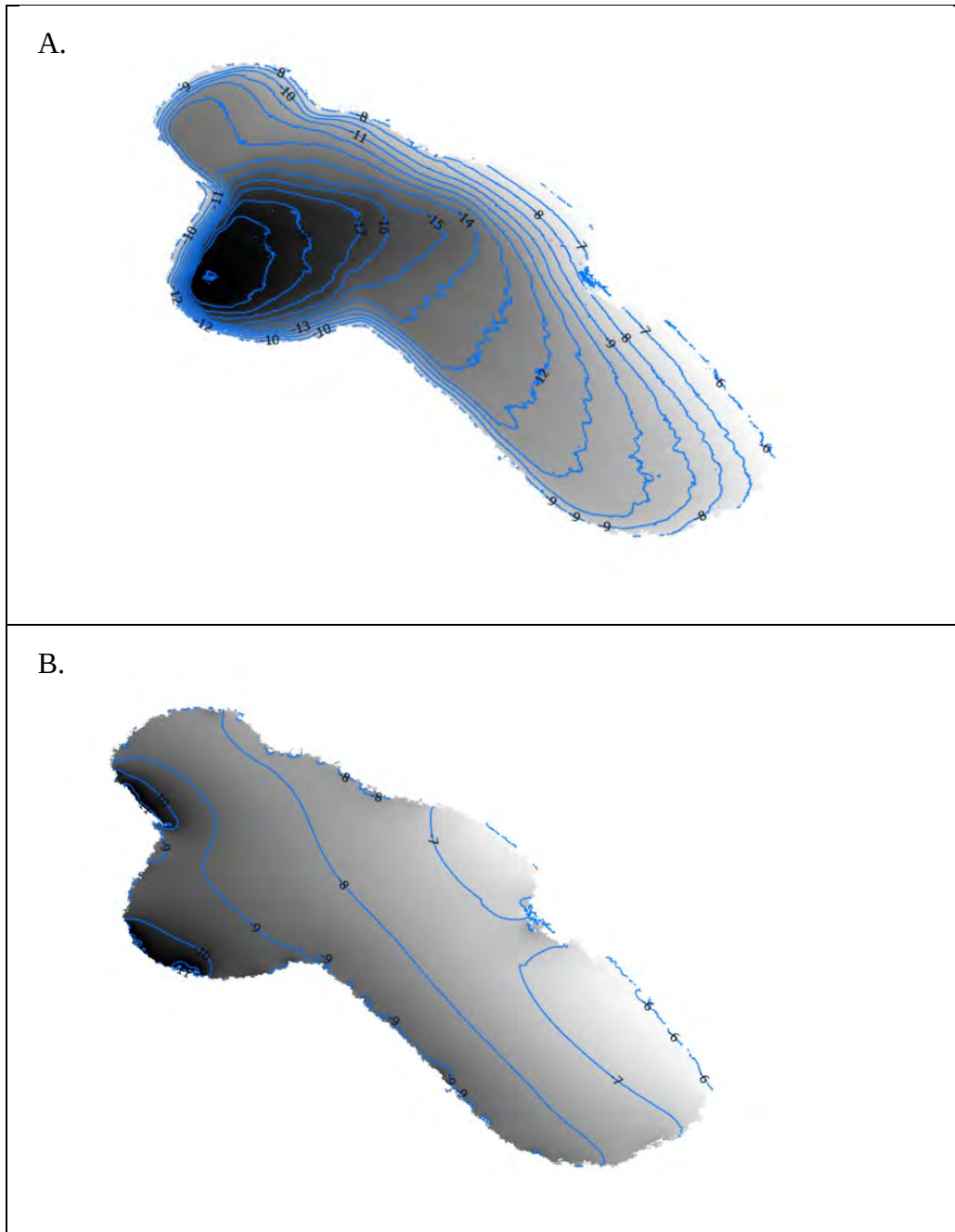


Figure 22 A. Current Clayton Beach Divot Bathymetry. Contours in MLLW ft.

