Natural Shoreline Infrastructure in Humboldt Bay for Intertidal Coastal Marsh Restoration and Transportation Corridor Protection: 50% Design Report

Prepared For: Humboldt County Department of Public Works

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Cover Photos: Comparison of project area from circa 1940s (left) and current (right). Photo sources, HSU Library and Brad Finney.

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PART I - INTRODUCTION

1. Background

1.1 Overview of Project Concept

This report evaluates the feasibility of a project to develop natural shoreline infrastructure, also known as nature-based adaptation strategies or nature-based solutions, along a vulnerable segment of Humboldt Bay shoreline adjacent to the Highway 101 transportation corridor between Eureka and Arcata. Transportation infrastructure, utilities, businesses, low-income residential areas, and wildlife areas are protected by this shoreline segment and a recently completed adaptation plan (Humboldt County 2021) identified the substantial risks to critical resources from continued shoreline erosion and coastal flooding.

The California Natural Resources Agency defines natural shoreline infrastructure (NSI) as “using natural ecological systems or processes to reduce vulnerability to climate change related hazards while increasing the long-term adaptive capacity of coastal areas by perpetuating or restoring ecosystem services” (Newkirk, 2018). The California Coastal Commission defines nature-based adaptation strategies (NBAS) as a resilient approach to climate adaptation that “incorporate ecological principles into shore protection strategies to support multiple benefits, including hazard adaptation and mitigation, natural resource resilience and enhancement, and recreation and scenic resource preservation (Vu, 2021). The Federal Highway Administration (2018) encourages nature-based solutions to prevent coastal highway flood damage and/or disruption by implementing approaches that mimic characteristics of natural features and protect or improve the build environment while maximizing the habitat value associated with the natural system. Similar terms include green infrastructure and living shorelines. For the purpose of this report the term NSI will be used to represent this broad suite of terms and definitions.

Although highly compelling conceptually and encouraged by public agencies, NSI projects are still considered innovative and relatively few projects have been implemented in California. The NSI approach face challenges, limitations, and tradeoffs which must be addressed in order to identify feasible projects. Feasibility encompasses multiple dimensions including technical feasibility (effectiveness at achieving goals and objectives), economic feasibility (capable of being funded), legal and regulatory feasibility (capable of receiving permits and approvals), and social feasibility (consistent with core community values). Each NSI project will have a unique design based on the geomorphic conditions, physical processes, and habitat types at a given site. One of the primary technical challenges is to understand the dynamics of natural systems at a specific location and how they have been disturbed by human intervention over time. Other challenges include demonstrating an overall net ecological benefit to the intertidal habitats affected; developing site-specific designs with interdisciplinary teams; and aligning the innovative approach with existing permitting paradigms. This feasibility study was developed specifically to address these challenges. The overall goals of the study are to:

- Integrate the natural flood risk reduction properties of salt marsh into the shoreline management strategy for the Eureka-Arcata Highway 101 transportation corridor.
- Perform site characterization and prepare preliminary designs for a project utilizing tidal benches or similar NSI techniques.
- Lay the groundwork for an innovative approach to restore and perpetuate intertidal coastal marsh, increase community resilience to flooding and demonstrate the use of natural ecological systems for sea level rise adaptation.

1.2 Project Location

The project is located along an approximate 1.25-mile section of the eastern shoreline of North Humboldt Bay or Arcata Bay, situated between Bracut and Brainard adjacent to Highway 101 (Figure 1 and Figure 2). Humboldt Bay is the second largest enclosed bay (approximately 17,000 acres) within California and supports more than 250 species of birds, 95 species of fish, 50 species of mammals, 20 species of reptiles and amphibians, and 300 invertebrates with its diverse subtidal and intertidal habitats (Harbor District 2007).

The project area includes intertidal mudflats, salt marsh, partially eroded rail prism and the alignment of the planned Humboldt Bay Trail South (HBTS) situated between the rail prism and Highway 101. The project area spans both County of Humboldt and City of Eureka jurisdictions and bisects multiple parcels (Exhibit 1.1). Note all referenced Exhibits are located within Appendix A.

The project area shoreline provides a tidal barrier between the Arcata Bay and an approximate 1,000 acres former tidelands comprised of various land uses with an interconnected drainage network and protected by levees ("diked former tidelands") referred to as Cell A (Humboldt County 2021). Cell A includes the Jacobs Avenue commercial and residential area bounded by Eureka Slough and Highway 101, the Murray Field airport, Mid-City Motor World, CDFW Fay Slough Wildlife Area and Brainard. Important utility infrastructure also traverses Cell A including Pacific Gas & Electric (PG&E) natural gas and electrical distribution systems, regional communications, and the City of Eureka water and sewer systems. The transportation corridor is a critical land use within the basin, comprised of Highway 101, future alignment of the HBTS, and the North Coast Railroad Authority (NCRA) right of way. Highway 101 is the primary connector between the cities of Eureka and Arcata, with average annual daily traffic of nearly 40,000, is the most traveled route in Humboldt County, and is managed as a Safety Corridor to limit speed to 50 miles per hour (Caltrans 2017). The Humboldt Bay Trail, which is partially completed north and south of project area, will be a significant non-motorized connector for the region, and part of the Pacific Coast Bike Route.

Figure 1 Project shoreline between Brainard and Bracut showing Highway 101, rail prism and variable intertidal shoreline conditions facing south at Indianola Interchange (left) and north (right). Photo source, HCDPW.

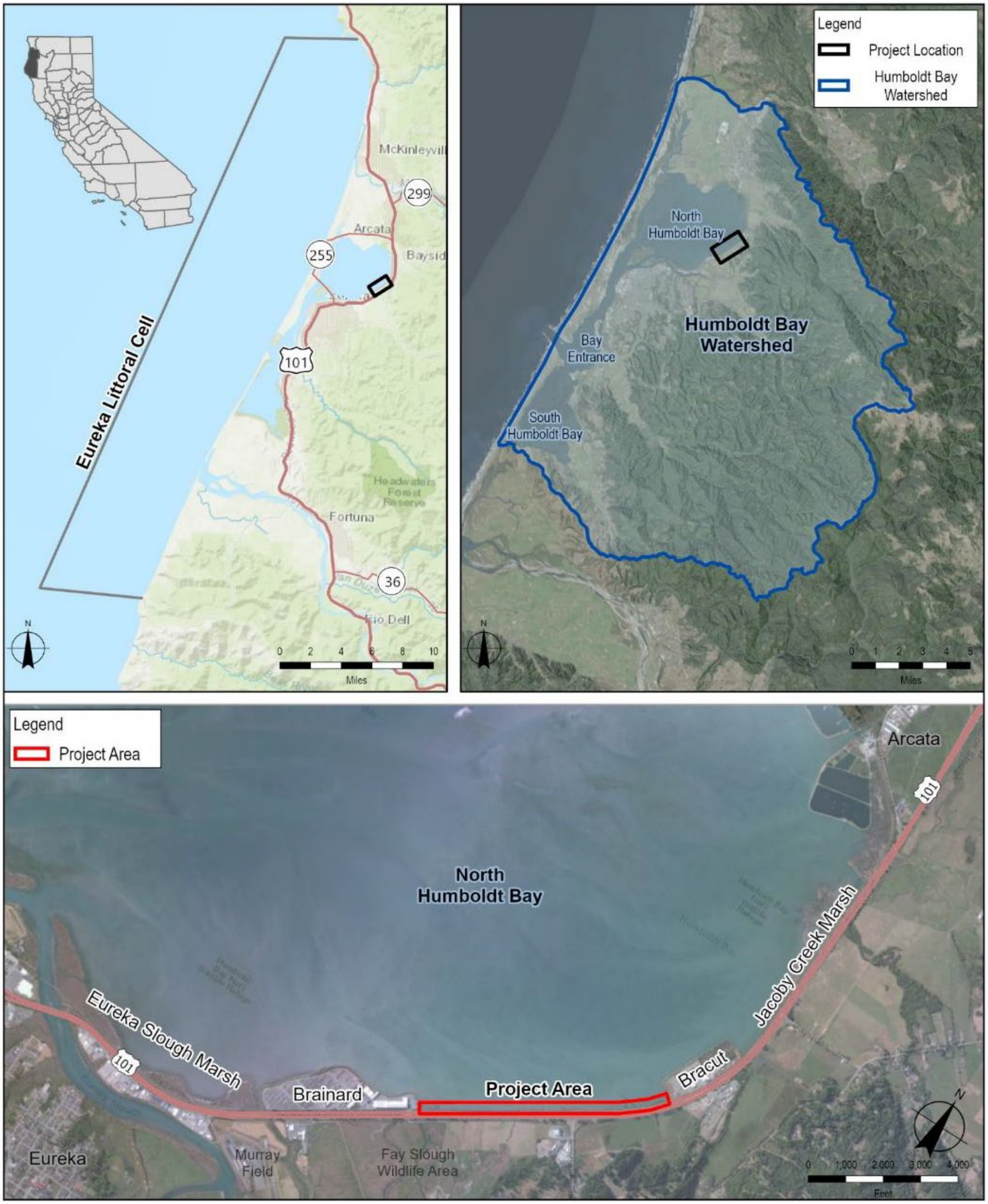

Figure 2 Location of project shoreline on North Humboldt Bay

1.3 Project Area Vulnerability

Numerous studies have identified the project shoreline as vulnerable to sea level rise and continued coastal erosion and flooding. The most recent studies include the Sea Level Rise Adaptation Plan for Eureka Slough Hydrographic Area (Humboldt County 2021), Sea level Rise Vulnerability and Adaptation Report for Humboldt Bay Trail South (ESA 2018) and the Shoreline Condition Assessment for Humboldt Bay Trail South (GHD 2017). These studies have built upon previous sea level rise vulnerabilities (Laird 2015 and NHE 2015) to increase the understanding of coastal erosion and flood risk within the project area and provide adaptation strategies to reduce current and future risk associated with sea level rise. Coastal flood and erosion risk and adaptation strategies identified in the 2021 Sea Level Rise Adaptation Plan for Eureka Slough Hydrographic Area are summarized below.

1.3.1 Coastal Erosion Risk

Anthropogenic interventions and natural processes have contributed to salt marsh and rail prism erosion within the project area. The rate of salt marsh and rail prism erosion within the project area has been documented (see Section 3.1) to be more extensive relative to the shorelines both north and south of the project area at the Jacoby Creek and Eureka Slough marshes, respectfully. Natural processes such as sediment supply/distribution, sea level rise, tidal currents, and wind generated waves can all influence salt marsh persistence. While the shoreline exposure to these processes differs along the eastern shoreline of the Bay, the relative higher rates of erosion of the project shoreline are likely attributed to the early intervention of marsh edge leveeing that did not occur at the Jacoby Creek and Eureka Slough marshes. This report further explores the previous anthropogenic interventions and physical processes comparatively between the project shoreline and shorelines to the north and south to substantiate the causal effects. Under current conditions, the remaining salt marsh provides a buffer in reducing wind-generated wave energy along the rail prism. Rail prism conditions within the project area were mapped in 2017 to support the HBTS project (GHD 2017) and it was determined the most severe rail prism erosion exists where salt marsh is absent, and where salt marsh has persisted, rail prism erosion is less severe (Figure 3). Rail prism erosion within the project area has resulted in displacement of the ballast fill material and has effectively lowered the prism crest elevation from the built condition, thereby increasing flood risk landward (Figure 4).

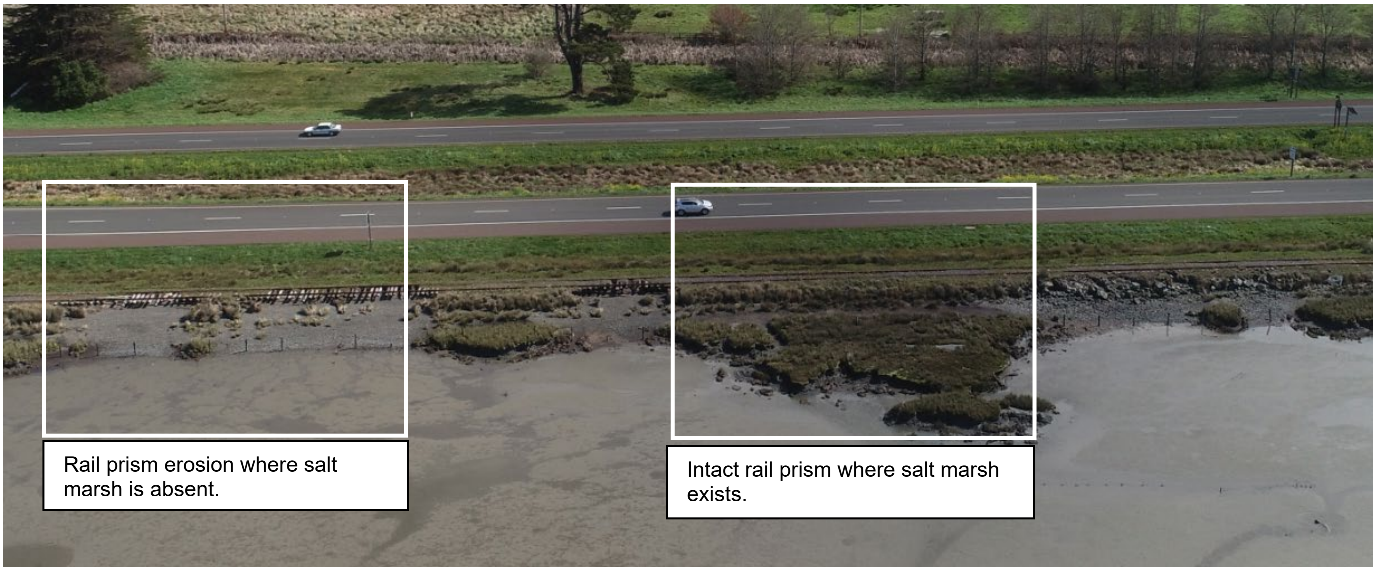

Figure 3 Project shoreline showing rail prism erosion on the left correlated to the absence of salt marsh, while on the right, intact salt marsh has prevented erosion. Photo source, HCDPW.

Figure 4 Rail prism erosion and tidal overtopping in project area. Photo source, HCDPW.

1.3.2 Coastal Flood Risk

As a result of the rail prism erosion within the project area, the rail prism crest elevation within the project area is lower relative to the remaining perimeter shoreline elevations protecting Cell A. Consequently, the primary source of tidal flooding into Cell A initiates from the project shoreline and is conveyed through an internal drainage network with two outlets to Eureka Slough (Figure 5). As previously described, critical resources within Cell A are vulnerable to this flooding source given the interconnected interior drainage system, limited drainage outfalls and low interior elevations.

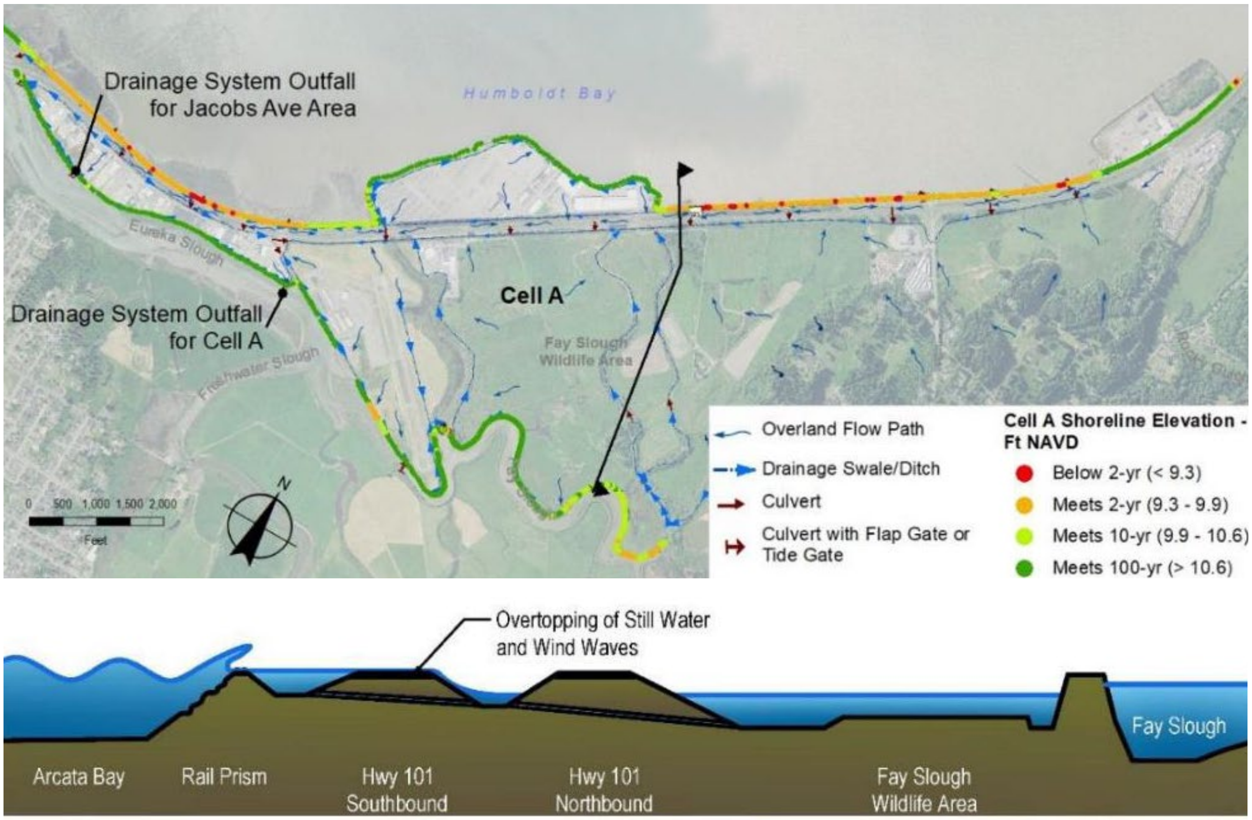

Figure 5 Cell A shoreline elevations, interior drainage network and conceptual cross-section showing rail prism overtopping and flooding.

The projected frequency of extreme tidal still water levels (NHE 2015) and wind-wave events were developed for the HBTS project (ESA and GHD 2018) and further assessed in the Sea Level Rise Adaptation Plan for Eureka Slough Hydrographic Area (Humboldt County 2021). Extreme tidal still water levels in the project area relative to the rail prism and Highway 101 elevations are shown in Figure 5 and Figure 6. The frequency and extent of tidal flooding within Cell A resulting from overtopping of the project shoreline are summarized below.

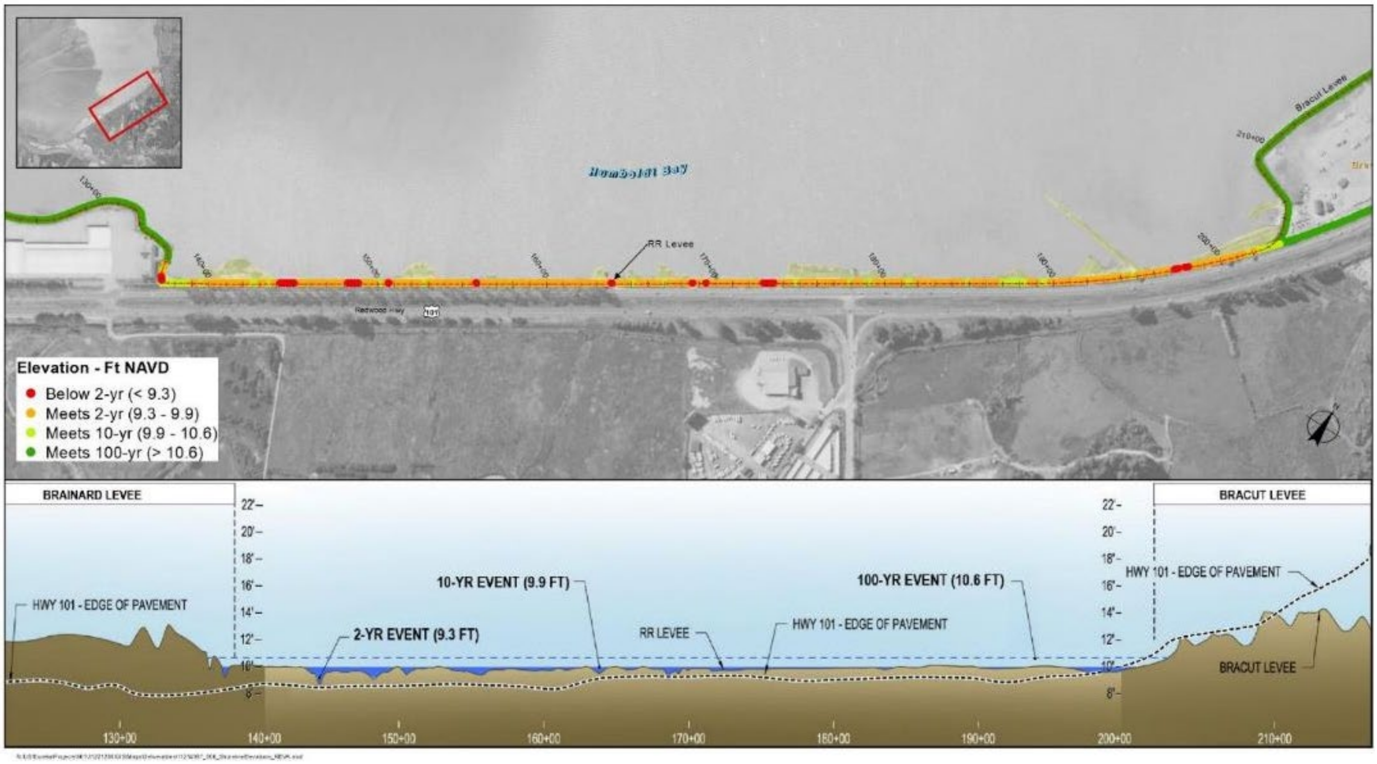

Figure 6 Profile of Highway 101 and existing rail prism with recurrence still water levels (NHE 2015, ESA 2018 and Humboldt County 2021).

Overtopping of the rail prism in the project area begins at a tidal still water level of approximately 9.1 feet (NAVD) which is approximately the astronomical high tide also referred to as the annual King Tide. Water levels of 9.5 to 10 feet (NAVD) which have a recurrence interval of approximately 10-years mark the initiation of overtopping of the entire rail prism in the project area resulting in inundation of the Caltrans drainage channel between the rail prism and Highway 101 southbound shoulder. The drainage channel is capable of temporarily storing and conveying a relatively small volume (approximately 100 acre-feet) of tidal floodwaters; however, water levels between 10 and 10.5 feet (NAVD) will initiate flooding on Highway 101, as was experienced on December 31, 2005. This event was also influenced by wind-generated waves and resulted in temporary closure of Highway 101 and erosion damage to the rail prism (Figure 7).

Figure 7 Flooding and closure of Highway 101 within the project area from wind wave and tidal storm event (December 31, 2005). Photo source, HCDPW.

Water levels of 10.6 feet correspond with the 1-percent annual chance (100-year recurrence) still water event and would cause approximately 940 acre-feet of floodwaters to inundate Cell A, resulting in temporary closure of Highway 101 southbound. Water levels of 11.6 feet (100-year plus 1-foot of sea level rise) mark a significant increase in the extent of overtopping and conditions that have a high potential to create a breach of the rail prism due to erosion within the project area. Given the lower elevation of the rail prism relative to the remaining shoreline elevation around Cell A, the volume of flooding from overtopping of the rail prism is an order of magnitude greater than the volume of overtopping from the balance of the shoreline structures protecting Cell A. For example, a water level of 11.6 feet (NAVD) results in 4,700 acre-feet of inundation over the rail prism and 300 acre-feet over the balance of the Cell A shoreline perimeter. Additionally, the highway is generally lower in elevation relative to the rail prism within the project area, so widespread flooding that exposes the highway and motorists to direct flooding would occur at tidal water levels between 10.6 and 11.6 feet (NAVD). At these higher water levels, the Caltrans drainage channel is overwhelmed and tidal waters will flood the southbound lanes of Highway 101. The median drainage system conveys flood waters to the drainage channel along the eastern edge of the northbound lanes, resulting in the continued usability of Highway 101 north lanes to be maintained for water levels up to 10.6 feet (NAVD). An extreme tide event of 11.6 feet (NAVD) would overwhelm the entirety of the Cell A drainage network and flood waters would rise to cause closure of the Highway 101 northbound lanes.

In addition to the tidal still water flood risk, the project shoreline is exposed to a 4 mile-long wind fetch associated with the dominant northwest wind direction. High wind speeds occurring coincident with high tides can create incident waves that increase the rate of shoreline overtopping and erosion potential. Wave heights and corresponding total water levels were calculated for the project area (FEMA 2014 and ESA 2018) and the associated flooding within Cell A was estimated and mapped (Humboldt County 2021). Wind generated waves are a function of water depth, wind speed and fetch length. As waves approach the shoreline and depth decreases, the steepness increases until a limiting value is reached and the wave breaks, dissipating energy (USACE 2003). Under these conditions, waves are considered to be depth-limited when the depth of water is less than or equal to the wave height. The dominant topographic features along the project shoreline are the mudflats, salt marsh and the rail prism. Abrupt elevation changes occur at the interfaces of each of these features. The mudflat elevation is typically around 4 to 5 feet, salt marsh 7 feet, and the top of the rail prism 9-10 feet (NAVD). Therefore, a wave that is 1 foot in height will break and dissipate energy on the mudflats when water levels are below elevation 6 feet, on the salt marsh when water elevations are 6 to 8 feet, and on the rail prism when waters levels are above elevation 8 feet (NAVD). If there is no salt marsh present, waves will break directly on the rail prism at water levels greater than elevation 6 feet. This explains the presence of rail prism erosion where salt marsh is absent. Wind wave analyses are further described in this report as related to wave attenuation from salt marsh. Project Need, Development and Assumptions

As sea level rises, the frequency and severity of storm impacts are anticipated to increase along with the erosion and flooding risk within the project area. The Sea Level Rise Adaptation Plan for the Eureka Slough Hydrographic Area (Humboldt County 2021) identified Cell A as having the highest concentration of potential impacts based on the flood and erosion risks summarized above. The most severe consequences are due to the importance of Highway 101 as a regional transportation route and local evacuation route, the density of residential and commercial development at low elevations (especially along Jacobs Avenue), the economically disadvantaged community status indicating a lack of resources to support recovery, and the presence of sewer pump stations, active and closed contaminated sites, and regional utilities. Under current conditions, if Highway 101 closes due to flooding, Myrtle Avenue and Old Arcata Road would provide alternate access around the Bay up to a still water elevation of 11.6 feet (NAVD) and Highway 255 up to 10.6 feet (NAVD). Above elevation 11.6 feet, vehicle access around the bay would no longer be accessible. As previously noted, this water surface elevation corresponds with the 1-percent annual chance still water event with 1-foot of sea level rise. Populated areas of Cell A, including the Jacobs Avenue area and Highway 101, are considered to exhibit the greatest risk in the project area, due to the number of people, structures, and transportation facilities impacted by flooding and erosion.

The Sea Level Rise Adaptation Plan for the Eureka Slough Hydrographic Area (Humboldt County 2021) developed an extensive list of recommended flood reduction studies and projects to reduce impacts from sea level rise. Four (4) adaptation projects were selected from the list, based on the greatest need and the following screening criteria:

1. Adaptation project concepts should be feasible projects that can be implemented within approximately 5-20 years.
2. The project concepts developed will provide the basis for future supporting studies and preliminary design phases.
3. Projects are designed for the Likely (66% probability) SLR Projections (Low Risk Aversion) over the estimated project life AND cross-checked for adaptability to 0.5% probability projections (Med-High Risk Aversion)
4. Project benefits assume a completed HBTS project which is planned to be completed in 2022/2023.
5. Projects would focus on Cell A, given the results from the vulnerability assessment indicate that impacts to critical resources in Cell A pose the greatest risk to the local and regional community.

The four adaptation projects that were developed in the plan are listed and described below:

- Project 1 (HBTS) - elevating rail prism to elevation 11.5ft (NAVD 88) to reduce coastal flooding from tidal still water and wave runup.
- Project 2 (this project) - was conceptually developed and assumed re-establishment of the tidal marsh to reduce wave exposure between Bracut and Brainard and provide Cell A additional resilience to coastal hazards through a multi-benefit design approach.
- Project 3 - Jacobs Avenue Flood Resiliency Improvements.
- Project 4 - Jacobs Avenue Levee Resiliency Improvements.

The following assumptions were included in the Sea Level Rise Adaptation Plan for the Eureka Slough Hydrographic Area (Humboldt County 2021) and provide the basis for project development.

1. The HBTS (Project 1) will be constructed in 2022/2023.
2. The Highway 101 transportation corridor between Eureka and Arcata will likely need to be reconstructed as a causeway or viaduct before the end of the 21st century. This corridor is expected to remain in its current location along the Humboldt Bay shoreline for the following reasons:
    a. The transportation corridor along the bay provides a direct connection between the segments of Highway 101 passing through the two cities.
    b. Re-location inland would displace communities along Myrtle Avenue and Old Arcata Road and cause significant environmental impacts.
    c. Re-location inland would cost several hundreds of millions of dollars and is likely cost prohibitive.
    d. Construction of a causeway or viaduct along a portion of the Highway 101 corridor is technically feasible (although at a very high cost and with many design aspects to resolve).
3. Adaptation projects will need to minimize impacts to coastal resources (including public access, recreation, marine resources, sensitive habitats, archaeological resources, and scenic and visual resources) to the extent practicable and comply with applicable laws and regulations. Projects will need to be based on the least environmentally damaging feasible alternative and will need to minimize the use of hard armoring (built structures).
4. Adaptation projects will depend on the availability of state or federal funding and participation from adjacent landowners.

Conceptual designs for Projects 2, 3, and 4 were developed for evaluation purposes to gain useful information, but no commitments have been made to implement these projects. The projects would be highly expensive and further feasibility studies are warranted. Project 1 – Humboldt Bay Trail South Humboldt County Department of Public Works (HCDPW) is preparing to construct the 4.25 mile Humboldt Bay Trail South (HBTS) project that will be a Class I multi-use trail and will complete the Bay Trail between Arcata and Eureka (Figure 8). HBTS within the project area has been designed to be situated between the rail prism and Highway 101 to enable future Rail-with-Trail use. For the segments of railroad that have been damaged by flooding and erosion, HBTS proposes to repair and maintain the existing shoreline armoring on the bay-facing slope, remove the rails, and raise the elevation of the rail prism to 11.5 feet (NAVD) to provide resiliency to flood hazards and sea level rise. The basis for this design is described in Humboldt County (2020). Permits and approvals are expected by the end of 2021 and construction is expected to start in 2022.

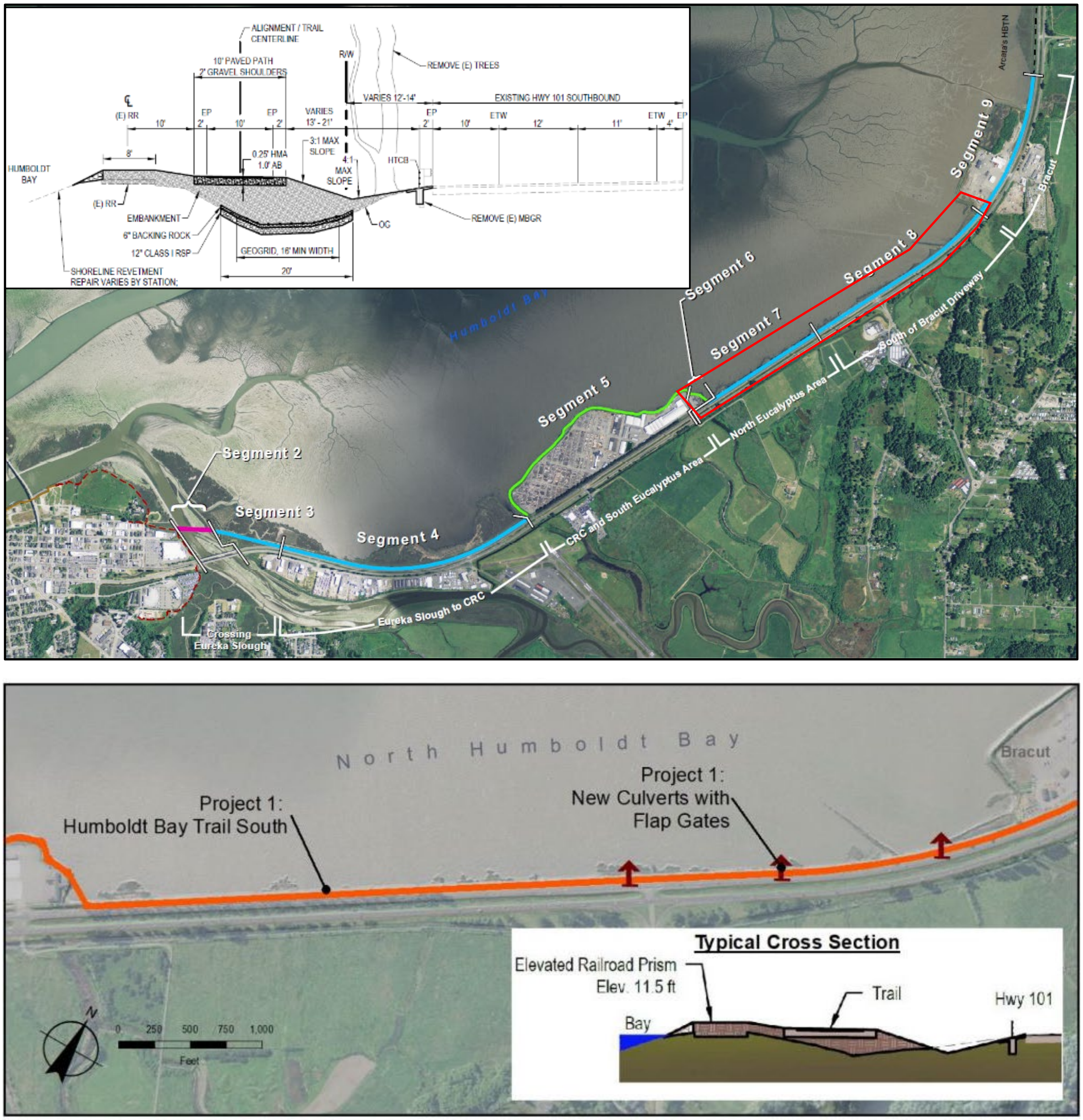

Figure 8 Humboldt Bay Trail South planned for construction in project area in 2022/2023 with Segments 7 and 8 located within Project Area.

As previously described, the existing shoreline segment from Brainard to Bracut serves as the primary flood protection barrier for Highway 101 and Cell A, but is overtopped with tidal still water events as low as 9.1 feet (NAVD). Elevating the rail prism to 11.5 feet (NAVD) through the project area as part of the HBTS project will provide a significant reduction in flood risk to Highway 101 and interior lands of Cell A. Most notably, at still water levels of 11.6 feet (1-percent annual chance event plus 1 foot of sea level rise), overtopping of the project shoreline into Cell A will cause 4,700 acre-feet of floodwaters to inundate Cell A, causing full closure of Highway 101, water depths of up to 6 to 7 feet, and widespread flooding damage to residential and commercial properties along Jacobs Avenue and nearby agricultural land. The increased rail prism elevation to 11.5 feet (NAVD) proposed by the HBTS project would reduce the volume of tidal floodwaters associated with this flood event to 10 acre-feet, with water depths reduced to 1 to 2 feet (Figure 9). While HBTS will provide significant flood reduction benefit, Cell A will still be vulnerable to interior flooding from shoreline overtopping along Fay Slough and the elevated rail prism within the project shoreline will remain vulnerable to erosion and overtopping with sea level rise and wind-wave exposure.

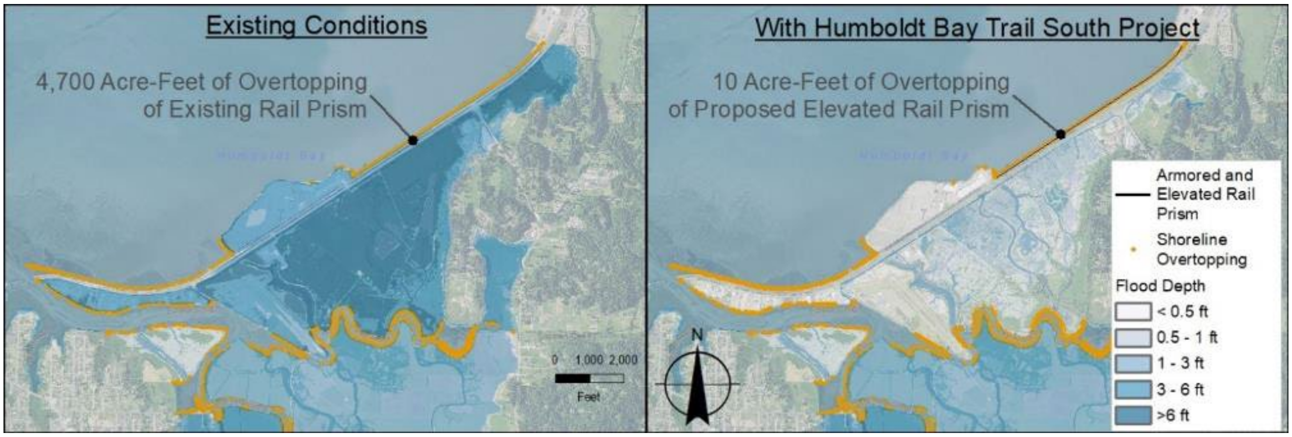

Figure 9 The implementation of Humboldt Bay Trail South Project significantly reduces flooding in Cell A by reducing overtopping of the rail prism. Inundation mapping showing water levels of 11.6 feet (NAVD) which correspond with a 100-year event plus an additional 1 foot of sea level rise.

1.3.3 Project 2 – Natural Shoreline Infrastructure

Project 2 (this project) consists of natural shoreline infrastructure (NSI) that provides a salt marsh and transition ecotone slope extending bayward from the rail prism to the mudflat along the 1.25-mile shoreline between Brainard and Bracut. The purpose of this project is to reduce flood and erosion hazards by dissipating waves generated in Arcata Bay, and providing ecological benefits with a nature-based design that restores salt marsh. The project would protect the proposed HBTS (Project 1) and reduce wave exposure to Highway 101 located slightly landward. The project builds upon Project 1 that forms the landward boundary (Figure 10). The salt marsh geometry provided by the project would provide space and elevation for marsh habitats to transgress (migrate) upslope with sea level rise, preserving ecosystem benefits into the future and continued sediment accretion. Project 2 utilizes a nature-based approach, creating a gradient of marsh elevations that: increases habitat diversity where historical marsh once existed; enhances safety and the recreation experience for trail users; enhances safety for vehicle travel along Highway 101; sequesters carbon with marsh creation; provides a potential co-benefit for the reuse of dredge spoils in Humboldt Bay that would otherwise require costly disposal; extends the service life of Project 1; and provides flood reduction benefits.

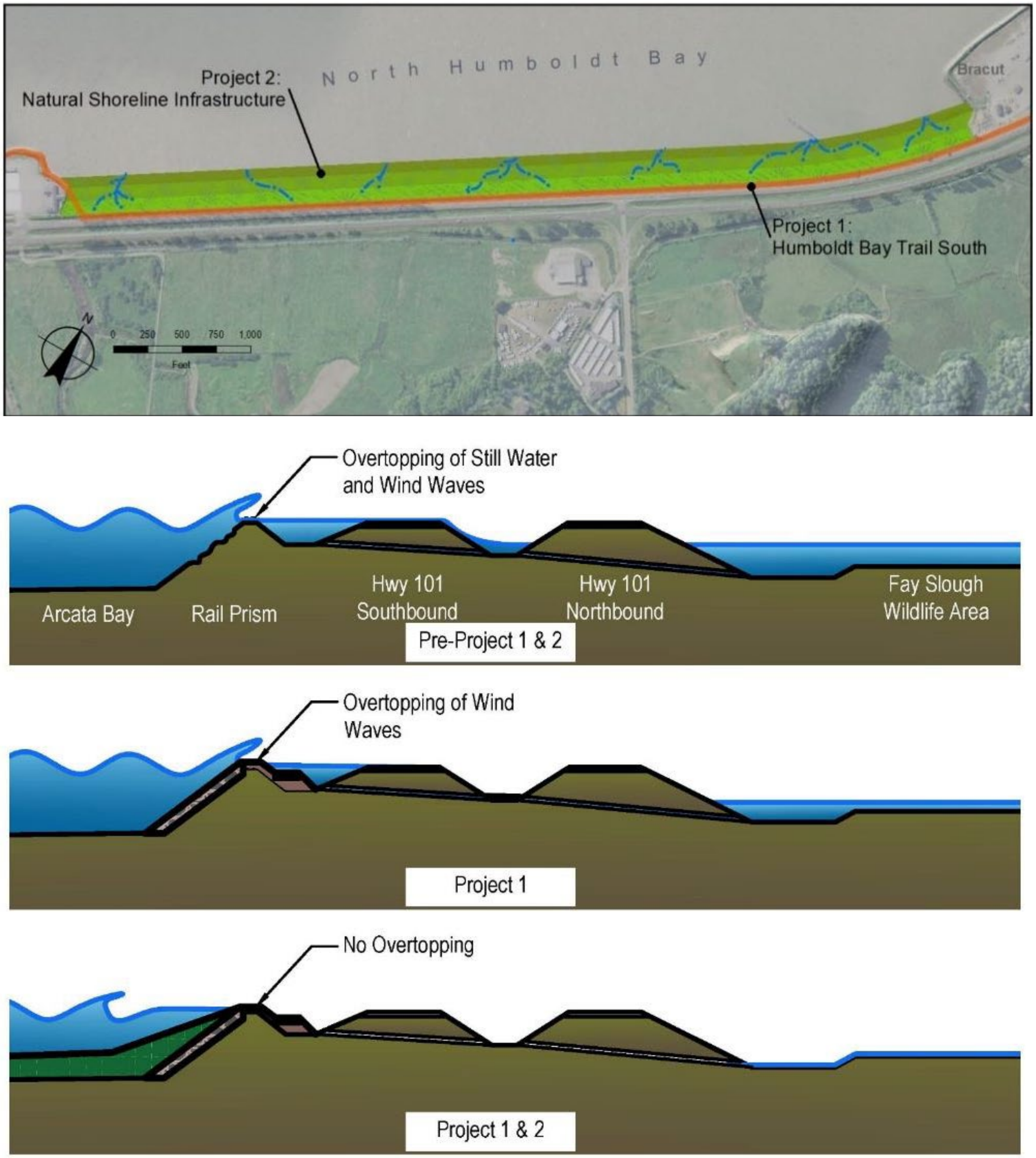

Figure 10 Project 2 (this project) proposes natural shoreline infrastructure (NSI) such as salt marsh creation between Brainard and Bracut to reduce wind wave overtopping and erosion. The implementation of a salt marsh and ecotone transition reduces wave overtopping and shoreline erosion, reducing flood frequency of Highway 101 and developed areas.

Project 2 would extend the service life of shoreline protection by creating a landform that could naturally adapt to sea level rise with natural marsh accretion, saving maintenance, repair and reconstruction costs in the future. The project, when first constructed, would dissipate wave energy and associated overtopping for tidal water levels up to 11.5 feet in combination with wind events. A higher level of protection may be experienced with marsh accretion and also provides potential adaptability options with the use of dredge spoils.

The Project 2 concept is further developed in this report to better understand the efficacy of salt marsh restoration and other NSI techniques that meet specific project goals and objectives defined in the subsequent sections.

1.3.4 Projects 3 & 4 – Jacobs Avenue Flood Resiliency

Projects 3 and 4 focus on increasing the flood resiliency of the Jacobs Avenue area by increasing the height and stability of the existing Jacobs Avenue levee and modifying the interior drainage system. These projects are compatible with Projects 1 and 2 described above. Additional information regarding these projects can be found in the Sea Level Rise Adaptation Plan for the Eureka Slough Hydrographic Area (Humboldt County 2021).

1.3.5 Project Cost and Avoided Damages

Construction cost and avoided damage costs were previously estimated (Humboldt County 2021) for projects 1, 2, 3 and 4, as summarized in Table 1. The avoided damage costs represent the potential costs to repair or replace critical resources from flood damage associated with the OPC 2018 “likely” rate of sea level rise through 2100. Although the estimating methods have limitations and depend on many assumptions, the avoided damage costs or benefits appear to be greater than the construction cost for each project, suggesting an overall net benefit from implementing each project.

Table 1 Estimated Project and Avoided Damage Costs (Humboldt County 2021)

Project	1: Humboldt Bay Trail South	2: Natural Shoreline Infrastructure (Bracut to Brainard)	3: Jacobs Avenue Flood Resiliency	4: Jacobs Avenue Levee Resiliency
Construction Cost	$22M	$20-29M	$9-12M	$7-9M
Avoided Damage Cost (Likely Sea Level Rise Rate through 2100)	$114M	$43.2M	$82.3M	$38.5M

1.3.6 Eureka-Arcata Corridor Improvement Project

Caltrans is currently constructing a series of projects on Highway 101 between Eureka and Arcata collectively referred to as the Eureka-Arcata Corridor Improvement Project. The individual projects include the Indianola Undercrossing & Half Signal Project (Figure 11), Jacoby Creek/Gannon Slough Bridge Rail/Bridge Replacement Project, High Tension Cable Median Barrier Project, Acceleration/Deceleration Project, Tide Gates Replacement Project and Offsite Wetland Mitigation. The total cost for these projects (including preconstruction, right-of-way, construction, and mitigation) is over $110 million. The projects are being implemented through a phased approach between 2020 and 2025.

Figure 11. Photo simulations of planned Indianola Interchange Improvements and Humboldt Bay Trail South adjacent to project area, courtesy Caltrans.

The Eureka-Arcata Corridor Improvement Project received a Coastal Development Permit (CDP) from the California Coastal Commission in 2020 with a condition of approval stipulating that Caltrans shall develop a Phased Sea Level Rise Adaptation Plan for the Eureka-Arcata Highway 101 corridor by 2025. The plan is expected to be a foundational planning document for the shoreline and protected interior lands between Eureka and Arcata. Given Caltrans current investment into the Eureka-Arcata Corridor, in addition to the Eureka Slough Bridge Replacement Project planned for construction in approximately 2030, it is assumed that a major sea level rise adaptation project for Highway 101 will not occur until later in the 21st century due to the many complexities and anticipated high costs. Relocating Highway 101 to a new inland retreat alignment was determined to be much higher in cost relative to elevating in its current alignment (GHD 2015).

1.4 Project Goals and Objectives

The fundamental concept of the project is to integrate the natural flood-risk reduction properties of salt marsh into the shoreline management strategy for the Eureka-Arcata Highway 101 transportation corridor in an area where salt marsh was historically abundant but currently exists only in small, isolated patches. Based on the assumptions previously listed, the following project goals and objectives have been defined:

Goal 1: Restore and enhance intertidal coastal marsh habitat

Objectives:

1. Provide a tidal ecotone extending from intertidal mudflat through low, middle, and high marsh to the upland transition zone.
2. Increase salt marsh area.
3. Increase habitat for native salt marsh plant communities and rare plant species.
4. Avoid infestation by the invasive dense-flowered chordgrass (*Spartina densiflora*).
5. Create landforms that are in dynamic equilibrium with hydraulic and geomorphic processes under current conditions and projected future conditions.
6. Create conditions where vertical accretion of sediment keeps pace with relative sea level rise.
7. Provide elevation gradients that allow upward migration of salt marsh in response to sea level rise.
8. Provide a diversity of habitat forms that emulate natural systems.

Goal 2: Protect transportation infrastructure

Objectives:

1. Prevent substantial erosion of the shoreline by reducing wave height and energy.
2. Reduce wave runup and overtopping onto the railroad, Humboldt Bay Trail, and Highway 101.

Goal 3: Create opportunities for innovation and learning

Objectives:

1. Serve as a demonstration project for natural shoreline infrastructure and nature-based sea level rise adaptation strategies within Humboldt Bay.
2. Explore the feasibility of beneficial reuse of dredged sediment.
3. Collect and publish monitoring data.

1.4.1 Basis for Project Goals and Objectives

The goals and objectives above build on the vision statement and guiding principles in the Sea Level Rise Adaptation Plan for the Eureka Slough Hydrographic Area (Humboldt County 2021) and support the following plans and policies:

- The Humboldt Bay Management Plan (Harbor District, 2007) emphasizes the use non-structural shoreline protection using marsh and transitional upland vegetation (policy HSM-6) in addition to accommodating sea level rise and potential effects of climate change (policy HSM-7).
- The Humboldt County General Plan (Humboldt County, 2017), policy WR-P39, encourages restoration projects aimed at reducing erosion and improving habitat value.
- The City of Eureka General Plan (City of Eureka, 2018) encourages the preservation and habitat enhancements of natural shoreline areas (policy SL-1.5) and encourages innovative solutions to reduce damage from peak tidal and storm events using a combination of hard engineered and soft engineered reefs, marshes and living shorelines (policy SL-1.11).
- The multi-objectives and multi-benefits anticipated from the project align with the management recommendations for coastal intertidal marsh sustainability and restoration identified in the Humboldt Bay and Eel River Estuary Benthic Habitat Plan (Schossler & Eicher, 2012).
- The project would provide a direct nexus with ecosystem restoration strategies and goals identified in the Humboldt Bay Initiative Strategic Plan (2009) and Humboldt Bay Watershed Salmon and Steelhead Conservation Plan (2005).
- The flood reduction benefits to Highway 101 and future Humboldt Bay Trail South support polices in the 2017 Humboldt County Association of Governments (HCAOG) 20-year Regional Transportation Plan (RTP). HCAOG encourages partnerships to develop adaptation strategies that address sea-level rise (Policy Climate-6), will prioritize planning, design, construction, adequate maintenance, and other actions to improve the safety of the regional trails system (Policy Trails-8) and will lead, facilitate, and support efforts to incorporate climate change and adaptation into emergency transportation and evacuation planning (Policy Emergency-2).

1.5 Role of the Technical Working Group

This project includes a technical working group (TWG) comprised of regulatory agencies, public agencies, scientists, and other stakeholders that understand the physical and regulatory drivers. The overall purpose of the TWG is to provide technical feedback during the project, especially with respect to the development of alternatives. The following expectations were identified for the TWG participants.

- Participate in six meetings
- Provide input on goals and objectives, approach and methods, design concepts and features
- Help understand context within Humboldt Bay
- Help identify important studies and reference sites and apply best available science
- Represent your agency’s perspective and mission
- Technical assistance with site characterization (if possible)

PART II - ENVIRONMENTAL SETTING

The following sections describe the physical and biological conditions of the project area within Humboldt Bay and a summary of historic conditions and the anthropogenic interventions that have contributed to the current shoreline form and function.

2. Existing Physical Conditions

The following description of the existing physical conditions within the project area was adapted from the Sea Level Rise Adaptation Plan for the Eureka Slough Hydrographic Area (Humboldt County 2021), Sea level Rise Vulnerability and Adaptation Report for Humboldt Bay Trail South (ESA 2018) and other sources referenced.

2.1 Eureka Littoral Cell and Humboldt Bay

The project area extends along the east shore of North (Arcata) Humboldt Bay between Brainard and Bracut. in North Humboldt Bay. Humboldt Bay is located within the Eureka Littoral Cell which was delineated in 1966 and is generally defined by rocky headlands forming the upcoast and downcoast boundaries with little or no sand and sediment exchange across the boundaries (USACE 2017). Sources of sand and sediment enter the littoral cell from a variety of sources (e.g. rivers, bluff erosion, dunes and mudflats) and leaves through sinks (submarine canyons, offshore transport, dunes and mudflats). Beaches and mudflats represent temporary repositories of sand and sediment within the littoral cell in response to the differential between source and sink volumes. The Eureka Littoral Cell lies between Trinidad Head to the north and False Cape (just north of Cape Mendocino) to the south. This encompasses approximately 40 miles of coastline that includes major rivers, a coastal dune field, the Eel Submarine Canyon, and Humboldt Bay. Within the littoral cell there are three rivers (Little, Mad, and Eel) that discharge directly into the Pacific Ocean, and four watersheds that drain into Humboldt Bay (Salmon, Elk, Jacoby, and Freshwater), which together comprise the major sources of sediment input into the Littoral Cell (USACE 2017).