Figure 19 B. Interpolated bathymetry of filled Clayton Beach Divot. Contours in MLLW ft.

4 Conclusion

In late summer of 2023, DNR's Aquatic Assessment and Monitoring Team mapped a zone surrounding a large restoration project at Clayton Beach, Larrabee State Park, WA, for bathymetry and eelgrass presence. A dense eelgrass bed surrounds the Clayton Beach restoration site and was found to abut the Clayton Beach dredge hole at bathymetric contours from -6 to -9 ft. MLLW.

This eelgrass bed was found to extend relatively high into the intertidal (up to 0 ft. MLLW), and down to -10 ft MLLW at its deep edge. Because eelgrass grows up to the riprap restoration site (at 0 ft. MLLW), it is possible that after removal and re-grading of riprap, pilings, and sediment, that eelgrass will move into this newly restored zone. Based on bathymetry and the certainty that eelgrass will grow up to 0 ft. MLLW, this may be more successful if the newly restored zone is designed like the surrounding natural shoreline and graded to remain flat until meeting the steep beach.

Our surveys detected large patches (~ .68 acres) of unvegetated seafloor in front of the trestle (riprap) restoration zone. These large patches are not evident in locations without shoreline armoring. The absence of eelgrass in localized patches could be due to several reasons, with some that are related to the presence of the current trestle. Thom et al. (2011) notes that while the impacts to eelgrass from armoring are not well studied, eelgrass will eventually be negatively affected by substrata changes associated with the reduction in fine sediment delivery to the beach. In the case of Clayton Beach, the absence of fines could be due to a scouring effect of finer sediments related to increased wave energy on the armored wall. We were not able to collect sediment samples at the base of the armored wall, and so a confirmation of this hypothesis cannot be tested. If true, the removal of armoring and recontouring of the seafloor could promote natural restoration of fine sediments back into the unvegetated patches that currently exist, making these patches more suitable for eelgrass.

In addition to this new shoreward expansion, the Clayton Beach divot presents a unique opportunity to restore 13.9 acres of eelgrass to Puget Sound. This aligns with the Statewide Kelp Forest and Eelgrass Meadow Health and Conservation initiative to conserve and restore 10,000 acres of kelp and eelgrass habitat by the year 2040 (WADNR 2023). To restore the original seafloor slope at the divot, it is estimated that approximately 236,435 m³ of sediment will be needed. While it is not currently known where this large quantity of fill will come from, data from large scale dredged capping projects will identify important considerations for this restoration. A primary factor in divot restoration success will be to work around the consolidation time of deposited sediments. After sediment deposition, it will be important to allow consolidation time for successful eelgrass shoot plantings. Depending on the void ratio (the volume of voids in any sediment relative to the volume of solids) of the fill, and the total depth of deposit, the deposited sediment will consolidate substantially. Based on data from the

US Army Corps of Engineers, fill may continue to consolidate for an extended period. A report on consolidation time for different sediment void ratios indicates that subsistence and settling of material will continue for approximately 3000 days (8.2 years) post deposit regardless of sediment void ratios. Over this time, a surface may subside anywhere from 2 to 5 feet or more (Rollings 2000).

In addition to settlement time, it will be important to ensure a uniform seafloor surface is restored within the divot. Eelgrass is light limited, and the surface depth of new material should uniformly slope across the current depression at a constant from -6 to -9 ft. MLLW. It must not exceed -10 ft. MLLW in depth (the natural deep edge extent of eelgrass at the site). If a uniform slope is not achieved, a patchwork may occur where depressions in the surface exist, instead of a dense meadow of successfully restored eelgrass.

DNR plans to continually monitor the Clayton Beach restoration and divot zones for eelgrass bed distribution and seafloor bathymetry. The data compiled for this report will be included in future analyses of restoration success at the site. We thank our partners in this project – the Northwest Straits Foundation, the Whatcom County MRC, the Skagit County MRC, and Washington State Parks, and appreciate the support and opportunity to carry out this important work.

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