Humboldt Bay contains three distinct sub-bays referred to as Entrance Bay that fronts Eureka, North (or Arcata) Bay, and South Bay (Costa 1982; Costa and Glatzel, 2002). Entrance Bay is connected to the ocean through the Entrance Channel with defined jetties. South Bay is directly connected to Entrance Bay through a natural constriction referred to as the Fields Landing Channel. Arcata Bay is connected to Entrance Bay via the long North Bay Channel that fronts Eureka and Samoa and splits into the Samoa and Eureka Channels, just before connecting with Arcata Bay. The U.S. Army Corps of Engineers conducts regular maintenance dredging on the Entrance, Fields Landing, Entrance Bay, North Bay, Samoa and Eureka Channels (USACE 2017). The contributing watershed area to Humboldt Bay is approximately 223 square miles and has a tidal prism of approximately 9.63 to 9.91×10^7 cubic meters during a spring tide range and about 70% less over a mean tide range (Costa and Glatzel, 2002). Arcata Bay contributes approximately 50% of the tidal prism whereas South Bay contributes approximately 30%.

Humboldt Bay tides are mixed, semidiurnal, and show tidal amplification and phase that lags with distance from the entrance (Costa, 1982; Costa and Glatzel, 2002; NHE 2015). Arcata Bay has a mean tide range of approximately 4.8 feet, diurnal range of 6.7 feet, and a maximum range of about 11 feet during spring tides. Due to the small freshwater inflow relative to the tidal prism, the general circulation of Humboldt Bay is dominated by tidal currents that are influenced by the bay bathymetry (Costa, 1982; Costa and Glatzel, 2002). Costa (1982) reports that circulation patterns can be affected by waves entering through the Entrance Channel (which primarily influence the Entrance Bay only), internally wind-generated waves, and density differences. Humboldt Bay is typically well mixed vertically, and normally consists of unstratified marine water (Costa and Glatzel, 2002). Although Arcata Bay is sheltered from large swell waves frequent in the Entrance Bay, strong wind events can generate local, short-period wind waves across the approximately four-mile-long fetch which results in significant wave height[1] of approximately 2 to 3 feet along the eastern shore of Arcata Bay in the project area (FEMA 2014 and ESA 2018).

Variations of the surface sediments in Humboldt Bay, including silt, clays, and coarse material (e.g., sand, shell fragments, etc.) are associated with the bay morphology (Thompson 1971). Bottoms of the tidal channels are covered by gravelly and shelly sand that becomes finer and muddier with increasing distance from the tidal inlet. Clayey silt predominates on the tidal flats, and highly organic silty clay or clayey peat occurs in salt marshes. The distribution of sediment size is controlled by tidal currents, except where direct discharge from streams and wind-generated wave action. Sediment size and distribution patterns are further described in subsequent sections of this report. The Thompson (1971) study suggests that the Bay was in an approximate geomorphic equilibrium at the time of the study, filling at rates on the order of 2 to 4 mm/year, commensurate with relative sea level rise of the time, and that most of the sediment is sourced from the Eel and Mad River littoral systems directly and indirectly from tidal currents. Direct measurements showed that accretion and erosion rates up to 4 cm/year and 11 cm/year on the mudflats, respectively, fluctuate on a seasonal basis in response to alternating wind wave patterns, which also reflects in-Bay relocation of materials. Finally, Thompson (1971) suggested that the presence of extensive tidal flats and salt marsh imply former high rates of accretion and bay infill, but the recent change toward equilibrium conditions in the latter half of the 20th Century may relate to sediment removal by dredging, and/or to a reduction in sediment supply due to the northward shift of the Mad River course.

During the last ice age about 15,000 to 20,000 years before present, sea level was 100 to 200 meters lower than it is at present and Humboldt Bay was a river valley that became drowned by sea level rise (Barnhart and others 1992). The relatively high and steady sea level that has been observed over the past 4,000 years facilitated sediment deposition that resulted in the formation of the beach-dune littoral ridge on the western side of Humboldt Bay, and the marshes and mudflats along the eastern shore of Arcata Bay (Barnhart and others 1992; Costa and Glatzel 2002; Schlosser and Eicher 2012). As sea levels increase, sediments deposited forming sediment flats and marshes. Large earthquake subsidence events caused the sediment deposits to lower and then be buried by subsequent sediment deposits between earthquakes. The natural Bay morphology consists of three distinct habitats: (1) subtidal channels, (2) mudflats and (3) salt marshes (Thompson 1971). Subtidal channels are tidal channel features with a bottom elevation below the lowest tides, and which retain a residual depth at these low tides. Subtidal channels are formed by tidal currents that exchange a large volume of water over a tidal cycle and equilibrate to a geometry that is proportional to the tidal prism (Williams et al. 2002). Mudflats are the expansive tidal flats that establish in the intertidal zone. Salt marshes are the flat and vegetated areas along the shore and typically adjacent to the mudflats and tidal slough channels. The salt marsh establishes at elevations approximately from mean high water (MHW) to over mean higher high water (MHHW) and are periodically inundated by extreme high tides. A historical and contemporary shoreline profile of Arcata Bay is shown in Figure 12.

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[1] Significant wave height is an average measurement of the largest 33% of waves (National Weather Service, 2021)

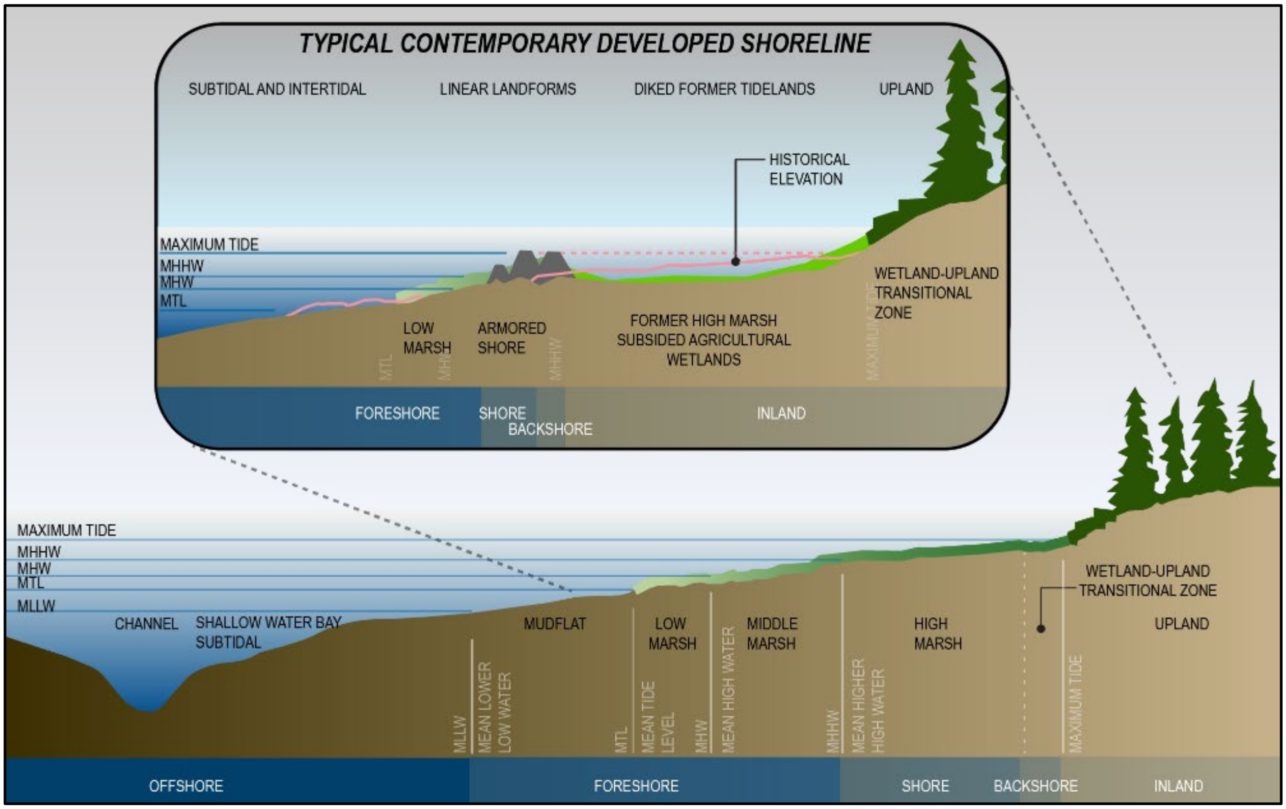


Figure 12 Arcata Bay Conceptual Shore Profile Adapted from Barnhart (1992), Monroe (1973) and Humboldt County (2021) showing pre- and post-development conditions.

2.2 Project Area

The landscape of the project area has been shaped by the interplay of human activity with natural processes driving the movement of water and sediment. The interactions of tidal currents, wind waves, and watershed sediments have formed the salt marshes, slough channels, and mudflats along the eastern shoreline of Arcata Bay. Over a hundred years ago, a system of levees and drainage structures converted tidelands to agricultural land. Railroads and roads also were built on top of the salt marsh and blocked tidewaters. The levees, railroads, and roads have fixed the shorelines in-place and have altered flow patterns and exchanges of sediment. These altered processes result in distinct topographic variation and habitat zones that define mudflats, salt marsh and other landforms across the project area that are present today (Figure 13).

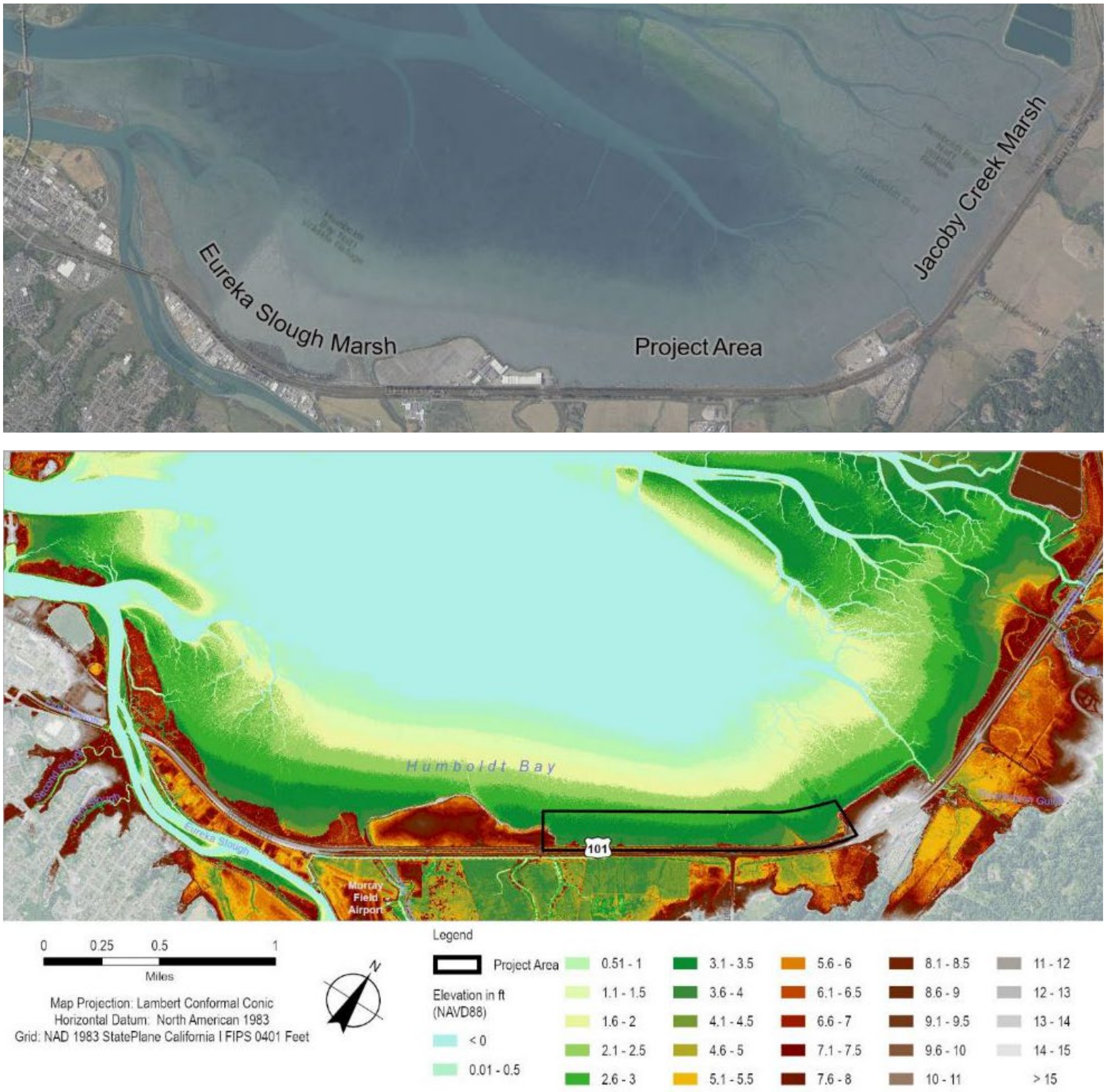


*Figure 13 Aerial Map **(NAIP 2018)** and Digital Terrain Map (County LiDAR 2019) of Project Area*

Extensive mudflats are located immediately offshore of the project area, with patches of fragmented salt marsh along the shoreline fringe. Typical daily low tides expose extensive mudflats throughout Arcata Bay while high diurnal tides inundate the salt marshes, with much of the inland low-lying lands buffered from tidal waters by the rail and highway prisms. While only small, isolated portions of salt marsh are still present along the shore, the mudflats have persisted over time and support an abundance of eelgrass in the upper sub-tidal mudflat areas approximately 3,000 feet offshore.

The following photos with captions provide a characterization of the existing intertidal shoreline conditions within the project area that supplement previous shoreline condition assessments focused on the rail prism condition (GHD 2018 and Laird 2013). Figure 14 shows the location and orientation of five (5) low altitude oblique aerial photos which is followed with ground-based photographs and description of existing physical conditions.

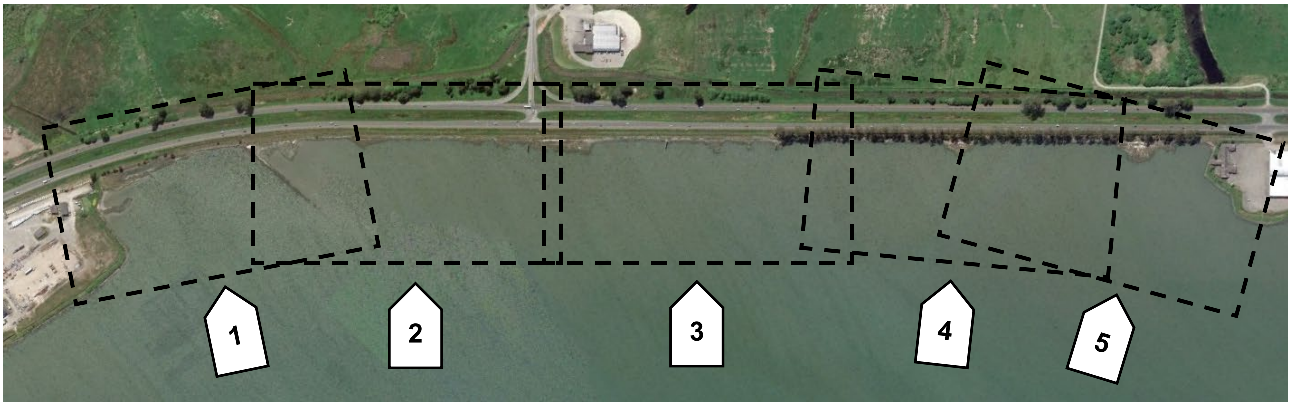
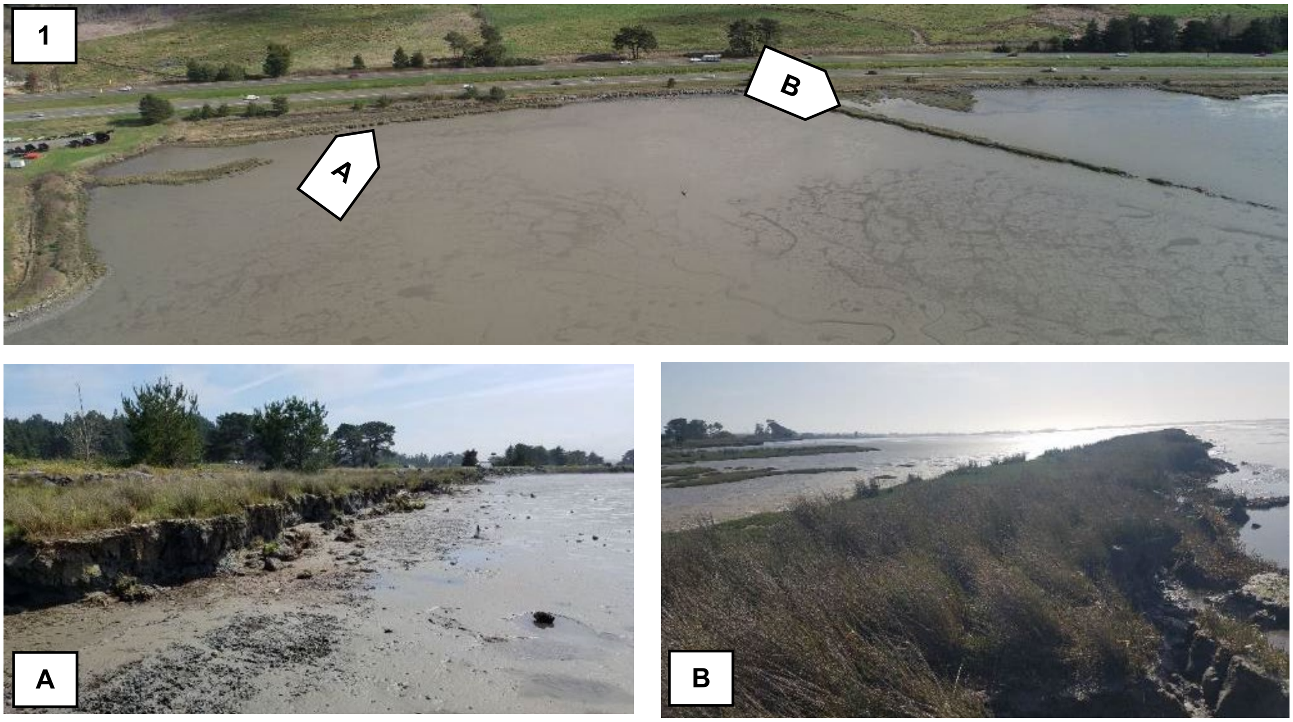
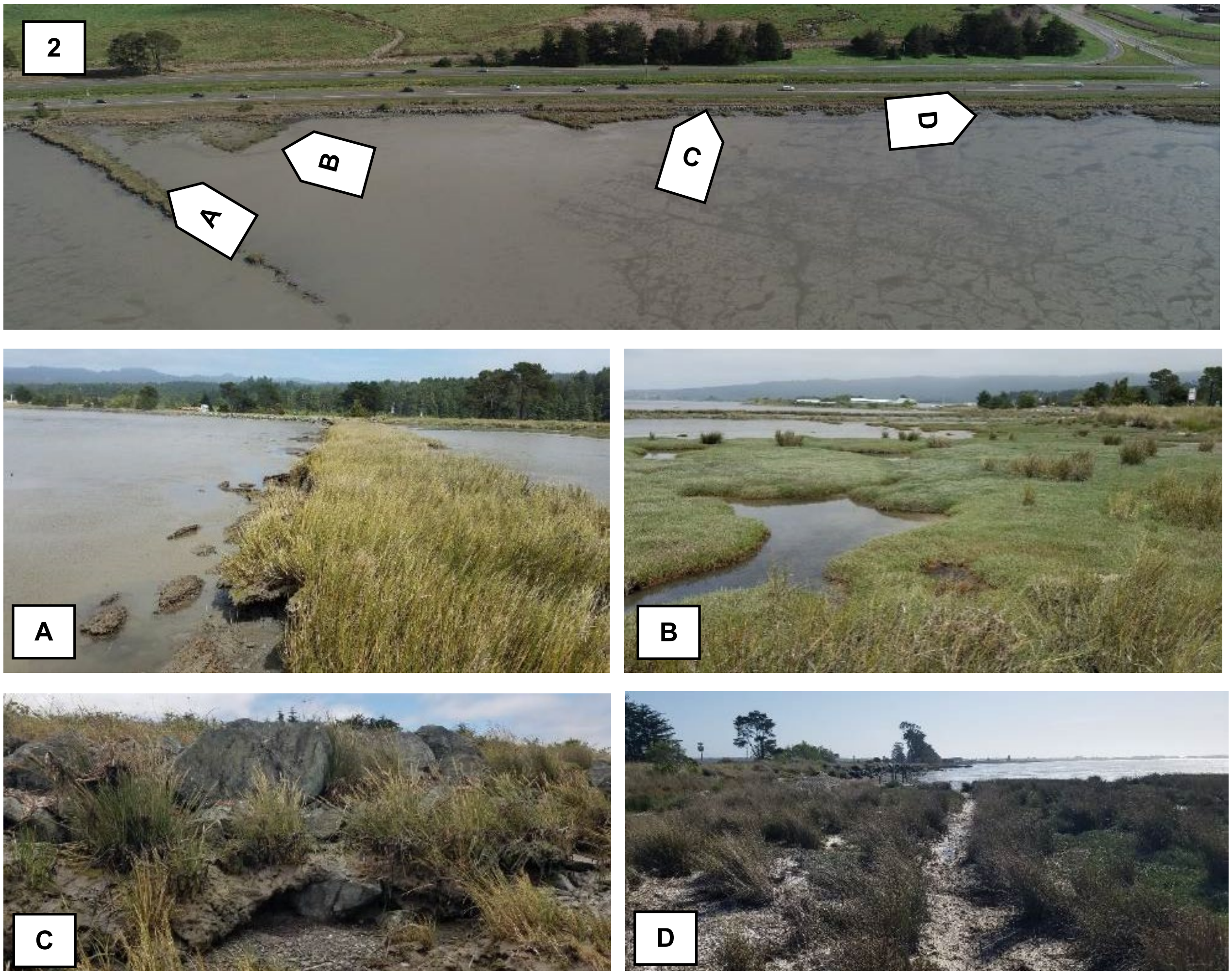


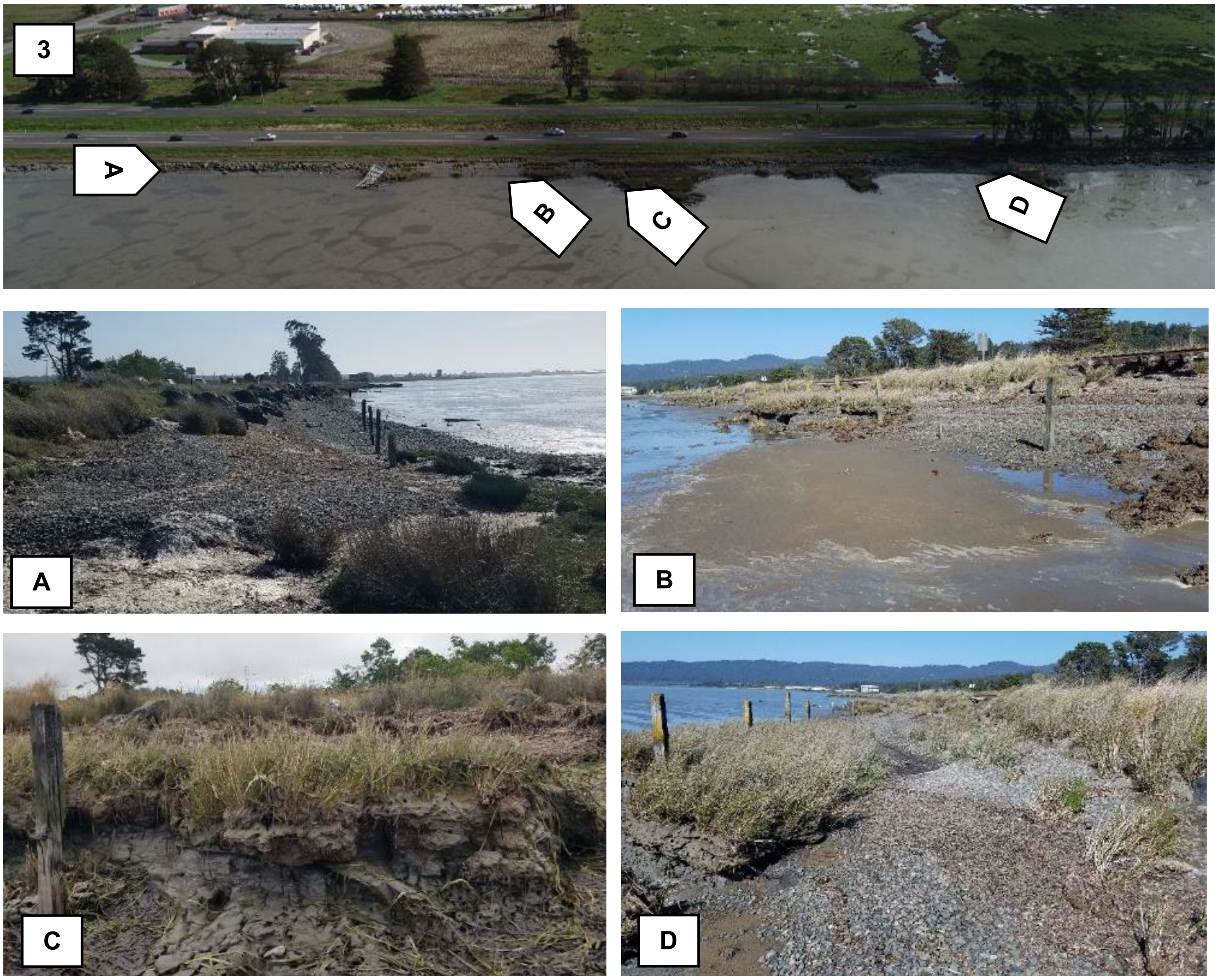
Figure 14 Location of five oblique photos shown on the following pages.



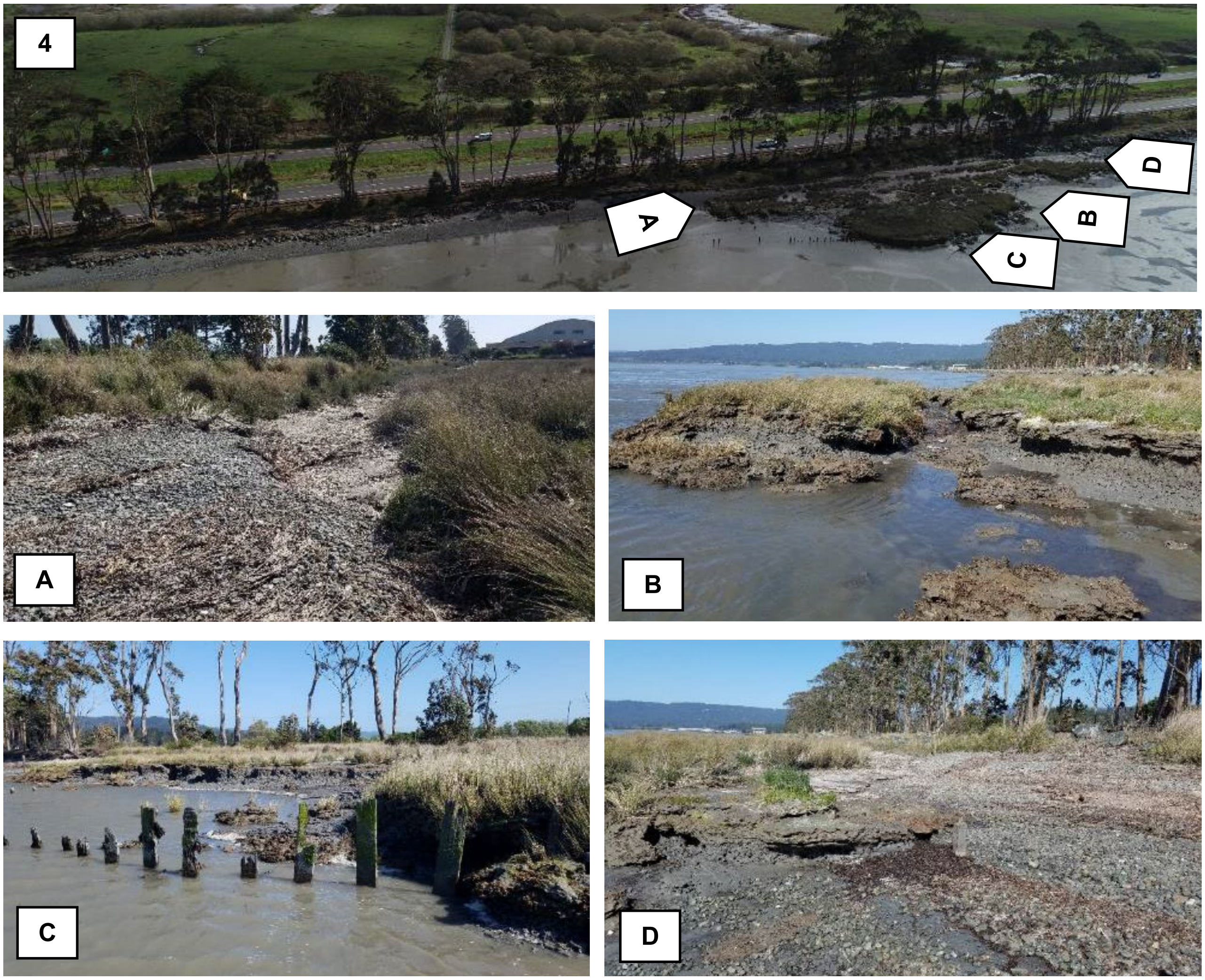
Oblique Photo 1: (A) Salt marsh scarp with thin (1-2 inch) fine sand deposit on adjacent mudflat. (B) Scarping with Spartina dominated failure blocks on windward (north) side of constructed remanent levee and pickleweed dominated low marsh on lee (south) side.



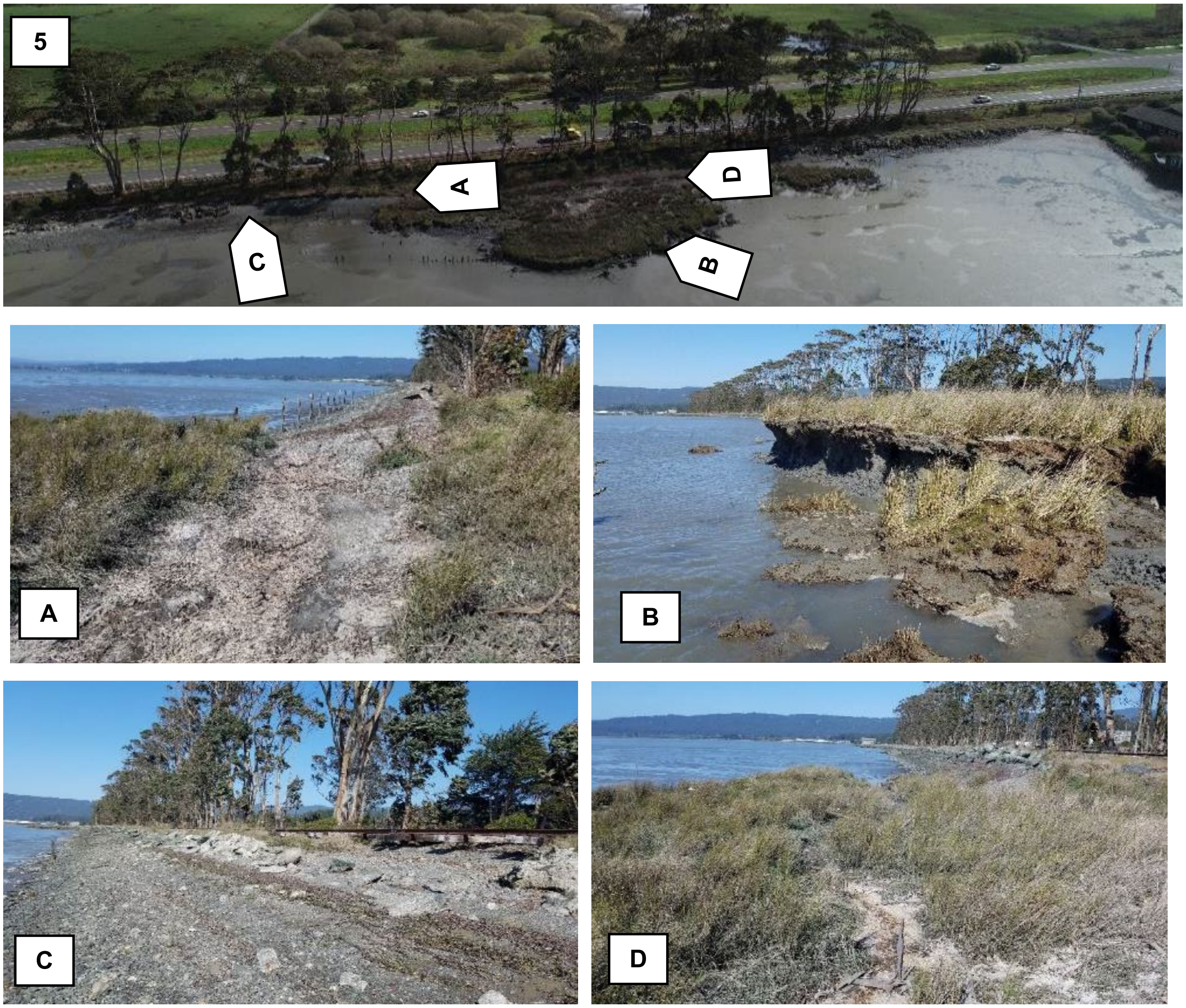
Oblique Photo 2: (A) Scarping with Spartina dominated failure blocks on windward (north) side of constructed remanent levee. (B) Pickleweed dominated low/mid marsh on lee (south) side of constructed remnant levee. (C) Vegetated deposited sediment on rock suggesting deposition potential during elevated water levels with suspended sediment. (D) Non-vegetated marsh gully/rill formed parallel to shoreline from concentrated marsh drainage/runoff and alongshore currents.



Oblique Photo 3: (A) Rocky intertidal/gravel beach from rail prism erosion that has sorted on shore profile with thin depth (typically less than 6") overlaying bay sediments. (B) Isolated fine sand deposit from rail prism erosion with ripples over mudflat. (C) Horizontally exposed milled wood in scarp of marsh under 12-18" of deposition. (D) vegetative wrack over railroad ballast gravels on upper shoreline profile with sorted finer sediment (fine sands and silts) lower on shoreline profile.



Oblique Photo 4: (A) Deposited railroad ballast gravel in former borrow ditch between rail prisms. (B) Gully/rill bifurcating marsh plain formed parallel to shoreline from frequent runoff of incident wind-wave overtopping and alongshore current. (C) Wood piles understood to have been placed during former oyster farming. (D) thin approximate 2" gravel layer (shingle) overlaid fine sands and silts with transition to marsh scarp and rills formed from marsh plain runoff during wave overtopping events.



Oblique Photo 5: (A) Non-vegetated area with deposits of railroad ballast gravel and wrack on upper shore profile from wind-wave and alongshore tidal driven currents. (B) Undercut cantilever marsh scarp approximately 4 feet tall and spartina vegetated failure blocks in scoured trough along toe of marsh scarp. Scoured trough indicates exposure to high wind wave energy. Marsh plain slopes from top of marsh scarp landward indicating higher accretion rates with closer proximity to wave run-up/splash and source of deposition at top of marsh scarp edge. (C) Eroded rail prism that has provided source for the adjacent rocky intertidal shoreline. (D) Spartina dominated marsh with organic debris deposited from wave overtopping.

The current intertidal shoreline conditions within the project area reflect the former anthropogenic interventions and historic use of Humboldt Bay, which are described below.

3. Historic Conditions

Humboldt Bay was settled in the 1850’s and development was initiated by the gold rush and then accelerated with logging. Anthropogenic interventions within Arcata Bay and tributary watersheds were documented by Rohde (2020). These interventions have been depicted on Exhibits 2-1, 2-2 and 2-3 (Appendix A) and are summarized below with the likely landscape response (Table 2). Figure 15 and Figure 16 include additional historical maps and corresponding oblique historic photos with interpretation of the observed shoreline interventions which are also summarized in Table 2.

Table 2 Anthropogenic Interventions and Likely Landscape Response

Date and Description of Intervention		Likely Landscape Response
See Exhibit 2-1		
1850's	Logging and rock quarrying in Humboldt Bay tributaries commenced. Logs and rock were transported on rail to multiple wharfs or log dumps in Arcata Bay	Increased watershed sediment delivery to Arcata Bay and availability to project area Increased project shoreline exposure to erosion from barge/ferry wakes
1854-1890	Canal channeling connected Mad River to Arcata Bay	Increased sediment delivery to Arcata Bay and availability to project area
1881	Dredging of Eureka-Arcata navigation channel commenced	Dredged channel created a sediment sink in Arcata Bay and may have altered tidal hydraulics
1889	Modifications and rock armoring at Humboldt Bay entrance to improve navigability	Modifications could have increased tidal prism and altered tidal circulation and sediment dynamics throughout the Bay
See Exhibit 2-2		
1892	Arcata Bay shoreline leveed between Butcher Slough and Jacoby Creek mouth near Arcata	Leveeing reduced tidal prism in Arcata Bay, eliminated salt marsh sediment sink increasing sediment availability
1895-1898	Salt marsh edge leveed between Brainard and Bracut (project area) and Freshwater Slough leveed creating ~1,000 acre diked former tideland	Leveeing reduced tidal prism and disconnected tidal/fluvial flow/sediment exchange throughout Freshwater/Fay Slough dendritic tidal marsh network Levee constructed along marsh edge between Brainard and Bracut from dredge spoils created abrupt shoreline edge that may have increased the erosion potential for salt marsh on the inboard side of the levee during wind-wave events (see Section 5.4.3.2)
1900	Two parallel rail prisms constructed landward of marsh edge levee in project area	Impacted salt marsh by creating backshore barriers that can reflect wave energy and converted salt marsh to rail prism fill and borrow ditches
1918-1925	Redwood Highway 101 (2-lanes) constructed landward of rail prisms in project area	Highway created an additional tidal barrier
See Exhibit 2-3 and Figure 16		

Date and Description of Intervention		Likely Landscape Response
1930's	Oyster beds created with driven wood stakes throughout project area	Wood stakes would have dissipated wind-wave energy and increased deposition potential
1952	Bracut Lumber Company expanded levee and created a 32-acre addition immediately north of project area	Near shore wind wave and tidal currents could have been altered from levee construction
1955	Additional 2-lanes added to Highway 101 landward of existing 2-lanes	Additional wetlands were filled within Cell A, further reducing stormwater storage capacity during tidal overtopping events
1960-1970	Bracut Lumber Company constructed 1,500 foot levee "peninsula" into Bay in attempt to expand development but project was abandoned. Note, the 1970 aerial map shows the levee to extend approximately 2,300 feet offshore Salt marsh fronting Indianola Cut-off appears in present day photos but was absent in 1947 photos	Near shore wind wave and tidal currents could have been altered, likely reduced northwest wind exposure to project shoreline and reduced erosion potential "Peninsula" has substantially eroded since construction from wind waves providing a sediment source

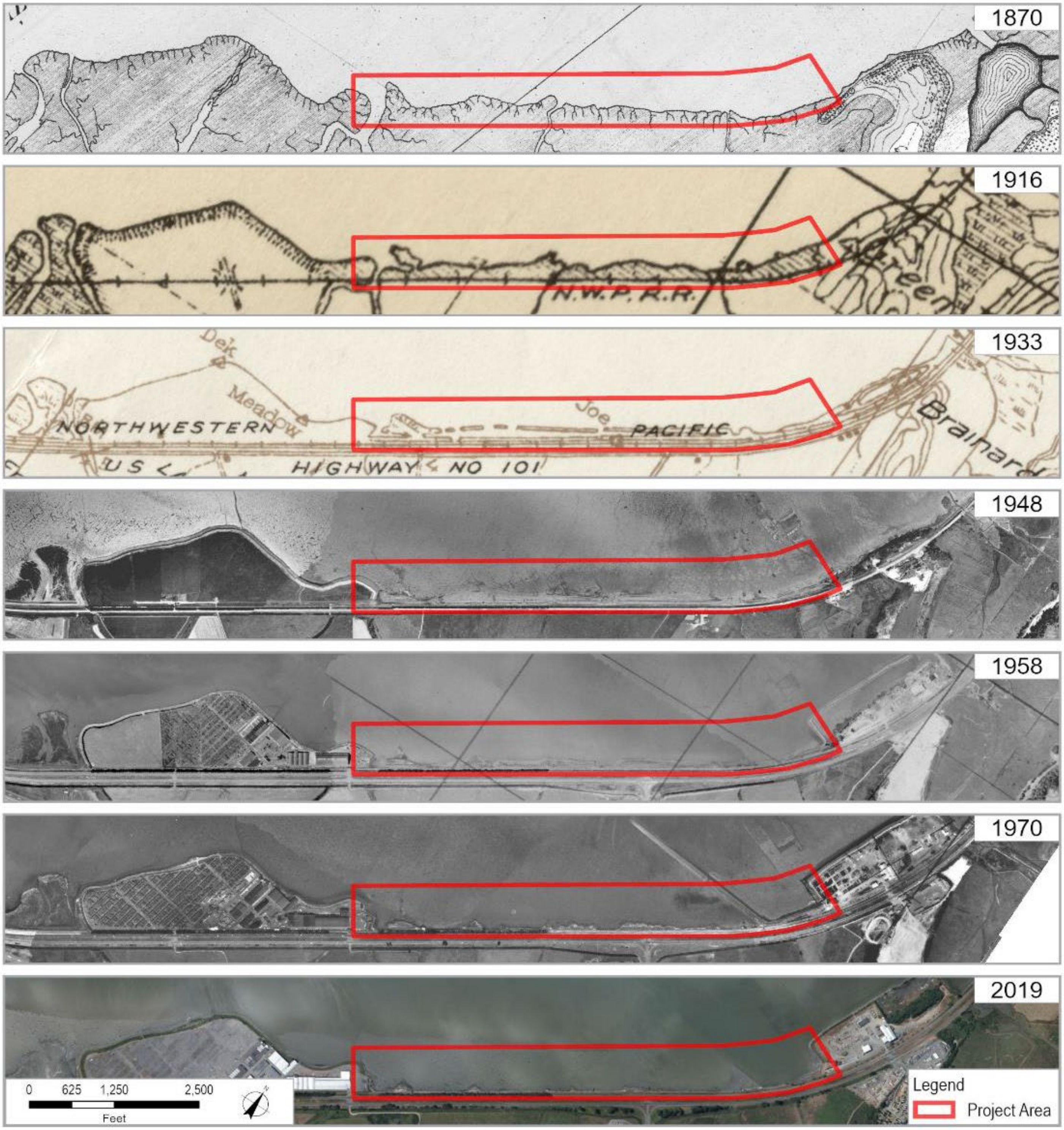
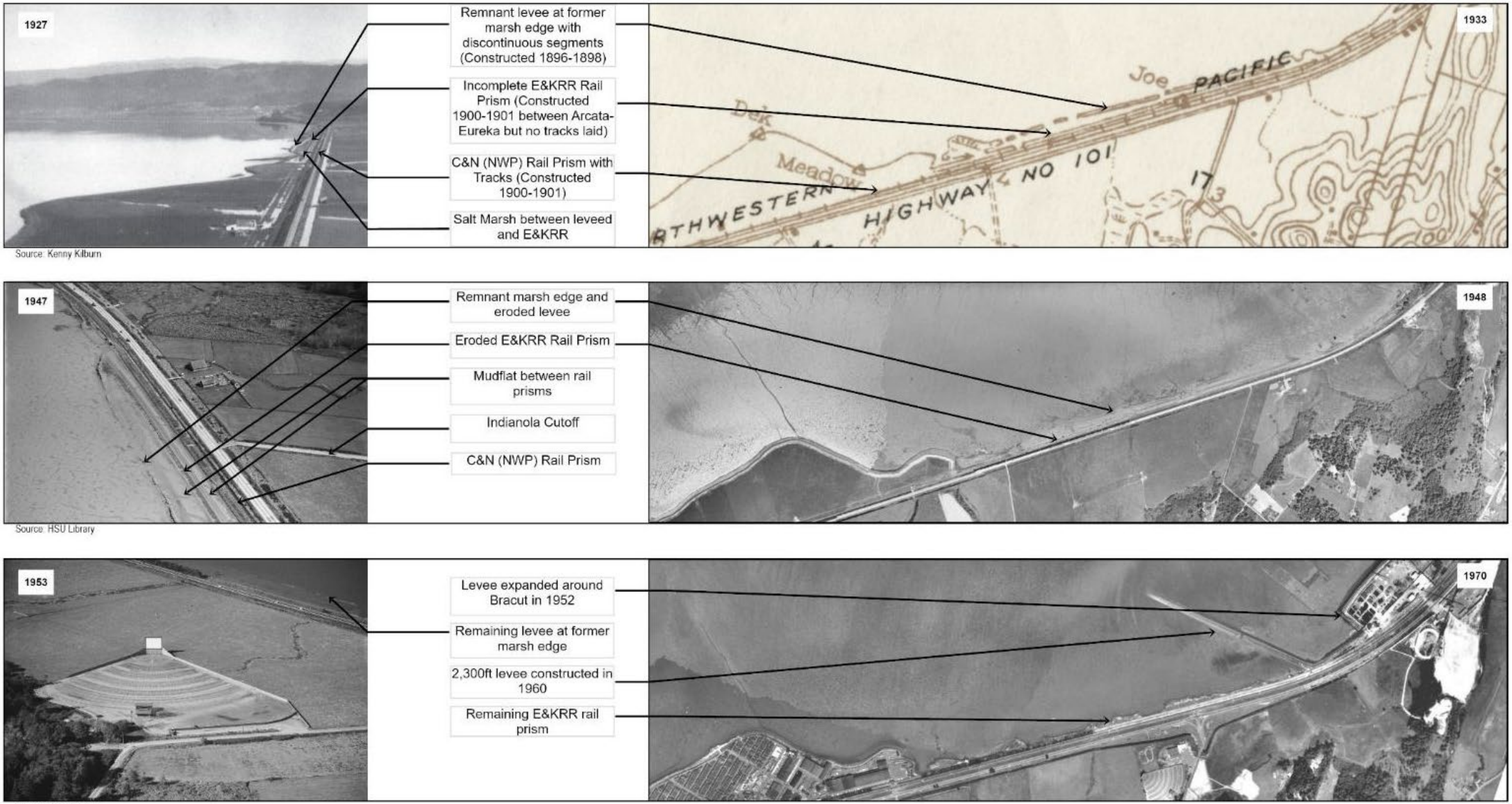


Figure 15 Project Shoreline Change from 1870 to Present.



Source: Kenny Kilburn

Source: HSU Library

Source: HSU Library

Figure 16 Shoreline Interventions and Change in Project Area

3.1 Historic Shoreline Position

The anthropogenic interventions described above have contributed to shoreline change within the project area, most notably the change in marsh edge position. Using historic georeferenced maps compiled for the Humboldt Bay atlas (Laird 2013), the marsh edge position was digitized for select years (1870, 1958, 1970 and 2020) to assess the lateral change in position overtime (Exhibits 2-4, 2-5 and 2-6). The mapping provides an approximate rate of horizontal marsh edge change over time. Relative to the Eureka Slough and Jacoby Creek marsh edges, the project area marsh edge has eroded at greater rates due in part to the former marsh edge leveeing and rail prism construction. Based on interpretation of the historic maps, approximately 44.3 acres of salt marsh existed within the project area in 1870 relative to 4.8 acres currently, an approximate 90% reduction (Figure 17). Generally, the shoreline position within the project area has shown a recession trend, however small discrete locations of salt marsh such as those present between the rail prisms near Indianola Cut-off appear to have formed following 1950 (Figure 18, Figure 19 and Figure 20).

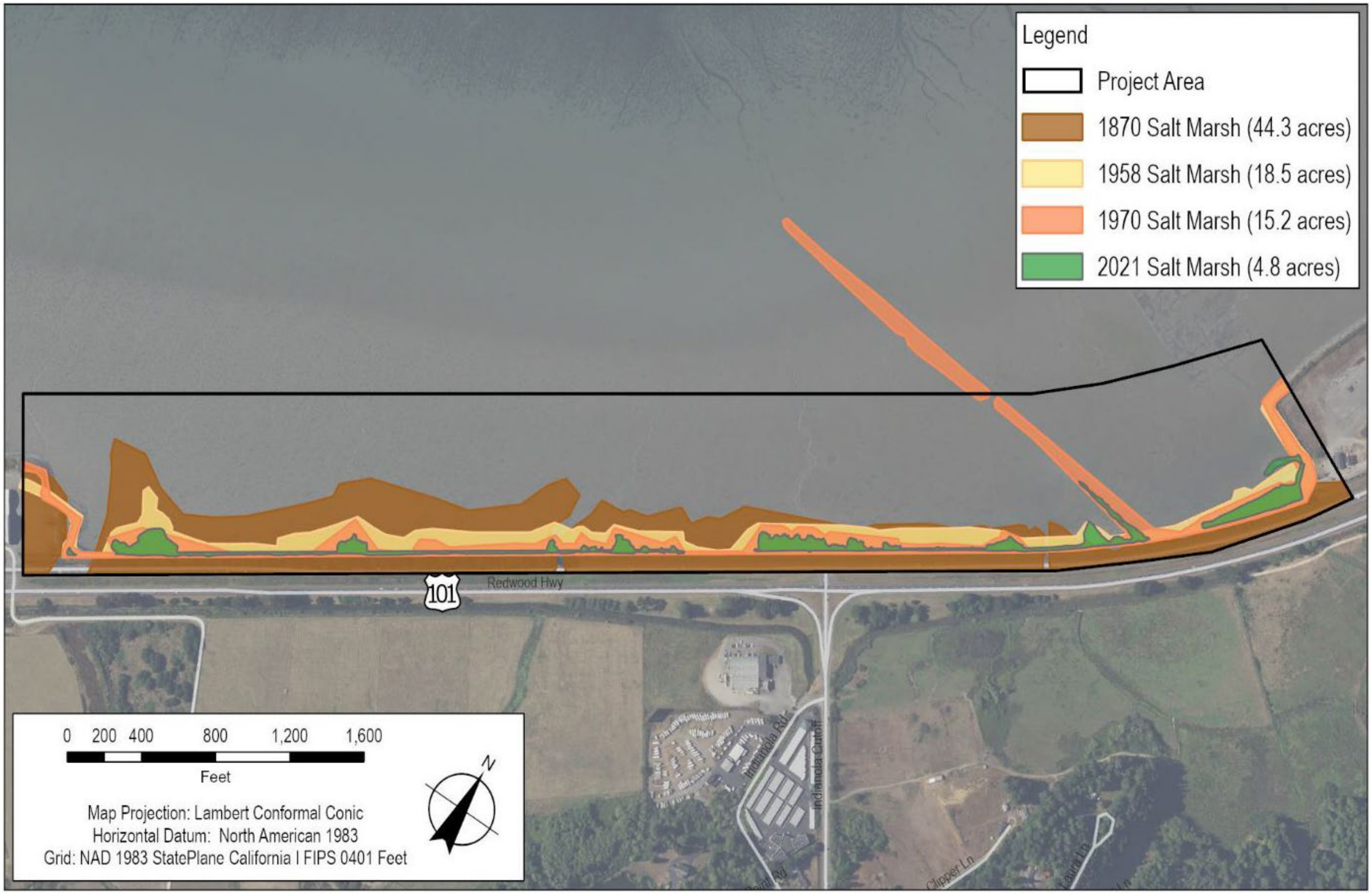


Figure 17 Reduction in Project Area Salt Marsh Since 1870.

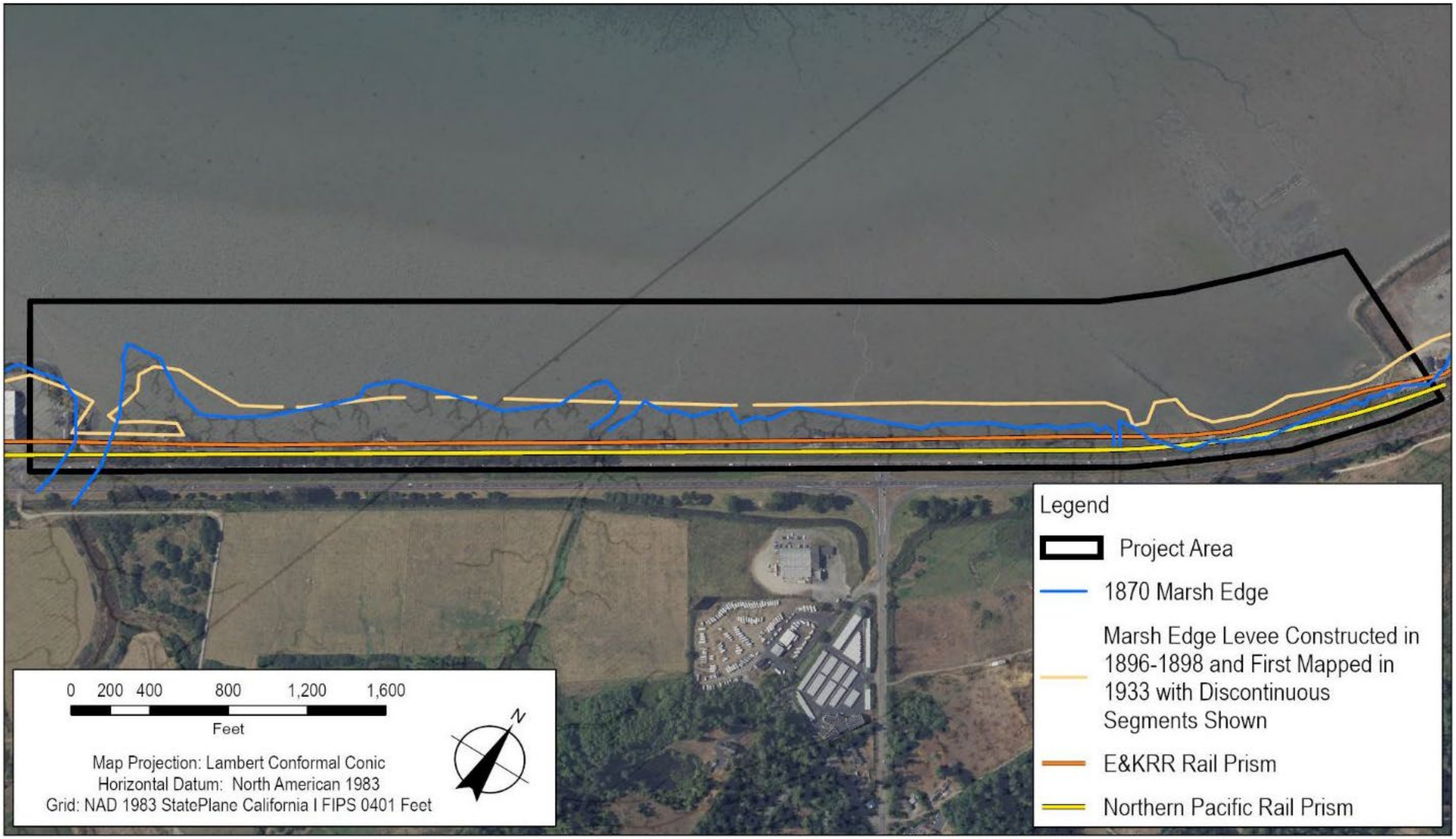


Figure 18 Map showing 1870 marsh edge, rail prisms and marsh edge levee constructed in 1896-1898 that was first mapped in 1933 showing disconnected segment

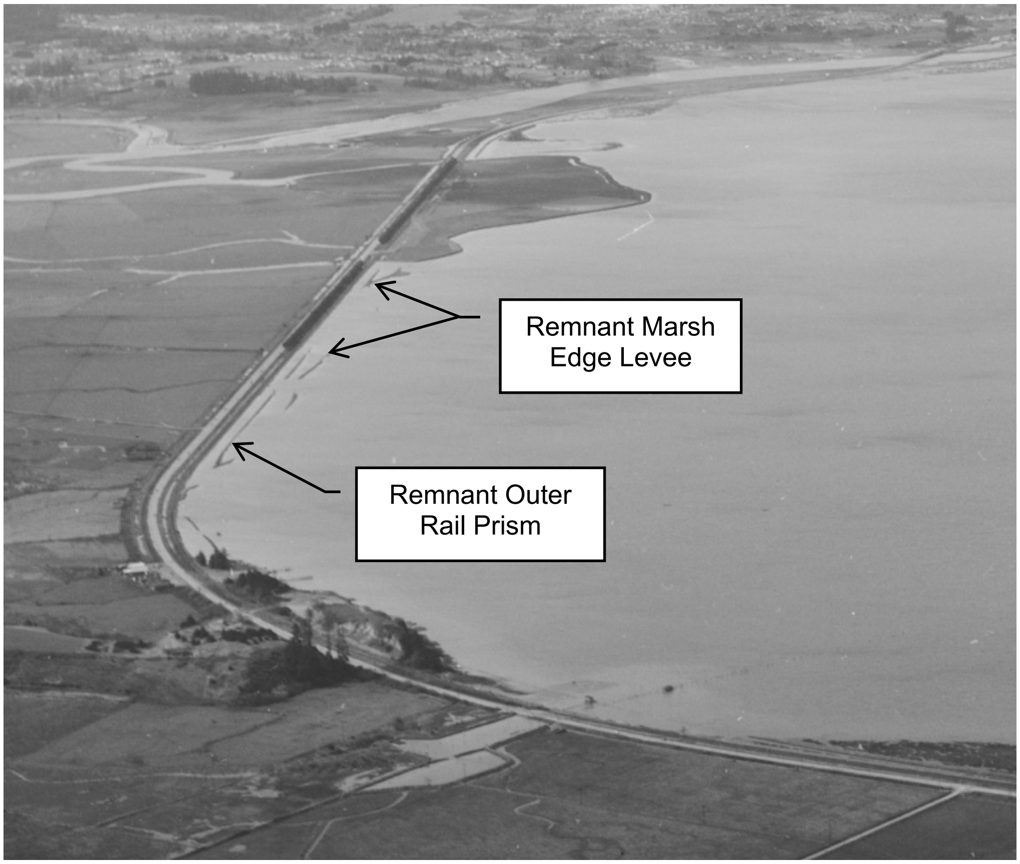


Figure 19 Aerial photo (circa 1940s) showing remnant marsh edge levee and outer rail prism

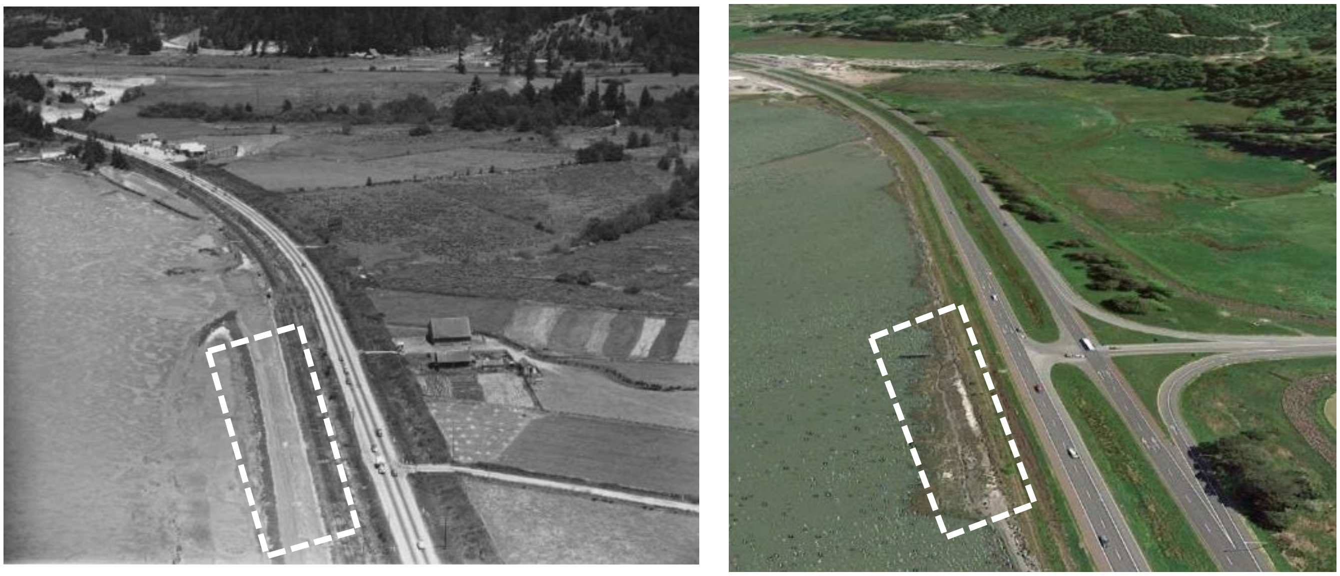


Figure 20 Comparison of 1947 (left) and current (right) air photos showing current presence of salt marsh in area that was mudflat in 1947

3.2 Summary of Historical Condition and Interventions

The interventions that have contributed most significantly to the shoreline change within the project area are shown on Figure 18 and the evolution of the project area from the pre-settlement period to current conditions can be summarized as follows:

- Stable sea level over the past 4,000 years facilitated formation of the dune ridge on the west side of Arcata Bay and the mudflat and salt marshes along the east shore of Arcata Bay.
- Landforms including subtidal channels, mudflats, and salt marsh suggested an equilibrium condition of sediment and hydrologic processes, and these distinct features are also closely related to the unique habitats of the Bay.
- Historic land practices in Humboldt Bay tributaries would have increased sediment delivery to the Bay and availability of sediment to the project area relative to current sediment loads.
- Historic dredging in Arcata Bay navigation channels may have influenced sediment distributions in the project area vicinity and created a temporal sediment sink.
- Increase in leveeing and draining of former tidelands around Arcata Bay during the early 1900's would have reduced sediment sinks, allowing more sediment availability to areas with full tidal exchange.
- Early modifications to the jetties and Bay entrance channel dredging to maintain a more persistent and deeper entrance channel could have increased the tidal prism, tidal range and circulation in Arcata Bay altering sediment dynamics.
- The salt marsh edge in the project area was leveed in 1895 and the salt marsh has experienced lateral erosion rates much greater than the Jacoby Creek and Eureka Slough marshes which were not leveed.
- The leveed marsh edge in the project area and rail prism construction in 1900 would have altered near shore tidal sediment exchange across the salt marsh and created an abrupt shoreline vulnerable to scour and erosion from wind-wave attack and overtopping (see Section 5.4.3.2 for discussion of the hydraulic effects that are hypothesized to have accelerated marsh erosion). Portions of the remnant marsh present today are located within the footprint of the outer rail prism (E&KRR) alignment.
- Frequent ferry and barge use during the logging and quarrying era would have exposed the unstable marsh edge to boat wake induced waves and increased shoreline erosion potential.
- The Bracut levee "peninsula" constructed in 1960, which has eroded laterally and longitudinally since construction, would have dissipated incident wind waves and reduced near-shore currents in the northern portion of the project area; this may have contributed to the expansion of the salt marsh present today near Indianola Cut-off and situated between the former rail prisms.

4. Existing Biological Habitats and Communities

The following sections describe the existing biological conditions of the project area within Humboldt Bay with a focus on habitat types, vegetation communities, and use of these habitat types by fish and wildlife.

4.1 Humboldt Bay Salt Marshes

Although approximately 90% of Humboldt Bay's salt marsh has been lost to development and agriculture, Humboldt Bay still supports approximately 905 acres of salt marsh (Pickart 2001, Schlosser and Eicher 2012). Coastal salt marshes occur within the upper intertidal zone in sheltered bays and estuaries (Schlosser and Eicher 2012). In Humboldt Bay, the most extensive un-diked salt marshes that are exposed to full tidal influence occur at the outlet of Jacoby Creek (~1 mile north of the project site), near Eureka Slough (~1 mile south of the project site), along the Mad River Slough, and on Indian Island (Pickart 2001). Humboldt Bay's salt marshes provide important ecosystem services such as absorbing wave and wind energy, supporting a productive food web, providing juvenile fish habitat, and carbon sequestration (Schlosser and Eicher 2012, Townend et al. 2011). Humboldt Bay's salt marsh vegetation is often classified into low marsh dominated by pickleweed (*Salicornia pacifica*), diverse high mixed-marsh with pickleweed and many other salt-tolerant species, and invaded marshes dominated by non-native dense-flowered cordgrass (*Spartina densiflora*) (Eicher 1987). Salt marsh vegetation zonation along an elevational gradient is an often-observed phenomenon that has been the topic of research worldwide. Salt marsh vegetation is exposed to increasing salt-water inundation and erosive wave action at lower elevations. Plants that can tolerate the stress of abiotic conditions at lower elevations may be outcompeted by less specialized plant species at higher elevations (Pennings et al. 2005, Townend et al. 2011, and others). Previous research in northern Humboldt Bay found that native pickleweed and non-native dense-flowered cordgrass may both be found at a wide tidal elevational range, but pickleweed tended to dominate the lower elevation marsh, dense-flowered cordgrass tended to dominate the middle of the tidal elevation range, and high marsh tends to have more native diversity and may be co-dominated by pickleweed and salt grass (*Distichlis spicata*) (Eicher 1987, Eicher and Schlosser 2012). Salt marsh is classified under the National Wetland Inventory/Cowardin wetland classification system as Estuarine Intertidal Emergent Wetland (FDGC 2013). Humboldt Bay shorelines with less than 30% vegetation cover that are primarily characterized by boulders, stones, or bedrock may be classified as Estuarine Intertidal Rocky Shore, whereas shorelines dominated by cobbles, gravel, sand, or mud are designated as Unconsolidated Shore (FDGC 2013).

4.2 Rare Plants

Rare plants associated with Humboldt Bay salt marshes include two hemiparasitic annual plants—Humboldt Bay owl's clover (*Castilleja ambigua* ssp. *humboldtiensis*) and Point Reyes bird's beak (*Chloropyron maritimum* ssp. *palustre*), that often co-occur and are typically associated with high marsh (Eicher 1987). Hemiparasitic plants such as Point Reyes bird's beak and Humboldt Bay owl's clover photosynthesize as well as parasitizing other salt marsh plants by tapping into the xylem of the host plant via haustoria (Grewell 2008, Eicher and Schlosser 2012). Parasitic plants may have a role in maintaining or enhancing biodiversity. Point Reyes bird's beak has been shown to reduce abiotic stress on some salt marsh host plants by extruding salt and to play a role in maintaining native biodiversity in the salt marsh (Grewell 2008).

Humboldt Bay owl's clover is a CNPS-listed 1B.2 rare annual herb endemic to the North Coast of California (Baldwin et al. 2012). NatureServe ranks the subtaxon as imperiled throughout its range (G4T2 S2). Humboldt Bay owl's clover may be threatened by development and non-native plants (CNPS 2020) such as dense-flowered cordgrass. Dense-flowered cordgrass invasion may displace the diverse high mixed marsh that supports Humboldt Bay owl's clover (USFWS 2020).

Point Reyes salty bird's beak is a CNPS-listed 1B.2 rare annual hemiparasitic herb that occurs in coastal salt marshes from Central California to Southern Oregon (Baldwin et al. 2012). Point Reyes salty bird's beak typically occurs in diverse mixed high marsh habitats in Humboldt Bay, much like Humboldt Bay owl's clover (USFWS 2020). The rare salt marsh plant was once common within its habitat, but populations have been greatly reduced by development (CNPS 2020). Point Reyes salty bird's beak may also be threatened by invasive dense-flowered cordgrass (USFWS 2020), trampling, hydrological alterations, and cattle grazing (CNPS 2020).

Western sand-spurrey (*Spergularia canadensis* var. *occidentalis*) is an annual salt marsh plant known only to occur in Humboldt Bay within California (CNPS 2021). Western sand spurrey is primarily distributed in salt marshes along the coast of the Pacific Northwest to British Columbia (Baldwin et al. 2012). Although secure throughout its northern range Pacific Northwest, CNPS considers the plant to be seriously endangered in California (CNPS 2021). NatureServe ranks the small annual plant as apparently secure throughout its range (Global Rank G5T4), but critically imperiled in California (State Rank S1) (CNPS 2021). This small annual plant can be somewhat cryptic where it may occur among the common co-generic salt marsh sand-spurrey (*Spergularia marina*), and the rare plant is best differentiated by its slightly larger winged seeds (Baldwin et al., 2012). CNPS considers the plant to be threatened by development (CNPS 2020), and it might also be threatened by invasive dense-flowered cordgrass displacing native pickleweed marsh habitat in Humboldt Bay. Like Humboldt Bay owl's clover and Point Reyes bird's beak, western sand-spurrey is typically associated with high marsh (Eicher 1987, Eicher and Schlosser 2012).

Previous botanical surveys have documented and mapped Humboldt Bay owl's clover, Point Reyes bird's beak, and western sand-spurrey in the vicinity of the project area (GHD 2017, Pickart 2001, and others as documented in CNDDB). Annual plant populations have the potential to shift and fluctuate from year to year, and updated surveys are needed to accurately determine any potential impacts to these plants.

4.3 Threats to Native Salt Marsh

The remaining native salt marsh in Humboldt Bay is vulnerable to invasion by dense-flowered cordgrass and increasing inundation and storm erosion associated with sea level rise. Invasive dense-flowered cordgrass, which is suspected to have arrived in the ballast of ships from Chile in the mid to late 1800s (Spicher and Josselyn 1985, H.T. Harvey and Associates 2012), invaded 94% of Humboldt Bay's salt marshes by 1999 (Pickart 2001). Dense-flowered cordgrass can outcompete and displace native pickleweed salt marsh (Pickart 2001). Studies in Humboldt Bay have shown that dense-flowered cordgrass invasion reduces primary productivity of the salt marsh (Lagarde 2012), reduces the biomass and abundance of algae (Augyte and Pickart 2014), reduces the abundance and diversity of native terrestrial invertebrate species (Mitchell 2012). Dense-flowered cordgrass is a prolific seed producer (Pickart 2012), and some seeds remain viable in the seedbank for at least four years (Abbas et al. 2021). Seeds are likely to disperse on tidal currents from invaded to restored salt marshes in Humboldt Bay (McDonald 2014) and floating seeds may be dispersed from Humboldt Bay on ocean currents south to central California and as far north as Alaska (Morgan and Sytsma 2013, McDonald 2014). Dense-flowered cordgrass invasion poses an ongoing threat to native and restored salt marshes in Humboldt Bay as well as salt marshes along the Pacific coast.

Sea level rise poses additional compounding threats to native salt marshes associated with increased frequency and duration of inundation, increased salinity, and increased erosive wave action. Because the native marsh habitat that supports rare annual plants as well as the highest biodiversity occurs at the upper extent of the tidal range, it may be the most immediately vulnerable to the increased abiotic stress associated with sea level rise (Donnelly and Bertness 2001). Salt marshes are a dynamic ecosystem that typically exist at a tidal elevation equilibrium level between sediment deposition and erosion (Thorne et al. 2014, Townend et al 2011, and others). Where sedimentation is high, salt marsh accretion may be able to keep pace with the rate of sea level rise (Curtis et al 2019, Thorne et al. 2014, Townend et al. 2011). Where salt marshes are backed by a natural low sloping brackish marsh to upland ecotone, salt marshes may be able to retreat and persist further inland as the sea level rises (Townend et al. 2011). However, narrow fringe marshes backed by steep dikes without a substantial source of sediment, such as the project area, are at risk of disappearing as the sea level rises (Curtis et al. 2019, Schlosser and Eicher 2012, Thorne et al. 2019). Salt marshes in Humboldt Bay have shown overall accretion trends, but accretion rates appear to be falling short of the local rates of relative sea level rise (Curtis et al. 2019).

4.4 Restored Salt Marshes

U.S. Fish and Wildlife and other natural resource managers in Humboldt Bay have conducted extensive salt marsh restoration by removing dense-flowered cordgrass. Intensive dense-flowered cordgrass removal efforts in Humboldt Bay began in 2004 in salt marsh managed by U.S. Fish and Wildlife Service along the Mad River Slough (Pickart 2005). Jacoby Creek restoration efforts began with an experimental pilot project in 2011 (Pickart 2013). Restoration at both the Mad River Slough and Jacoby Creek sites resulted in rapid expansion of Humboldt Bay owl's clover populations (Eicher and Pickart 2011, Pickart 2012). Mechanical treatment of dense-flowered cordgrass caused an initial lowering of the salt marsh elevation, which rebounded within two years of treatment (Pickart 2013). Jacoby Creek, which may be a major source of sediment to the surrounding salt marsh, has shown steady accretion and increases in elevation relative to a local benchmark since 2016 (Curtis et al. 2019). Eureka Slough, which was formerly highly invaded by dense-flowered cordgrass (Grazul and Rowland 2011), was most recently restored, beginning around 2013.

4.5 Project Area Habitat Types and Vegetation Communities

Reconnaissance-level surveys for rare plants were conducted on May 29, 2020, by walking the project area from south to north and noting rare plant occurrences. Vegetation communities below the rail prism were documented in the field and classified at the alliance level according to the Manual of California Vegetation (Sawyer et al. 2009) using the Rapid Assessment conducted on March 30, 2021. Vegetation Assessment forms (Appendix B) are used to characterize dominant vegetation and evaluate habitat quality, and these assessments provide the basis for designating vegetation as Sensitive Natural Communities per CDFW. Photodocumentation of habitats observed onsite can be found in Appendix B, Vegetation communities were mapped using points collected in the field with an Eos Arrow 100 Submeter Global Positioning System (GPS) Receiver with Global Navigation Satellite System (GNSS) and an iPad running ArcGIS Collector software in the WGS84 datum. Vegetation community boundaries were then digitized with GIS from aerial imagery based on field observations and visible vegetation signatures. Wetland habitat mapping along the rail prism was conducted by GHD in 2014 to 2017 and incorporated into vegetation maps for this project.

4.5.1 Special Status Plants

Rare Humboldt Bay owl's clover, Point Reyes bird's beak, and western sand-spurrey were observed within the project area. Strong overlap in habitat was observed among all three species, which typically were associated with diverse high salt marsh dominated by pickleweed (*Salicornia pacifica*). Western sand-spurrey was present in salt marshes throughout the project area and was commonly associated with patches of low vegetative cover, pickleweed dominance, and high-marsh species such as common arrowgrass (*Triglochin maritima*) and marsh jaumea (*Jaumea carnosa*). Both Humboldt Bay owl's clover and Point Reyes bird's beak occurred from the central portion of the project area (south of the Indianola cut off) to the northern extent of the project area at Bracut. Humboldt Bay owl's clover and Point Reyes bird's beak often occurred in the same areas and were strongly associated with the remaining diverse native high marsh habitat dominated by pickleweed (Figure 21). Humboldt Bay owl's clover appeared to be less prevalent than the other two rare species within the project area. Mapping the populations and systematic sampling to obtain population estimates will be needed prior to any potential impact.

Figure 21 Unusual salt marsh zonation in central project area with diverse native high marsh and rare plants in the foreground, and dense-flowered cordgrass dominating the area along the rail prism and portions of the outer fringe.

4.5.2 Vegetation Alliances and Habitat Types

Vegetation below the rocked rail prism was mapped by vegetation alliance by GHD in 2021 to supplement wetland habitat typing in 2014-2017 (Appendix A). Out of the approximately 6,700-foot stretch of rail prism within the project area between Bracut and Brainard, approximately 60% (~6,040 feet) is fringed by vegetated salt marsh, and 40% is lacking substantial salt marsh vegetation. The areas lacking salt marsh primarily consisted of gravelly and cobbly unconsolidated shore below the rocked rail prism, which was classified as Estuarine Intertidal Rocky Shore. An area of mudflat in the vicinity of the rail prism was mapped as Unconsolidated. Both the vegetated salt marsh and unconsolidated shore showed widespread signs of erosion, with undercut banks occurring both in the salt marsh and along the rocked rail prism. Total acreages of vegetation and other land cover types can be found in Table 3.

Table 3 Acreage of Vegetation and Land Cover Types within the Project Area

Vegetation Type	Area (acres)
Native pickleweed salt marsh	1.93
Invasive dense-flowered cordgrass salt marsh	1.57
Coastal tufted hairgrass high marsh	0.17
Coyotebrush shrubland	0.06
Intertidal rocky shore	1.43
Unconsolidated shore	0.67

Pickleweed (Salicornia pacifica) Alliance (S3, G4)

Pickleweed dominated 1.93 acres of the remaining fringe salt marsh that has not been highly invaded by dense-flowered cordgrass. The pickleweed alliance as mapped in the project area is predominantly diverse high marsh that supports rare Humboldt Bay owl's clover, Point Reyes bird's beak, and western sand-spurrey as well as other native species such as common arrowgrass, marsh jaumea, saltgrass (*Distichlis spicata*), and marsh rosemary (*Limonium californicum*). Invasive dense-flowered cordgrass was present throughout the project area, and percent cover of invasive dense-flowered cordgrass ranged up to an estimated 25% absolute cover (<50% relative cover) within native pickleweed salt marsh. Native pickleweed salt marsh composed approximately 55% of the marsh in the project area.

Invasive Dense-flowered Cordgrass (Spartina densiflora) Semi-Natural Alliance

Highly invaded areas with >50% relative cover of non-native dense-flowered cordgrass were classified as part of the dense-flowered cordgrass semi-natural alliance (Sawyer et al. 2009). Dense-flowered cordgrass dominates 1.57 acres of the salt marsh in the project area. High cover of dense-flowered cordgrass appeared to be associated with the outer fringe of the salt marsh, particularly in areas that may be subjected to higher disturbance from wind-waves such as the northern side of the remnant levee “peninsula” in the northern portion of the project area. Dense-flowered cordgrass also appeared to thrive around lower elevation tidal channels within the project area, and it is hypothesized that dense-flowered cordgrass may be invading areas with higher abiotic stress from inundation and disturbance at a higher rate than sheltered, higher elevation areas. Additional research is recommended to test this hypothesis and determine the primary factors that lead to rapid invasion, and conversely, factors that may facilitate the preservation of native high salt marsh. Rare plants were also observed within areas mapped as greater than 50% relative cover of dense-flowered cordgrass, but were observed less frequently and often in small native-dominated patches within the dense-flowered cordgrass vegetation.

Tufted Hairgrass (Deschampsia cespitosa) Alliance (S3, GNR)

Tufted hairgrass occurred as a narrow, but notable, linear feature near the upper limit of potential tidal influence at the transition to upland along the rail prism along small segments of the project area. In addition, tufted hairgrass was sparsely distributed along the upper tidal transition zone elsewhere along the rail line. Tufted hairgrass was also abundant within a sheltered pocket of high marsh south of the Bracut industrial area Figure 22. A total of 0.17 acres were mapped as coastal tufted hairgrass marsh. Other species associated with this herbaceous vegetation type included saltgrass, San Francisco rush (*Juncus lescurii*), red fescue (*Festuca rubra*), sparse dense-flowered cordgrass, and non-native ruderal grasses such as sweet vernal grass (*Anthoxanthum odoratum*). Tufted hairgrass overlapped with shrubs at the upper elevational range such as coyotebrush (*Baccharis pilularis*), California wax myrtle (*Morella californica*), cascara sagrada (*Frangula purshiana*), and coast twinberry (*Lonicera involucrata*), but areas with coyotebrush and other shrubs were separately classified as the coyotebrush shrubland alliance. Tufted hairgrass is a salt-tolerant native wetland grass that may be associated with high salt marsh (Eicher 1987), brackish areas, and wet meadows (Sawyer et al. 2009).

Figure 22 Tufted hairgrass (Deschampsia cespitosa) with San Francisco rush near Bracut

Coyotebrush (Baccharis pilularis) Shrubland Alliance (S5, G5)

Coyotebrush and other shrubs such as coast twinberry and cascara sagrada with invasive species such as pampas grass (*Cortaderia jubata*) and teasel (*Dipsacus fullonum*) occurred on the top of the berm near Bracut industrial area within the project area. Shrubs and small trees were also widespread along the top of the rail prism, but these areas were not classified because they were outside of the project area.

4.5.3 Habitat and Vegetation Mapping Summary

Approximately 60% of the project area along the Highway 101 corridor between Bracut and Brainard is fringed by salt marsh. The native pickleweed alliance (1.93 acres) and the non-native dense-flowered cordgrass semi-natural alliance (1.57 acres) were the primary vegetation alliances classified according to the Manual of California Vegetation (Sawyer et al. 2009). The pickleweed alliance consisted of diverse high marsh and some of these native-dominated areas supported abundant populations of rare western sand-spurrey, Point Reyes bird's beak, and Humboldt Bay owl's clover. The dense-flowered cordgrass semi-natural alliance consisted of highly invaded areas with at least 50% relative cover of the non-native cordgrass, and highly invaded areas often appeared to be associated with the outer fringe of the salt marsh, small tidal channels, and areas that are likely to be exposed to increased wave action and inundation. Additionally, native tufted hairgrass (0.17 acres) was notably dominant along some narrow stretches of the rail prism near what appeared to be the upper limits of the tidal range and within a sheltered high marsh near the Bracut industrial area. Uppermost elevations within the project area along the high berm near Bracut was characterized by coyotebrush, other shrubs, and some weedy upland species.

Additional research correlating local tidal elevation with vegetation type and the occurrence of rare salt marsh plants (as in Eicher 1987), or developing a more detailed model to predict plant composition based on abiotic factors (e.g. inundation frequency and duration, exposure to erosive wave action, salinity, such as in Moffett et al. 2010) would help guide shoreline enhancement project design to create or preserve native high marsh habitat and rare salt marsh plant populations.

4.6 Fish and Wildlife Abundance and Distribution of Humboldt Bay

As described above, the diverse range of habitat types around the Bay support numerous fish and wildlife species (Monroe et al. 1973, Gleason et al. 2004, Harbor District 2007). Many of these species are federally or state protected. For example, various species of bats, many of which are state special status species, may forage throughout the vicinity of Humboldt Bay. Marine mammals, protected under the Marine Mammal Protection Act, occur throughout the Bay, but especially near deeper channels. Amphibian and reptile species, several which are state special status, are primarily located near perennial freshwater sources around the Bay, though a few will use very mildly brackish water.

Humboldt Bay is considered an atypical estuary because true estuarine conditions rarely occur due to limited freshwater inflows and little mixing occurs (Gleason et a. 2004). Noteworthy amongst the 110 fish species known from Humboldt Bay are the federally endangered Tidewater Goby (*Eucyclogobius newberryi*), federally threatened Green Sturgeon (*Acipenser medirostris,* Southern DPS) and anadromous salmonids: Coho Salmon (*Oncorhynchus kisutch*), Steelhead (*Oncorhynchus mykiss irideus*), and Chinook Salmon (*Oncorhynchus tshawytscha;* Barnhart et al. 1992). Critical habitat for these species has been designated within Humboldt Bay.

The state threatened Longfin Smelt (*Spirinchus thaleichthys*) is also known to occur in the Bay. Despite being under review for listing at the federal level several times since 1994, Longfin Smelt in Humboldt Bay (not part of the San Francisco Bay delta population which is a candidate species, proposed for listed but precluded) remain under review at this time (USFWS 2021). A 2000/2001 study of fish abundance, diversity, and distribution in Humboldt Bay identified 67 species from 25 families and found Threespine Stickleback (*Gasterosteus aculeatus*), Shiner Surfperch (*Cymatogaster aggregata*), and Topsmelt (*Atherinops affinis*) to be the most abundant species (Gleason et al. 2004). Fisheries investigations in Humboldt Bay have failed to observe large numbers of juvenile salmonids (Eldridge and Bryan 1972), although small individual counts were documented by Gleason et al. (2004). The Bay is also an important nursery for several commercial fisheries as well as for commercial crab (Barnhart et al. 1992).

Essential Fish Habitat (EFH) is designated for species managed in Fisheries Management Plans (FMP) under the Magnuson-Stevens Fishery Conservation and Management Act (MSA). Under the MSA, Humboldt Bay is designated as EFH within the Pacific Coast Salmon FMP (Chinook, Coho, and Pink Salmon), within the Coastal Pelagic Species FMP (5 species, including Pacific Herring, and Euphausiids), and within the Pacific Coast Ground Fish FMP (85 species; NOAA Fisheries 2021a).

Specifically, within the Pacific Coast Salmon FMP, Humboldt Bay includes EFH for Chinook and Coho Salmon. The Pacific Coast Salmon FMP (as amended) was created to manage commercial and recreational salmon fisheries along the West Coast of the U.S. In addition, the plan designates Habitat Areas of Particular Concern (HAPC) including complex channels and floodplains, thermal refugia, spawning habitat, estuaries, and marine and estuarine submerged aquatic vegetation (NOAA Fisheries 2021b). Some of these HAPCs are present in Humboldt Bay: The Bay is an estuary and contains floodplains and marine and estuarine submerged aquatic vegetation.

The Coastal Pelagic Species FMP (as amended) was created to promote efficient, sustainable, and profitable fishery practices and to prohibit the harvest of krill species. No HAPCs for the Coastal Pelagic Species FMP have been designated.

The Pacific Coast Groundfish FMP (as amended) prohibits activities such as bottom trawling and dredging that could result in long-term damage to the ocean floor (PFMC 2019). In addition, the plan designates HAPC including estuaries, canopy kelp, seagrass (i.e., eelgrass), rocky reefs, and areas of interest (NOAA Fisheries 2021b). Two of these HAPCs are present in Humboldt Bay: The Bay is an estuary, and presence of eelgrass has been documented (CDFW 2021, HBHRCD 2021).

A broad range of avian taxa utilize Humboldt Bay year-round, though there are strong seasonal fluctuations with highest numbers in the fall and winter (Monroe et al. 1973). The vast majority of these species are protected by the Migratory Bird Treaty Act and California Fish and Game Code. Due to its location along the Pacific Flyway (spanning the Pacific coast, west of the Rockies, of the Americas), Humboldt Bay is an important stopover site for Nearctic shorebirds (Colwell and Feucht 2018). It is recognized as an “Important Bird Area” by the National Audubon Society

(Audubon Society 2021), an “internationally significant area for migratory birds” by the American Bird Conservancy (USFWS 2013), and a site of International Importance by the Western Hemisphere Shorebird Reserve Network (WHSRN; Colwell and Feucht 2018). Colwell and Feucht (2018) have documented use of Humboldt Bay by 26 species of shorebirds, numbering over half a million birds during spring migration alone. These new numbers justified upgrading Humboldt Bay to Hemispheric (e.g., Hemispheric, International, or Regional) recognition in 2018 as well as promoting additional conservation efforts (Colwell and Feucht 2018). The Humboldt Bay Complex was recently announced as the first winner of the Outstanding WHRSN Site award (WHSRN 2021).

The following sections describe the wildlife, avian and fish use of salt marsh and mudflat habitats found within Humboldt Bay.

4.6.1 Wildlife Use of Salt Marsh

Numerous common mammalian species, particularly small mammals (such as California Vole [*Microtus californicus*], Vagrant Shrew [*Sorex vagrans*], Western Harvest Mouse [*Reithrodontomys megalotis*], and others), may be present in the salt marshes of Humboldt Bay. Common mesocarnivores (such as Gray Fox [*Urocyon cinereoargenteus*], Coyote [*Canis latrans*], Raccoon [*Procyon lotor*], Bobcat [*Lynx rufus*], skunks [*Mephitis mephitis* and *Spilogale putorius*], Long-tailed Weasel [*Mustela frenata*]) use the edges of Humboldt Bay and prey upon abundant small mammals (Monroe et al. 1973). Columbian Black-tailed Deer occur in the foothills surrounding Humboldt Bay and have been found swimming within the North/Arcata Bay (Monroe et al. 1973). Humboldt Bay hosts a healthy River Otter (*Lontra canadensis*) population that has been the focus of extensive research. Salt marshes do not include suitable roosting habitat for bats. Nonetheless, many species of bats may forage above or near salt marshes, if prey (such as flighted insects) is available (Johnston 2007).

Winters in Humboldt Bay typically involve extended periods of rainfall. Storms and king tides can lead to flooding which likely limits terrestrial wildlife activity within salt marshes. River Otter latrine use within Humboldt Bay peaks in both spring and fall (Torgerson 2014). Fish-eating predators such as River Otters, Raccoons, etc. likely follow anadromous salmonid migratory activity (timing varies by species with runs in every season and the largest runs in the fall and winter). Although many wildlife species utilize salt marshes, few are able to inhabit them year-round because of the extreme environmental conditions; rather most species are transient (USFWS 2019).

Microhabitat types within salt marshes include low marsh, high marsh, saltmarsh/upland ecotone, benthic habitat, and tidal creeks (Deering Estate and UM unkn. year). Levels of salinity affect plant diversity (high vs. low marsh) and therefore impact wildlife diversity based on what plants provide forage (e.g., seeds for small mammals), habitat for invertebrate species, height and cover (e.g., to escape flooding and predators).

Terrestrial wildlife use of salt marshes is likely limited by proximity to available food resources, cover from predators, suitable dens, high ground refugia from flooding, freshwater sources, and adjacent habitat corridors (Krebs 2009). Additionally, patch size and morphology of salt marsh, wildlife species home range, and human alteration all influence wildlife use within salt marshes (McKinney and Wigand 2006).

4.6.2 Avian Use of Salt Marsh

A wide range of avian species, including land birds (passerines, upland game birds, etc.) and water-associated birds (shorebirds, waterfowl, wading birds, miscellaneous, and pelagic and coastal birds) as well as raptors, may be found in the salt marshes surrounding Humboldt Bay (Monroe et al. 1973). Shorebirds (such as Dunlin [*Calidris alpina*], sandpipers [*Calidris* spp.], Black-bellied Plover [*Pluvialis squatarola*], dowitchers [*Limnodromus* spp.], Sanderling [*Calidris alba*], Willet [*Tringa semipalmata*], Marbled Godwit [*Limosa fedoa*], Black Turnstone [*Arenaria melanocephala*], Killdeer [*Charadrius vociferus*], phalaropes [*Phalaropus* spp.], and Wilson’s Snipe [*Gallinago delicata*]) may utilize salt marsh as resting and roosting areas (Monroe et al. 1973, Harris 2005, Conklin and Colwell 2007), and to a minor extent foraging habitat as well (Monroe et al. 1973). In addition to shallow water areas, salt marshes are important feeding grounds for wading birds (such as egrets, herons, and American Bitterns [*Botaurus lentiginosus*]) (Monroe et al. 1973). Raptors also utilize Humboldt Bay salt marshes to roost as well as forage upon small mammals within them. Some species, such as Northern Harriers (*Circus hudsonius*), may breed in these areas

(Smith et al. 2020). To avoid flooding, much of the nesting activity is concentrated in the high marsh (McKinney and Wigand 2006).

The highest avian numbers occur in the fall and winter due to large influxes of migratory and wintering birds (Monroe et al. 1973). Salt marshes serve as resting, roosting, and foraging habitat for wintering and migratory shorebirds (Burger et al. 1997, Conklin and Colwell 2007), with greatest numbers documented from September through April (Monroe et al. 1973). During the spring and summer, salt marshes serve as breeding habitat for land birds and miscellaneous water-associated birds (coots, rails, grebes, and loons), and to a lesser extent shorebirds and some raptors. Most waterfowl are migrant visitors to Humboldt Bay during fall and winter (Monroe et al. 1973). Although some breed locally, the vast majority breed in northern latitudes in Alaska and Canada (Monroe et al. 1973). Waterfowl nest near water courses and may be found nesting in salt marshes, though nesting primarily occurs in adjacent pasturelands, freshwater marshes, and sloughs (Monroe et al. 1973). Virginia Rail (*Rallus limicola*), Sora (*Porzana carolina*), and Pied-billed Grebe (*Podilymbus podiceps*) nest locally in the emergent vegetation of salt marshes (Monroe et al. 1973).

Tidal-marsh bird species occupy niches defined by food resources and habitat along the tidal gradient (Takekawa et al. 2011). These birds can be grouped into the following guilds: aerial, marsh surface, benthic, or aquatic foraging guilds (Takekawa et al. 2011). Each guild can be further grouped based on the habitat they utilize including upland transition and high marsh plain; mid- and low-marsh plain; tidal creeks and channels (Takekawa et al. 2011). The upland transition and high marsh plain occur at the inland edge of the marsh (Takekawa et al. 2011). The Song Sparrow (*Melospiza melodia*) is an example species that utilizes the upland transition and high marsh plain. The mid-marsh plain is characterized by regular inundation and plants with less tolerance for full inundation such as pickleweed. The mid-marsh plain is located between mean high water and mean higher high water (Takekawa et al. 2011). The Northern Harrier is an example species that utilizes the mid-marsh plain (foraging). The low marsh is characterized by daily inundation, tall emergent vegetation (e.g., cordgrass), and typically occurs near tidal channels (Takekawa et al. 2011). The Willet (*Tringa semipalmatus*) and Marsh Wren (*Cistothorus palustris*) are species that utilize the low marsh plain. Tidal creeks and channels make up an extensive drainage web through low-marsh and mid-marsh plain habitats and serve to move water, invertebrates, fish, sediment, and nutrients (Takekawa et al. 2011). Herons and egrets utilize tidal creeks and channels for foraging (Takekawa et al. 2011).

In a study of wildlife use within salt marshes in New England, high marsh was the most used of all marsh microhabitat types. Time of year, tides, vegetation density, height, and dominant species influence nest site selection of breeding birds (Gjerdrum et al. 2005). Human disturbance and proximity likely affect foraging and roost site use in Humboldt Bay, as well as location, distance to tidal flats, and habitat type (Conklin et al. 2008).

4.6.3 Fish Use of Salt Marsh

Fish use of salt marshes in Humboldt Bay has not been widely studied. Most fish species in Humboldt Bay are caught from deep channels, as well as near rocky structures and piers. However, salt marshes serve as important nursery habitat for numerous fish species (Barnhart et al. 1992). In addition to supporting fish, benthic invertebrates also utilize intertidal salt marshes as nursery habitat. Benthic invertebrates occur within salt marshes year-round at relatively stable numbers (Barnhart et al. 1992). Dominant species include gastropods, crustaceans, and polychaetes (Barnhart et al. 1992).

Salt marsh habitat is only intermittently inundated and thus not always available (West and Zedler 2000). Chamberlain and Barnhart (1993) documented fish use in established salt marshes at the present-day Woodley Island Marina and mitigation salt marsh in Freshwater Slough in an upper estuarine environment. The investigation identified 31 species of fish and two species of crab, noting high variability in seasonal salinities, water temperature, and marsh elevation influenced fish use in the mitigation marsh in Freshwater Slough. The salt marsh provided feeding and possibly spawning habitat to observed species (Chamberlain and Barnhart 1993). Dominant species in the mitigation marsh were euryhaline Sticklebacks and Topsmelt (Chamberlain and Barnhart 1993). Other species included Pacific Herring (*Clupea pallasii*), Prickly Sculpin (*Cottus asper*), Shiner Surfperch, Walleye Surfperch (*Hyperprosopon argenteum*), Surf Smelt (*Hypomesus pretiosus*), Pacific Staghorn Sculpin (*Leptocottus armatus*), English Sole (*Parophrys vetulus*), and White Surfperch (*Phanerodon furcatus*), Starry Flounder (*Platichthys stellatus*). Tidwater Goby and Arrow Goby (*Clevelandia ios*) were also present. Salmonids and Longfin Smelt were not detected.

The evaluation of regularly and irregularly flooded salt marsh estuarine habitat across numerous Humboldt Bay sites (including those near the NSI project shoreline) by Gleason et al. (2004) found the most abundant species to be Shiner Surfperch, Topsmelt, Surf Smelt, sculpin of various species, and Speckled Sanddabs. Two Coho Salmon (unknown life stage) were observed in small channels segmenting the mudflats in the northeast corner of Humboldt Bay.

Fish were estimated to use salt marsh habitat in Southern California approximately 16% of the time, given tidal constraints. Dietary analysis found the salt marsh provided fish foraging habitat during high tides when the salt marsh was inundated. Fish utilizing the salt marsh habitat consumed up to six times more food compared to fish of using only nearby creek habitats (West and Zedler 2000).

4.6.4 Wildlife Use of Mudflats

Marine mammals including Harbor Seals (*Phoca vitulina*) and to a lesser extent Steller Sea Lion *(Eumetopias jubatus)* and occasionally California Sea Lions (*Zalophus californianus*), may be found hauled out on mud flats. River Otters may travel through mudflats to access aquatic habitats. They may also forage on fish (such as those stranded at low tide) or shellfish in these areas.

Kelp greenling (*Hexagrammos decagrammus*) and lingcod (*Ophiodon elongatus*) may be found in mud flat water courses (Monroe et al. 1973). Flounders (eight species) are throughout Humboldt Bay within channels and sandy and mudflat bottoms. Many additional fish species associate with eelgrass present in shallow nearshore waters (temporally exposed mudflat) (provides foraging and nursery habitat). Mudflats also serve as important feeding areas for juvenile crabs (Monroe et al. 1973). Furthermore, areas with eelgrass are utilized for cover (Monroe et al. 1973).

A rich invertebrate community is present within intertidal mudflats. Invertebrate diversity and abundance are dependent upon “sediment composition and location in relation to tidal submergence time” (Monroe et al. 1973), as well as seasonal salinity (Barnhart et al. 1992). Dominant invertebrates within the high mudflats include polychaetes, crustaceans, and mollusks (Barnhart et al. 1992). Mollusks and polychaetes are the dominant invertebrates at low tidal levels in areas with sandy substrates.

Harbor Seals use Humboldt Bay as a pupping site (haul out on mudflats), with peak numbers from February through August (Monroe 1973). River Otters and other fish-eating mammals likely return to the mudflats of the Bay to capitalize on migratory salmonid activity (timing varies by species with largest runs in the fall and winter).

At lower tides, the vast majority of the expansive shallow North/Arcata Bay may be exposed. Water depth and proximity to deep channels (especially for movement of marine mammals and fish) as well as the mainland (especially for terrestrial mammals) likely influence distribution and use. Two types of mudflats, high and low, are present around the Bay. Low mudflats are characterized by areas of gradual contouring, irregular surfaces composed of small mounds and channels, as well as shallow water pools in which eelgrass and widgeon grass and associated plants grow (Monroe et al. 1973). In contrast, high mudflats are characterized by smooth surfaces, a gentle contouring, well-spaced tidal channels, and limited plant life (Monroe et al. 1973). Mammalian wildlife forage upon the abundant fish, mollusks, and crustaceans available within high and low mudflats of Humboldt Bay.

4.6.5 Avian Use of Mudflats

Mudflats are important foraging habitat for an array of water-associated birds including shorebirds, wading birds, waterfowl, and pelagic and coastal birds. Raptors (e.g., Peregrine Falcon [*Falco peregrinus*]) may also depredate on water-associated birds foraging on mudflats. Mudflats are utilized as important feeding grounds for diving ducks where they primarily consume marine organisms (Monroe et al. 1973). In contrast, puddle ducks (except for American Widgeon [*Mareca americana*] which largely feed on eelgrass) although often frequently seen in large numbers on the Bay, likely gain most of their food resources from adjacent freshwater mashes and pasturelands (Monroe et al. 1973). As previously discussed, Humboldt Bay is critically important area for shorebirds because of concentrated use along the Pacific Flyway, with intertidal mudflats being the most heavily used habitat type (Monroe et al. 1973). Shorebirds forage for organisms such as mollusks, gastropods, arthropods, and insects within the exposed mud, following the water line as it goes in and out with the tides (Monroe et al. 1973).

Humboldt Bay hosts the greatest numbers of avian species during fall and winter when migratory and wintering birds are present (Monroe et al. 1973). Many of these species depend upon the rich algal, plant, invertebrate, crustacean, and fish communities within the marsh to sustain their populations through the winter, to “fuel up” during migration, and/or during the breeding season.

Some species, such as the Western Sandpipers (*Calidris mauri*), specialize on mudflats, while others (e.g., Willits) opportunistically use mudflats and salt marshes at high tide (Long and Ralph 2001). Danufsky and Colwell (2003) investigated the relationship between wintering shorebird use and habitat characteristics in Humboldt Bay and determined that size (ranging from fine, clayey silts to coarse sands) can either positively or negatively affect distribution, depending on the species. Broadly, their study showed a positive correlation of shorebirds with sediment heterogeneity.

During high tides, birds are forced to vacate foraging areas within mudflats. Alternate foraging habitat is available within adjacent pasturelands during the winter and spring (Long and Ralph 2001). The two primary factors influencing field use by shorebirds in Humboldt Bay studied by Long and Ralph (2001) were 1) presence of short vegetation and 2) the presence or absence of standing water.

4.6.6 Fish Use of Mudflats

Pinnex et al. (2006) investigated fish communities in oyster culture, eelgrass, and mudflat habitats of northern Humboldt Bay during field investigations spanning two years. The study included four sample sites in the East Bay Channel – the channel nearest the project shoreline – and identified 49 fish species from 22 families. Juvenile salmonids were not captured. Of captured species, 57% of individuals were resident and 42% were using Humboldt Bay as a nursery (Pinnex et al. 2006).

Species captured in the largest numbers included Shiner Surfperch, English Sole, Northern Anchovy (*Engraulis mordax*), Speckled Sanddab (*Citharichthys stigmaeus*), and Pacific Herring. Additional species captured in significant numbers included Topsmelt, Pacific Sardine (*Sardinops sagax*), Bay Pipefish (*Syngnathus leptorhynchus*), Walleye Surfperch, Bay Goby (*Lepidogobius lepidus*), Surf Smelt and Staghorn Sculpin. Gleason et al. (2004) observed similar species richness in mudflat habitat. Of habitats sampled by Pinnex et al. (2006), species richness was lowest in mudflat habitat. Seasonally, species richness was generally highest during the spring and summer and lowest in the winter. Species diversity, which considers both species richness and a measure of abundance, in mudflat habitat was significantly lower than oyster culture and eelgrass habitat types. Seasonally, species diversity indices were variable, with diversity generally greater in the spring or summer (Pinnex et al. 2006).

Pinnex et al. (2006) noted the scale at which habitat change occurs due to channel bathymetry and the diurnal tidal cycle (two high tides and two low tides per 24-hour period) was a dominant consideration in the Arcata Bay. An enormous amount of water is exchanged every tidal cycle. A high tide will inundate the entire bay; however, a lower-low tide water is confined to the major channels, narrowing available mudflat habitat. During lower tides, fish in mudflat habitat are forced into the major channels or small pockets and depressions that contain enough water and cover (to avoid predation) to sustain them until the incoming high tide. Pinnex et al. (2006) concluded the scale of variability due to the tidal cycle can greatly affect fish assemblage distribution directly by limiting habitat suitability on a daily basis.

4.7 Fish and Wildlife Abundance and Distribution Within Project Area

4.7.1 Existing Avian Habitat and Use

The project area is known to provide breeding, roosting, and foraging habitat for a variety of avian species. A previous avian survey (G. Rozhon, pers. comm.) conducted in support of the HBTS project on May 16, 2018 documented breeding activity by Marsh Wren, Canada Geese (*Branta canadensis*), and Song Sparrows. A high and low tide field reconnaissance survey in support of this project documented temporal variation in avian use of the project shoreline. Avian activity was high prior to high tide, and dropped off dramatically when tidal water completely inundated the mud flats along the project shoreline (water reached edge of railroad levee). During high tide, all shorebirds vacated the area or moved onto adjacent salt marsh habitat.

During low tide, observed avian activity along the project shoreline was limited, likely as a result of the high wind speeds during the survey. Nonetheless, a small group of Willets was observed foraging for much of the survey within 25 feet of the shoreline. A Turkey Vulture (*Cathartes aura*) was observed roosting on salt marsh within the project shoreline and flushed at the approach of the surveyor. Nesting activity was observed including singing and territorial Song Sparrows throughout the project shoreline, an active European Starling (*Sturnus vulgaris*) nest, and an Osprey (*Pandion haliaetus*) gathering nesting material from within the project shoreline.

The highest levels of bird activity during high tide occurred in the northern portion of the project shoreline immediately south of the Bracut industrial yards. A degraded levee (a narrow [less than 10 feet wide] strip of salt marsh habitat, which is experiencing severe erosion) is also located in this area. Both the large levee protecting Bracut as well as the degraded levee provide protection from wind and waves in this northeastern corner of the project shoreline.

Willets were one of the most abundant species (approximately 40 individuals) observed foraging in the mudflats at high tide (the species with the greatest number observed on-site was Marbled Godwit; approximately 50 individuals). At high tide, the Willets moved onto the small patches of salt marsh along the project shoreline and appeared to continue foraging. During the low tide survey, nine Greater Yellowlegs (*Tringa melanoleuca*) were observed foraging on the mudflats. Limited activity during low tide may have been a result of high winds (Conklin et al. 2008). One Virginia Rail was encountered as well as numerous Song Sparrows within the salt marshes along the project shoreline.

A list of avian and other wildlife species observed during the surveys are included in Appendix C. Twenty-seven avian species were observed during the high tide survey, 16 avian species were observed during the low tide survey (total of 30 species at the project area).

The stand of blue gum Eucalyptus trees (*Eucalyptus globulus*) between the railroad prism and Highway 101 provide structure for tree nesting avian species as well as some cover for terrestrial wildlife. However, despite extensive survey effort, no egrets or herons were observed using these subject trees (S.E. McAllister & Associates 2020). This stand of eucalyptus is considered poor quality habitat as it is in an area of high disturbance and is surrounded by more suitable habitats around Humboldt Bay (S.E. McAllister & Associates 2020). Thick cover habitat was available along the southern levee bounding the Bracut industrial yards. Coyote brush (*Baccharis pilularis*) and Himalayan blackberry (*Rubus armeniacus*) were the dominant species in this area. Numerous well-worn wildlife trails likely belonging to mid-size mammals, such as mesocarnivores were observed in this area. Only Raccoon tracks (*Procyon lotor*) were detected on-site.

4.7.1.1 Avian Functionality and Benefits of Salt Marsh and Mudflats

Humboldt Bay is a critically important area for numerous wildlife species, especially shorebirds, because of the habitat and food resources available within its salt marshes and mudflats (Monroe et al. 1973, Barnhart et al. 1992). Of the dwindling remaining estuarine habitats within California, Humboldt Bay is still suitable for wildlife although it has experienced severe human modification (e.g., dredging, fill, commercial development, pollution; Monroe et al. 1973).

These habitats are important locally (to support resident wildlife) as well as internationally (to support avian populations along the Pacific Flyway).

Time of day, habitat type, location, and tide are all factors influencing shorebird use (Burger et al. 1997). Studies by Burger et al. (1997) justified that a mosaic of habitat types including mudflats, marshes, and beaches are necessary to maintain shorebird populations. In addition to foraging habitats within mudflats, Burger et al. (1997) found that feeding in all habitat types, including marshes, is important at nearly all tidal stages. The project area is dominated by mudflats, which leaves little available habitat for shorebird foraging when the mudflats are inundated, which is approximately 50% of the time. Figure 23 shows shorebird use of the Jacoby Creek salt marsh during a high tide when the adjacent mudflat is inundated.

Figure 23 Shorebird use of Jacoby Creek salt marsh during high tide.

4.7.2 Existing Aquatic Habitat and Use

As previously described, within the project area the habitat is primarily mudflats with intermittent narrow patches of salt marsh. No eelgrass (*Zostera maritima*) beds are located within the project shoreline as the intertidal mudflat elevations are above the suitable elevation range for eelgrass (Gleason et al. 2004 and based on field observations at low tide). In the North Bay, the depth criteria for eelgrass ranges from 1 foot to 4.3 feet MLLW (0.3 to 1.3 meters; Merkel & Associates 2017). Direct field investigation of fish species or fish habitat mapping along the project shoreline has not occurred; however, Gleason et al. (2004) documented Shiner Surfperch, Topsmelt, Staghorn Sculpin, Arrow Goby, and Bay Pipefish along the project shoreline.

4.7.2.1 Aquatic Habitat Functionality and Benefits of Salt Marsh and Mudflats

Expansion of the salt marsh along the project shoreline would increase foraging habitat for fish during higher tides, resulting in an increase in their overall fitness and likelihood of survival. Constructing small, tidal channels through the salt marsh would provide enhanced fish habitat that could be more fully utilized during a broader range of tidal elevations. The tidal channels would be proximal to expanded salt marsh habitat and would thus provide higher quality foraging and refugia habitat. Geomorphology and hydrology conditions would inform the degree to which constructed tidal channels along the project shoreline would be likely to persist and evolve, providing long-term habitat. A non-linear project edge would maximize habitat complexity and the wetted edge of salt marsh available to fish for foraging and other habitat types. A more complex shoreline habitat, including a non-linear wetted edge, is more likely to provide the higher level of ecosystem service benefits to best meet Project objectives.

4.7.3 Conservation Issues and Threats

Human activities have severely reduced salt marshes within Humboldt Bay (Pickart 2001). In particular, the construction of the railroad in the early 1900s had a significant impact on saltmarsh habitat (Pickart 2001). As a result of anthropogenic activities in the late 1800s through mid-1900s, salt marsh habitat decreased approximately 90% (approximately 9,000 to less than 900 acres; Pickart 2001) around the Bay.

Invasive species are also a concern. *Spartina densiflora* provides habitat, especially refugia during high tides, given its large height in comparison to native salt marsh plants. However, it has disrupted relationships of invertebrates and native plants (Mitchell 2012). Invertebrate species diversity (and therefore greater food resources) was present in restored marshes within Humboldt Bay following removal of *Spartina densiflora* (Mitchell 2012).

Shorebird decline has been documented worldwide largely as a result of estuarine and wetland habitat deterioration at stopover site and on the wintering grounds (Dias et al. 2006, Conklin et al. 2008). Loss and degradation of intertidal habitats is the primary threat to shorebirds utilizing Humboldt Bay (Colwell and Feucht 2018). Currently, threats to this habitat include oil spills, dredging, rising sea-levels, and expansion of aquaculture (e.g., oysters) farms (Colwell and Feucht 2018).

As tidal marsh restoration efforts have increased on both east and west coasts of North America, their benefits particularly for terrestrial wildlife, have been extensively documented within the literature. Many factors influencing the impact of restoration on bird populations are site specific, including establishment of target plant species verses invasive species, land use on adjacent properties, and marsh accretion through available sediment (Shriver and Greenberg 2012). Marsh specialists as well as generalist species have benefitted from tidal restoration through establishment of foraging and nesting habitat (Shriver and Greenberg 2012). Given the degradation and conversion that have occurred to natural habitats within Humboldt Bay, restoration efforts are integral in managing these important areas to sustain aquatic and avian species populations.

5. Geomorphic Assessment and Conceptual Model

5.1 Purpose

This chapter reviews the geomorphic context of the project area and discusses physical data collected and assessed to support development of a conceptual model. The conceptual model is used as a framework to describe the environmental drivers and physical processes that influence the sediment flux and shape the landforms within the project area. These landforms have evolved and have been altered through natural processes and anthropogenic interventions. An understanding of how the project area has evolved in the past improves the understanding of how it may evolve in the future with the implementation of natural shoreline infrastructure at the project area. The purpose of this section is to provide supporting information to address the following questions:

1. What are the key physical drivers, including previously described anthropogenic interventions, that influence physical processes along the eastern shoreline of Arcata Bay?
2. Which drivers and processes have attributed to the loss or gain of salt marsh in the project area?
3. Based on the drivers and processes described, what potential natural shoreline infrastructure measures could be implemented to achieve the project goals and restore a resilient salt marsh at the project area?

5.2 Overview of Drivers and Physical Processes Within Intertidal Habitats

This section provides a general introduction to the key drivers and physical processes within the intertidal mudflats and salt marsh.

Tidal marshes evolve from non-vegetated tidal flats, such as sand-flats or mudflats, when the flats become high enough above frequent tidal inundation to be colonized by marsh vegetation or can evolve on terrestrial lands in response to vegetative transgression from sea level rise and/or landslides and upland subsidence. Mudflats provide a balance between the deposition and erosion of sediments and can store and exchange sediment between intertidal marshes and sub-tidal channels. The shear forces from wind-generated waves necessary to resuspend and redistribute sediment depends on wave heights, which in turn depends on water depth and wind speed. Resuspended sediment transported by wind-wave energy and tidal currents will redeposit when the tide and waves subside. Under the right conditions, mudflats can accrete to achieve heights suitable for colonization by salt marsh vegetation. Limited sediment supply can limit marsh and mudflat accretion. However, marshes can also degrade from edge erosion where wind-generated waves and tidal currents are high and sediment supply is low. Conversely, marsh edge can prograde (extend laterally bayward) where wave exposure is low and sediment supply is high. A narrow fringe of tidal marsh can evolve and persist where the marsh vegetation can transgress landward on a gradual slope if unimpeded. However, an abrupt landform such as a bluff or fill prism can prevent landward transgression.

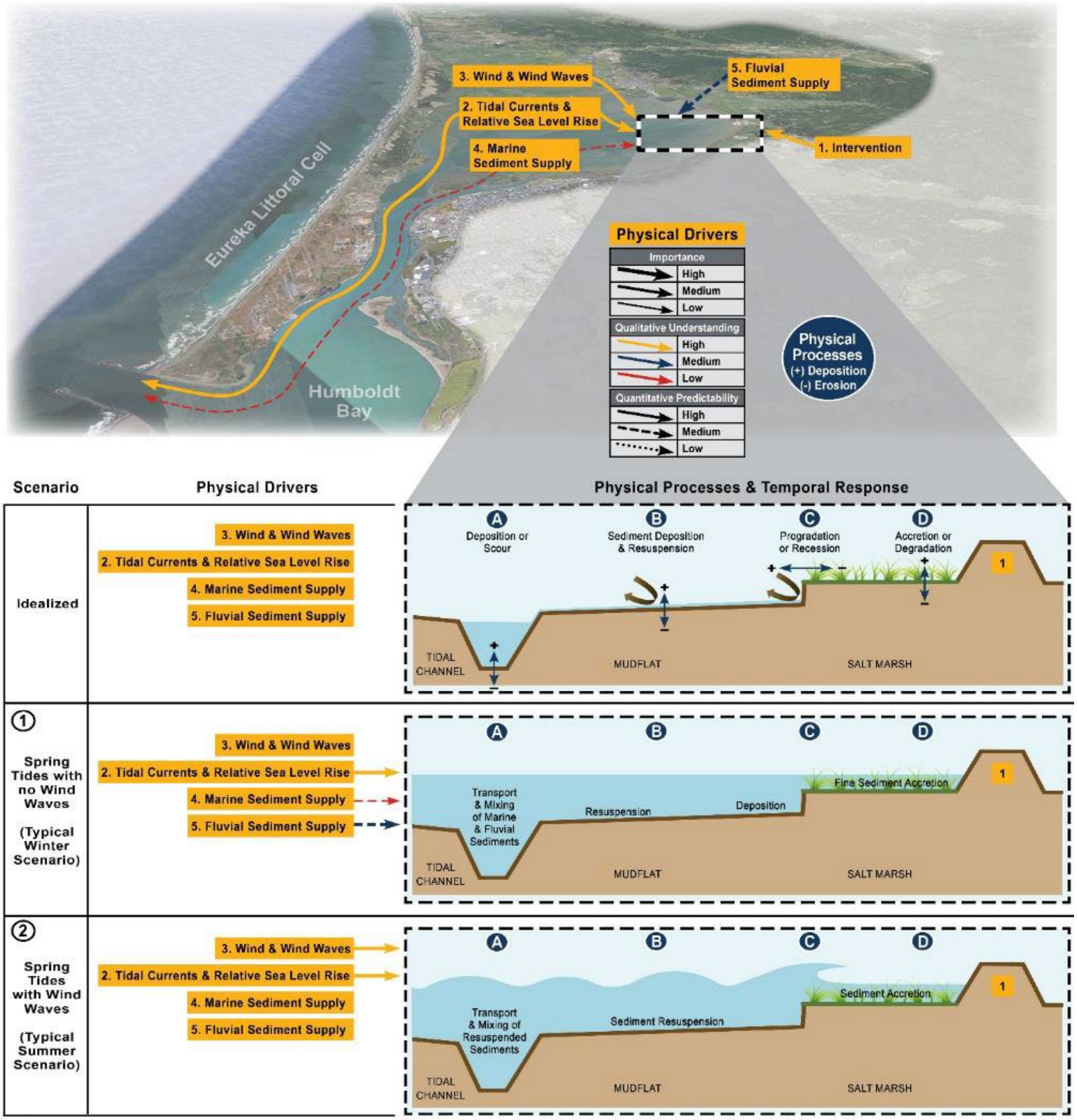
While marsh edge erosion may be perceived as a negative function, the eroded sediment deposited on the bordering mudflat can be transported back onto the marsh surface in subsequent high tides contributing to accretion (Wiberg and Fagherazzi, 2020). Wiberg and Fagherazzi reference several models developed (Mariotti & Fagherazzi 2010, Mariotti & Carr 2014) that show where high rates of marsh-edge retreat (strong winds, large fetch, and high erodibility) also promoted high rates of vertical accretion on the adjacent marsh surface, whereas conditions resulting in more stable marsh edges (weak winds, small fetch, and low erodibility) may promote marsh drowning by reducing sediment supply to the marsh surface.

There are three basic sources of sediment to establish and maintain tidal mudflats and marshes in Arcata Bay:

- Inorganic Terrestrial Source Sediments: The primary source of these sediments are the watersheds that drain directly into Arcata Bay. These sediments include gravels, sands, silts, clays, and debris delivered to the mudflat or marsh from their upland sources. Other terrestrial sources include material eroded from the shoreline which could include gravels and cobbles. Larger material size (i.e. course sands and gravels) transported from contributing streams are generally too heavy to be carried onto the marsh surface and remain stored in deeper channels whereas the small, finer-grained materials are stored on the mudflats and can be transported to the marshes during high tidal and wind events.
- Inorganic Marine Sediments: Inorganic marine sediments are from terrestrial sources that are transported into the Bay from the Eureka Littoral Cell watersheds such as the Eel and Mad Rivers. Dredging within Humboldt Bay that increases the amount of sediment suspended in tidal waters can also increase the availability of marine sediments.
- Organic Matter: The organic matter of a tidal marsh consists of roots, rhizomes, and other organic materials produced by growth and decomposition of marsh vegetation. The primary source of these materials are produced within the marsh and contribute to vertical accretion. Relative to inorganic sources described above previously and which dominate Humboldt Bay marshes, organic matter generally contributes less to vertical accretion. However, Cahoon et al. (2021) argues that organic material is a greater contributor than mineral sediment and acknowledges this point of disagreement with other research. Relative to East Coast marshes, Humboldt Bay marshes are younger as they have formed from rapid elevation changes following Cascadia events and higher fluvial sediment supplied from rapid erosion of uplifted weak soils and organic content is likely a lower contributor compared to inorganic.

5.3 Conceptual Sediment Flux Model

A conceptual model for movement and storage of sediment along the eastern shoreline of Arcata Bay is depicted in Figure 24. The conceptual model builds upon information presented in the Sea Level Rise Adaptation Plan for the Eureka Slough Hydrographic Area (Humboldt County 2021) and follows a similar framework developed for the Sacramento–San Joaquin Delta (Schoellhamer 2012). The conceptual model served as a starting point for implementing field investigations, hydrodynamic modeling and analyses of shoreline processes in the project area. The objective of these investigations was to develop a better understanding of the magnitude and importance of physical drivers in shaping the existing shoreline configuration and to guide the selection of adaptive measures for restoring a natural shoreline. These physical drivers and their linkages to landscape evolutions are summarized and further defined in the following sections.



① **Description:**
- Tributary flows deliver fluvial sediments to Arcata Bay
- Colloidal sediments remain in suspension and are circulated with tidal currents
- Silts and fine-sand sediments deposit on near-shore mudflats and resuspend when tidal currents shear stresses are high on off-shore mudflats
- Infrequent spring tides coincident with fine suspended sediment loads allow for marsh plain deposition

② **Description:**
- Wind generated waves increase shear stresses on mudflat and resuspend deposited sediments
- Infrequent spring tides coincident with high wind waves deliver fine-grained sediment resuspended from mudflat to marsh plain

Figure 24 Conceptual Model of Physical Drivers, Processes and Sediment Dynamics for the Eastern Shoreline of Arcata Bay. Each yellow box is a driver and each arrow describe the importance, qualitative understanding, and predictability to influence physical process. The linkages between the drivers and physical processes are described for two seasonal scenarios.

5.4 Physical Drivers and Interventions

Physical drivers affect the rate of which physical processes occur and the rate of landscape change. The physical drivers of Arcata Bay include the following, and each are further described below:

1. Interventions
2. Tidal Currents and Relative Sea Level Rise
3. Wind and Wind Waves
4. Marine Sediment Supply
5. Fluvial Sediment Supply

5.4.1 Driver: Interventions

Anthropogenic interventions have altered the Arcata Bay shoreline. In turn, these interventions altered how the landscape response to the physical drivers of tides, waves, and sediment supply. Anthropogenic interventions considered important to this project include:

- Diking and drainage of salt marshes: Starting in the 1890's, dikes were constructed along the outer edges of Arcata Bay salt marshes, separating the transfer of water, sediment, and organics between the bay and marshes. Borrow ditches were constructed on the interior of the dikes to supply material for the dikes. Numerous large and small tidal creeks were blocked or diverted, altering the delivery of sediment from upland areas to the bay.
- Construction of railway and roadway (US-101) embankments: Construction of railroad and highway embankments along the bayfront created additional impacts. Borrow ditches for the embankments were much wider and removed large swaths of exterior tidal marshes. The embankments were sometimes integrated into tidal flood protection by local landowners.
- Shore armoring: Shore armor was installed in locations where the embankments or dikes were placed on the shoreline and directly exposed to erosion by waves and currents. Armoring can result in the loss of habitat over time as the shore or channel bank is degraded as migration impinges on the armoring (often called "passive" erosion). Armoring can also actively induce erosion due to increased wave reflection, turbulence, and reduced hydraulic friction.
- Dredging: Dredging practices in Humboldt Bay removed sediment from stored sinks such as tidal channels and exported it off-shore and out of the local littoral system where it no longer available for redistribution to other sediment sinks.

5.4.2 Driver: Tidal Currents and Relative Sea Level Rise

The description for this driver is divided into three sub-sections below, tidal still water levels, tidal currents and relative sea level rise.

5.4.2.1 Tidal Still Water Levels

As previously described, tides in Humboldt Bay are mixed, semi-diurnal that amplify and lag with distance from the Humboldt Bay entrance (Costa and Glatzel 2002). Although the tides are driven by ocean tides, the high tide elevations at the project area are approximately 0.5 feet higher than at the entrance, and the low tides are slightly lower (NHE 2016). Table 4 presents values of the extreme still water levels and a selection of tidal datums for the project area as computed by NHE and extracted from their Humboldt Bay hydrodynamic model (NHE 2015). Note that the highest astronomical tide, which represents the highest pure astronomical tide (i.e., no storm surge or atmospheric effects) to occur over the tidal epoch, was computed by adding 0.49 feet to the value published at the North Spit tide gauge.

Table 4 Summary of Tidal Levels and Annual Extreme Still Water Levels [1] for Project Area

Water Level/Datum	Elevation (NAVD88)		Description
	(m)	(ft)	
100-year SWL	3.251	10.67	100-year still water level
50-year SWL	3.196	10.48	50-year still water level
10-year SWL	3.050	10.01	10-year still water level
5-year SWL	2.977	9.77	5-year still water level
2-year SWL	2.858	9.38	2-year still water level
HAT	2.746	9.01	Highest Astronomical Tide[2]
MAMW	2.874	9.43	Mean Annual Maximum Water
MMMW	2.562	8.40	Mean Monthly Maximum Water
MHHW	2.155	7.07	Mean Higher High Water

[1] Extreme water levels presented are based on probability analyses that used a 100-year historic tidal data record ending in 2012 (NHE 2015). To account for relative sea level rise between 2012 and current (2020), an additional 5 mm/year (35 mm or 1.4 inches total) could be added to the tabulated water levels above to reflect current (2020) conditions.

[2] Highest astronomical tide estimated for project area by adding 0.49 feet to value published for North Spit Tide Gauge, NOS NOAA Station 9148767. The HAT is the highest astronomical tide to occur over the tidal epoch and represents the largest expected spring tide.

5.4.2.2 Tidal Currents

Tides are the significant driving force in Humboldt Bay, with winds being the primary secondary forcing in the shallow portions of the north and south bays (Costa and Glatzel 2002). The mixed semidiurnal tides have a mean range of 4.9 ft and a diurnal range of 6.9 ft which generate the twice daily ebb and flood tidal currents bay wide. The basic circulation patterns in Humboldt Bay, summarized in Barnhart (1992), follow the main channels, are strongest with the main channels and decrease with increased distance from the Bay entrance.

Hydrodynamic Model Description

To better understand tidal and wind-wave generated currents, bed shear stresses, and circulation patterns within the project area an existing Humboldt Bay hydrodynamic model (NHE 2015; Anderson & Costello-Anderson 2019) was leveraged and modified within the project area. The focus of the hydrodynamic modeling effort was to assess the dominant physical processes (i.e. tidal, wind, and wind-wave drivers) and interactions on the large mudflat areas adjacent to the project area. The grid resolution of the modified hydrodynamic model in the project area (~ 65 m x 45 m grid cells) is adequate to assess general circulation patterns within the project area. However, the grid resolution is too coarse to capture all the complex topographic and/or bedform features along the immediate shoreline of the project area. Although the hydrodynamic model lacks the grid resolution to resolve all the local hydrodynamics affecting the immediate shoreline, the resolution is adequate for the adjacent mudflat areas and to provide a general understanding of circulation patterns along the shoreline of the project area.

The existing Humboldt Bay hydrodynamic model was developed using the Environmental Fluids Dynamics Code (EFDC) modeling platform (Hamrick 1992), which is a public domain model supported by the U.S. Environmental Protection Agency. Dynamic Solutions-International, LLC (DSI) has made several enhancements to the EFDC code and has its own version (EFDCPlus), which includes sediment transport and wind wave sub-models, and a windows-based GUI (EEMS10.3) for pre- and post-processing (DSI 2020a; DSI 2020b). The existing Humboldt Bay hydrodynamic model grid was refined bay wide and within North Arcata Bay to better support the Natural Shoreline Infrastructure (NSI) project area (Figure 25). Since the focus of the analysis was on North Arcata Bay, a smaller ocean and near shore grid was incorporated into the modeling domain. The refined hydrodynamic model will be referred to as the NSI model henceforth. In general, the model grid resolution is approximately 90 m x 50 m in North Arcata Bay, and 65 m x 45 m within the project area (Figure 26). The refined NSI model grid contains 23,950 horizontal grid cells and 5 vertical layers. Elevations were mapped to the refined model grid using a 2-m raster of the existing Humboldt Bay bathymetry (PWA 2014).

The DSI wind wave sub-model (DSI 2020a) is dynamically linked to EFDCPlus, and estimates wind-wave parameters at each model grid using the Sverdrup, Munk and Bretschneider empirical equations (SMP model) for shallow waters. The SMP model determines wave height, direction and period using wind speed, average water depth over the entire model domain, and wind fetch length from the model boundary to each grid cell over 16 directions. A key assumption of the SMP model is that the wave direction is the same as the wind direction; and the wind-wave sub-model does not account for the effects of wave shoaling, refraction, diffraction, and reflection, but does account for depth limited wave height. Although EEMS10.3 and EFDCPlus directly supports the SWAN wave model, the SWAN model is not dynamically linked to EFDC and requires an iterative procedure to temporally integrate circulation and wind-waves which is beyond the scope of this project. Given the maximum wind-wave heights (~ 2.5 ft) generated in North Bay, and the parallel shore and near-shore contours/bathymetry generally normal to the dominant wind (NW to SE) and incident wind-wave directions assessed, the SMP model is adequate for this general circulation analysis and supports the temporal analysis of tidal and wind-wave current interactions dynamically. Furthermore, the SMP model and assumptions are consistent with the sheltered waters coastal flood hazards analysis recently conducted by FEMA (2014), which also neglected wave shoaling, refraction, diffraction, and reflection in their analysis of locally generated wind-wave hazards in North Humboldt Bay.

The described NSI model was used to assess a number of physical processes and interactions (e.g. tidal, wind, and wind-wave currents and drivers) described in later sections of this report.

Model Parameters

The same general parameters used in previous Humboldt Bay hydrodynamic models (NHE 2015; Anderson & Costello-Anderson 2019) were used in the NSI model: (1) total effective roughness height (Z_0) set to 0.005 m for bay locations and 0.01 m for tidal wetlands, (2) background horizontal Eddy viscosity set to 5E-5 m^2 s^{-1}, and (3) horizontal momentum diffusivity coefficient (Smagorinsky coefficient) set to 0.1. Vegetation drag was also included in the model to account for the additional drag from wetland vegetation on the water column. The following parameters were used to represent tidal wetland vegetation measured near the Elk River (Caltrout et al. 2019): plant height of 1.219 m, plant diameter of 0.007 m, number of stems at 365 stems/m^2, and a drag coefficient of 0.5. Since wave data were not available to calibrate the wind wave sub-model, default wave parameters were used for all simulations with the Nikuradse sand roughness height (K_S) set to 2.5E-5 m to account for the fine-grained bed materials near the project area. Simulations used to assess shear stresses and sediment mobility did not account for the radiation stresses between waves and currents. However, simulations used to demonstrate the potential effect of waves on the bay and near-shore currents (e.g. longshore current) did include radiation stresses using default radiation stress parameters.

Boundary Conditions

Boundary conditions for the circulation and wind-wave analysis consisted of open ocean water levels, wind speed and direction. The purpose of the analysis was to better understand how tidal currents with no wind and combined tidal and wind-wave currents affect circulation and shear stresses within the project area over a range of coastal stillwater levels.

The tidal open boundary condition (Figure 27) for the analysis consisted of a 10-day period from the 100-yr hourly sea level height series derived for the Crescent City tide station (NOAA Station ID: 9419750) as part of the Humboldt Bay sea-level rise vulnerability analysis (NHE 2015). The 10-day period spanned 22 to 31 January 1983, which was during the 1982-83 El Niño. During this 10-day period a large El Niño driven storm coincided with higher-than-normal astronomical high tides producing the highest water levels of record at the Crescent City tide gauge. This 10-day tidal series contains a large tidal height range spanning mean higher high water (MHHW) to above the 1% annual chance extreme high-water level event.

For the wind-wave analysis the NSI model was run over a range of constant wind speeds and two dominant wind directions for the 10-day simulation period to understand how wind and wave conditions affect currents and shear stresses over a range of tidal heights. The constant wind speeds were 5 mps (~ 11 mph), 10 mps (~22 mph), 15 mps (~34 mph), and 20 mps (~45 mph), and the two wind directions were from the northwest (NW) and southeast (SE) which represent the dominant wind direction from March to November and the winter period (December to February), respectively (see the extreme wind speed analysis in Appendix D).

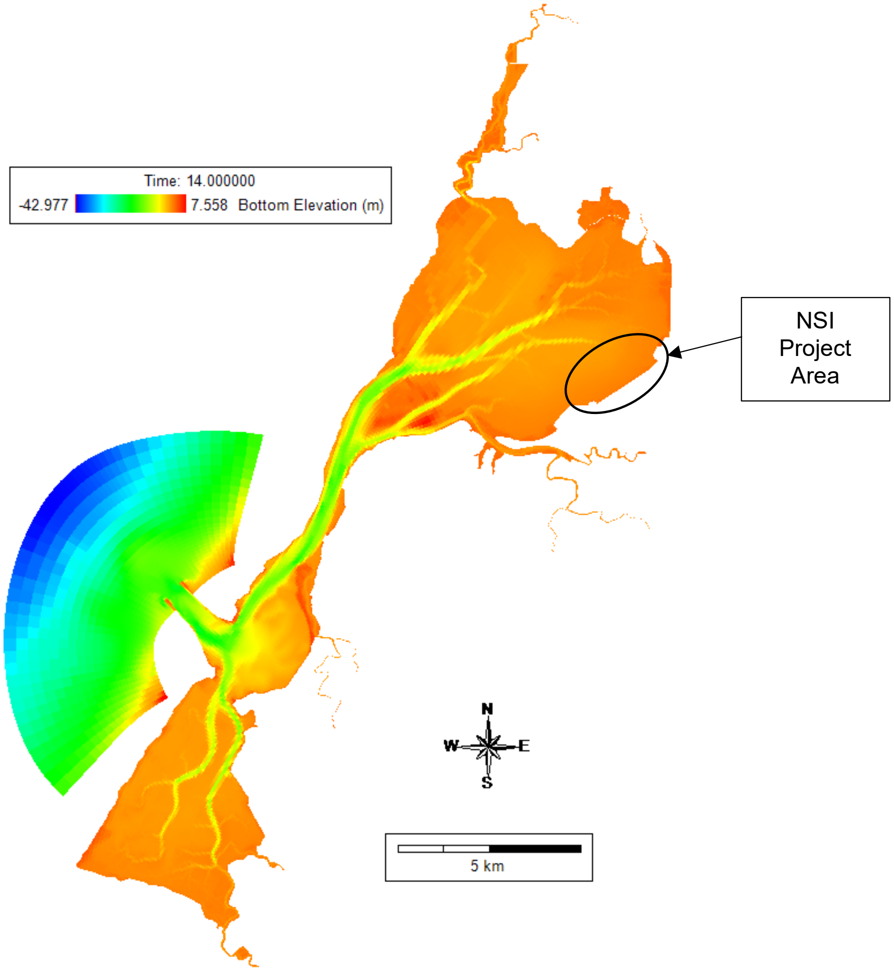


Figure 25 Humboldt Bay hydrodynamic model domain developed for the Project Area (NSI model). Bathymetry/topography based on grid cell elevations.

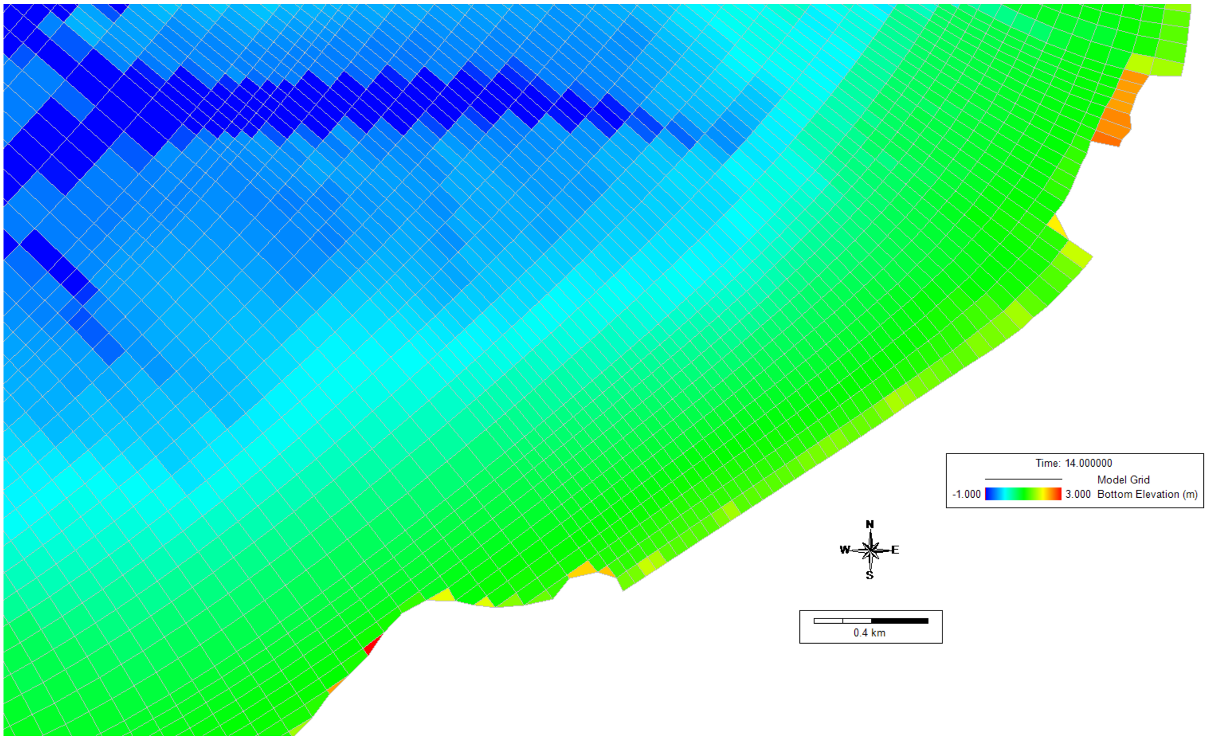


Figure 26 Humboldt Bay hydrodynamic model (NSI model) grid cell resolution and bathymetry at the project area.

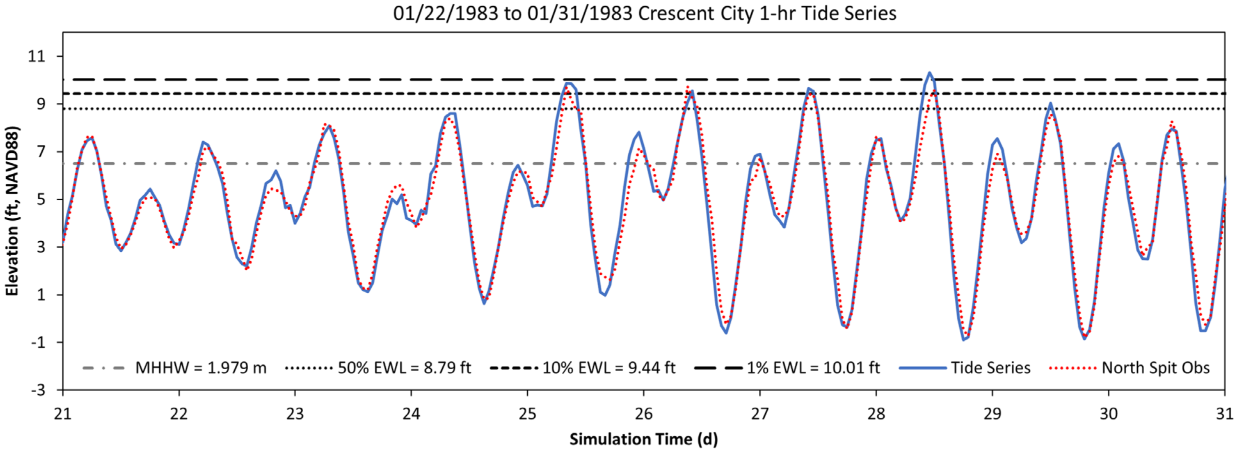


Figure 27 Tidal open boundary condition (blue line) used for the NSI Model simulations. Tidal series based on Crescent City tide station (NOAA Station ID: 9419750). Observed North Spit tide station (NOAA Station ID: 9418767) observations (red dotted line) corrected for ~2.3 mm sea-level change from 1982 to 2012. MHHW is mean higher high water; #% EWL (e.g. 1% EWL) represents the #% annual chance extreme high-water level (e.g. 1% chance extreme high-water level).

5.4.2.3 Relative Sea Level Rise and Projections

Relative or local sea level rise combines vertical land motion (tectonic subsidence) with eustatic (global) sea level changes. Tectonic plate motion in the Pacific Ocean off Cape Mendocino causes local sinking, or subsidence, of landforms around Humboldt Bay and the Eel River Delta. The rate of subsidence varies by location. Near Humboldt Bay's North Spit, subsidence is approximately 2.33 mm/year, or almost 10 inches per century (Patton and others 2014). Relative sea level rise rates for Humboldt Bay between 1977 and 2016 have been approximately 5 mm/year

(19 inches per century) which are higher compared to the rest of California (NHE 2018). These rates are expected to increase as the Earth warms creating thermal expansion for warming ocean water and melting ice sheets (OPC 2018).

Sea level rise projections developed for the North Spit of Humboldt Bay were presented in the Sea Level Rise Adaptation Plan for the Eureka Slough Hydrographic Area (Humboldt County 2021) and are shown below in Figure 28. The solid lines represent the projections of OPC (2018) and the dashed lines are the projections of NHE (2015 and 2019). The solid red curve is referred to as the “H++” scenario and is considered a “stand alone” worst-case scenario of unknown probability of occurrence. The probability cannot be estimated with confidence because the process driving the rapid sea level rise (i.e., catastrophic collapse of land-based ice sheets into the ocean), is not well understood. OPC (2018) recommends use of this curve for analyzing critical infrastructure and projects with high consequences to underestimating sea level rise. The solid blue line represents the sea level rise projection with a low likelihood of occurrence within the associated timeframe and provides a precautionary projection that should be used for less adaptive, highly vulnerable projects that will experience medium to high consequences as a result of underestimating sea level rise, such as a coastal housing development (OPC 2018). The probability of sea level rise exceeding the blue curve is 0.5%, or about 1 in 200 (OPC 2018). The solid green line represents the sea level rise projection that represents a “likely” range of sea level rise to occur within the associated timeframe with a probability of 66%, or about 1 in 1.5. The dashed blue, green and purple lines represent the projections by NHE (2015) and have subsequently been updated and presented in the City of Arcata Sea Level Rise Risk Assessment (April 2018) and these curves are referred hereinafter as NHE (2019) as shown on Figure 28. Overall, the NHE (2019) projections track closely to the projections for North Spit provided by OPC (2018). The relative sea level rise trend observed at the North Spit of Humboldt Bay between 1977 to 2016 (5 mm/year or 19 inches per century) is equivalent to the low end of the OPC 66% probability range.

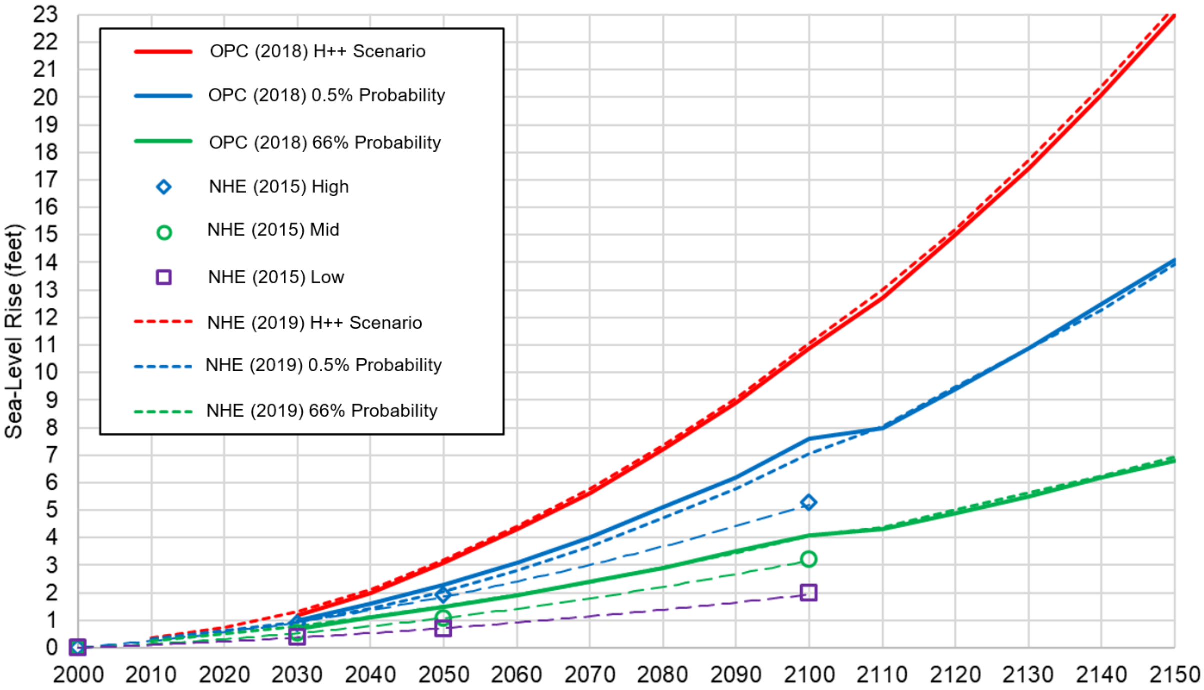


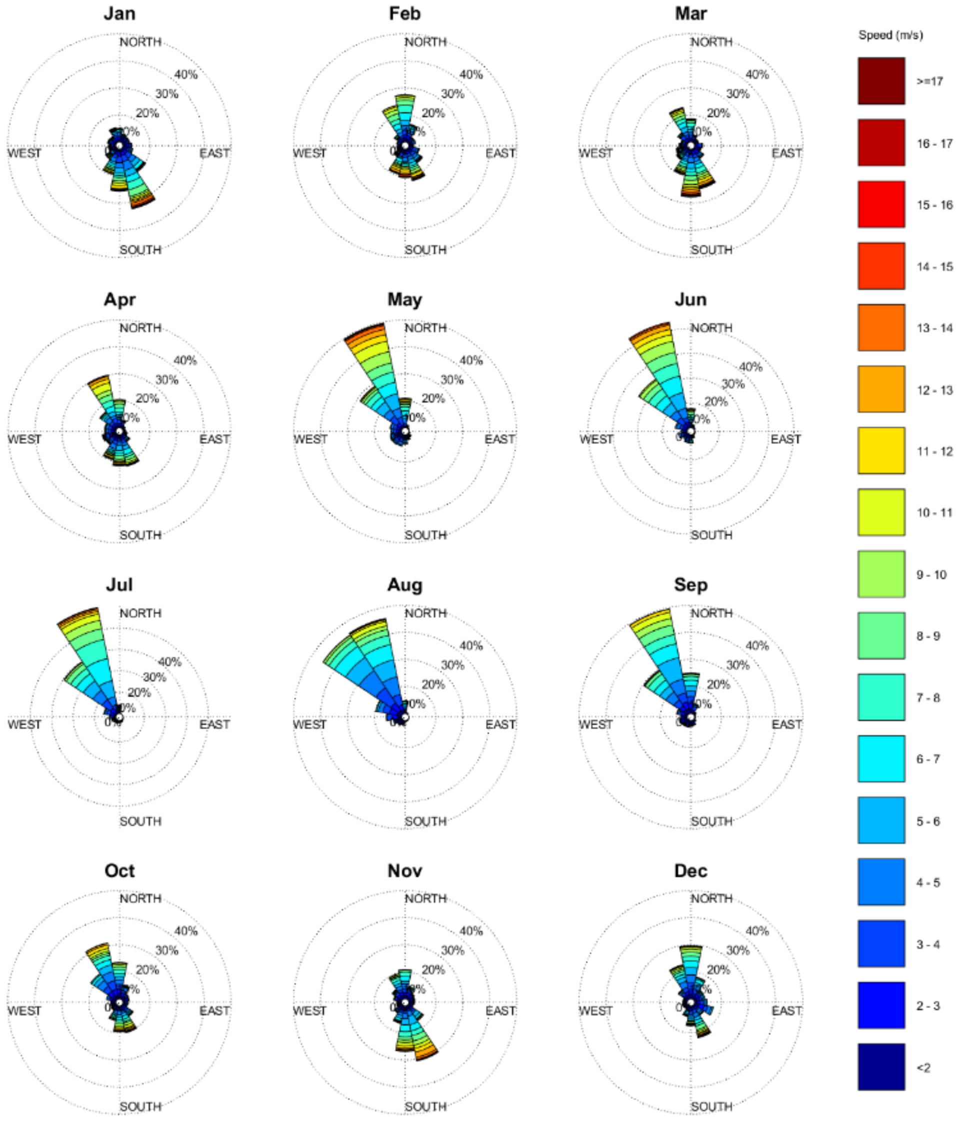
Figure 28 Sea level Rise Projections for North Spit, Humboldt Bay: OPC (2018) State Guidance (solid lines) and Regional Projections by NHE (2015) and NHE (2019)

5.4.3 Driver: Wind and Wind Waves

5.4.3.1 Wind

The project area is exposed to waves generated from both boat wakes and wind. Given infrequent boat use on Arcata Bay, this section focuses on wind-generated waves. Monthly wind rose plots from NOAA Station 9418768 (North Jetty

Landing, California) over the period of 2016-2018 were developed and shown in Figure 29. The North Jetty Landing is located at the end of the North Jetty in the ocean and external to Humboldt Bay. The wind regime is characterized primarily by northwesterly winds from May to September and both southerly and northerly winds at other times of year.



Wind roses from 01/01/2016 to 01/01/2019 at 40.96807 , -124.36392

Figure 29 Monthly wind rose plots from NOAA Station 9418768 (North Jetty Landing, California) over the period of 2016-2018.

5.4.3.2 Wind Waves

The project area is exposed to a wind fetch length of approximately four miles (7 km) from northwest winds which can create relatively high incident waves at the project shoreline during high tides (Figure 30).

Figure 30 Representative photo of project area during an approximate Mean High Tide and approximate 25-mph northwesterly wind.

Wind-wave and overtopping analyses were previously conducted as part of the HBTS project (ESA and GHD 2018). The analyses were conducted to characterize existing conditions and are summarized below. The analyses were expanded to inform the basis of design for this project. The expanded wind-wave analyses and runup analyses are presented in Appendix D and E and revisited in the basis of design section of this report.

FEMA (2014) estimated a wind wave height of approximately 2.4 feet with a period of 3 seconds during a wind speed of 45-mph corresponding with an approximate 50-year recurrence interval. A total water level (TWL) analysis was conducted that included incident wave height, wind and wave setup, and wave runup associated with various wind speeds and still water levels along the project shoreline in support of the HBTS project (ESA 2018). The runup analysis utilized the TAW method (van der Meer 2002; FEMA 2005) and results generally agreed with FEMA's (2014) wind wave generation model results used in the Flood Insurance Study (FIS). The primary purpose of the HBTS wave run up assessment was to determine average rates of overtopping of the rail prism and trail during higher and less frequent water level and wind events. The application of the TAW method assumed wind waves reach the existing rail prism. Several factors influence the location at which a wave will break, including wave height, wave period, topography, roughness, and depth. Given the variety of conditions analyzed and variations in the presence or absence of salt marsh, the ESA study assumed that the depth of water over the topography leading up to the rail prism was too great for the wave to break which yields a conservative estimate as variations in shoreline topography that reduce the depth or increase the roughness exist.

Wave Attenuation over Salt Marsh

As waves approach the shoreline and depth decreases, the steepness increases until a limiting value is reached and the wave breaks, dissipating energy (USACE, 2003). In general, for short period wind waves, a wave will break when the depth of water is equal to the wave height. Under these conditions, waves are considered to be depth-limited when the depth of water is less than or equal to the wave height. The dominant topographic features along the shoreline of Arcata Bay are the mudflats, salt marsh and rail prism. Abrupt elevation changes occur at the interfaces of each of these features. The mudflat elevation is typically around 4 to 5 feet (NAVD), salt marsh 7.5 feet, and the top of the rail prism 10 feet. Therefore, a wave that is 1 foot in height will break and dissipate energy on the mudflats when water levels are below elevation 6 feet (NAVD), on the salt marsh between elevations 6 to 8.5 feet, and on the rail prism above elevation 8.5 feet. If there is no salt marsh present, waves will break directly on the rail prism at water levels greater than elevation 6 feet.

During high wind events, as the tide rises and water depth increases, incident wave heights increase. Waves eventually begin to shoal and dissipate over tidal marshes and the toes of the rail prism and Brainard levee. The shallow depths over the marshes cause the waves to attenuate and decrease as they propagate toward the shore. As the tide continues to rise, the water depth over the tidal marsh increases. When waves are no longer depth limited, waves are expected to rush up on the rail prism, inducing wave runup, elevating peak water levels. Peak water levels are momentary but repetitive over multiple hours, as the waves break and splash vertically and landward. Overtopping of the rail prism begins with wave runup, contributing intermittent discharges of tidal waters above and over the rail prism.

To develop an understanding of the wind wave dampening effects between the salt marsh plain at the Eureka Slough marsh compared to the project shoreline, a WHAFIS model was developed and simulated under various water level and wave height conditions. This WHAFIS analyses was completed to understand wave effects along the existing shoreline, and does not contradict the wind-wave analysis conducted for design conditions in subsequent sections of this report.

WHAFIS is a software program developed for FEMA as a tool to assist with flood insurance studies (FIS's). It is a part of the Coastal Hazard Analysis Modeling Program (CHAMP), which allows users to enter data, perform coastal engineering analyses, view and tabulate results, and collect summary information for representative transect locations along a coastline. To use the model, the modeler needs an understanding of the input and output data in addition to coastal engineering and mapping principles. The model requires starting wave conditions (significant wave height and wave period), still water elevation (SWEL) data, terrain (topography and bathymetry) data, and the obstructions to waves (FEMA 2014). The model has been previously used by ESA in 2012 to assess wave attenuation along a marsh in the Corte Madera Baylands in the San Francisco Bay. The results of that study are discussed below and compared to the model results prepared for this report.

Bathymetry data at three different transect locations (Jacobs Avenue and Indianola Avenue) was sampled. The Jacobs Avenue transect was considered representative of the Eureka Slough salt marsh plain extending approximately 500 feet into the bay from the toe of the railroad prism and was used as a reference transect. Two transects were sampled within the project area near Indianola Cutoff: (1) a transect with limited or remnant salt marsh, extending 40 feet into the bay from the toe of the rail prism and (2) a transect with no marsh, with uniform transition from mudflat to rail prism. Much of the project area does not have any salt marsh, but where present, a 40-foot section is representative. All transects extend inland to the roadway (11 feet NAVD88) and into the mudflats of the bay (0-2 feet NAVD88).

Two initial wave height scenarios were run for each of the transects, a 1-foot wave generated by an 11 mph wind and a 2.4-foot wave generated by a 45 mph wind. WHAFIS allows a wave height input and transforms the wave across the transect using representative wind data to generate the corresponding wave periods. 1- and 2.4-foot wave heights were chosen to represent a range of wind-generated wave events and includes values previously calculated by FEMA in the 2014 FIS for Humboldt Bay using a 45-mph wind event. An analysis of wind and water level data by FEMA showed that elevated water level events are decoupled from wind events. Thus, the 1% water level event was paired with a more statistically representative wind speed. The Eureka KEKA wind station was chosen given its continuous record and location in the bay. With this data and a 3-hour averaged 50-year return period wind speed of 43.4 mph (Pacific Gas and Electric Company, 2013), a wind value of 45 mph was selected for starting wave conditions.

The still water elevations (SWEL's) used in the model were an 8-foot water level and a 10.6 ft water level. An 8-foot water level is representative of the high spring tides and the 10.6 ft water level is the 100-year SWEL.

Wave setup, the increase in mean water level due to the presence of a breaking wave, was assumed to be 20% of the wave height for each scenario. Wave setup parameters of 0.2 ft and 0.5 ft were assigned for wave heights of 1-foot and of 2.4-feet, respectively. For the WHAFIS analysis the wave setup was applied across the entire transect water level, although the actual wave setup would only apply within the wave breaking zone closer to the shoreline.

The model includes parameters to represent the variation and presence of vegetation along each transect. The model provides default parameters for specific plant species and allows for multiple species of plants to be modeled at each point along the transect. The two species of plants used in the model were salt grass and medium salt meadow cordgrass. These species are found primarily in marshes on the east coast as WHAFIS was developed for use on the east coast, but they are similar in roughness characteristics (height and texture) to pickleweed and cordgrass, respectively, the two primary vegetation types found along the bay shoreline. ESA completed a sensitivity analysis with respect to the amount and type of vegetation included in the model for the Corte Madera Baylands. ESA reported that the model was relatively insensitive to vegetation species, but very sensitive to the presence or absence of vegetation, consistent with previous studies. ESA also completed a sensitively analysis of marsh width within the WHAFIS model. They found that a wider marsh exposed the waves to more of the frictional forces due to marsh vegetation, which led to a decrease in wave height across the marsh. This remained true for a range of water levels and wave heights analyzed, as shown in Figure 31. The increased attenuation of wave height with decreased water depth is consistent with the expected relationship of depth limited waves and exposure to marsh vegetation. ESA noted that plunging waves, created by sudden depth changes, breaking in shallower water have more erosive power. This effect can potentially erode the marsh toe or other surfaces faster than sediment can accrete in the vegetation. An optimal marsh height would need to be found to be the most resilient to the greatest number of water level and wave scenarios.

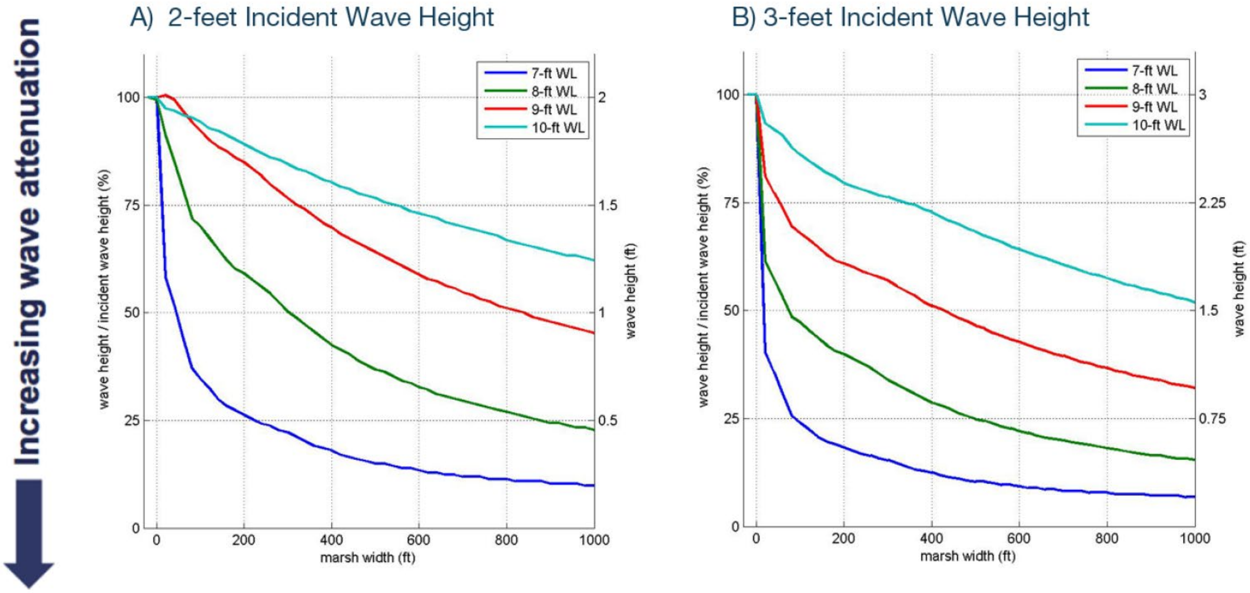
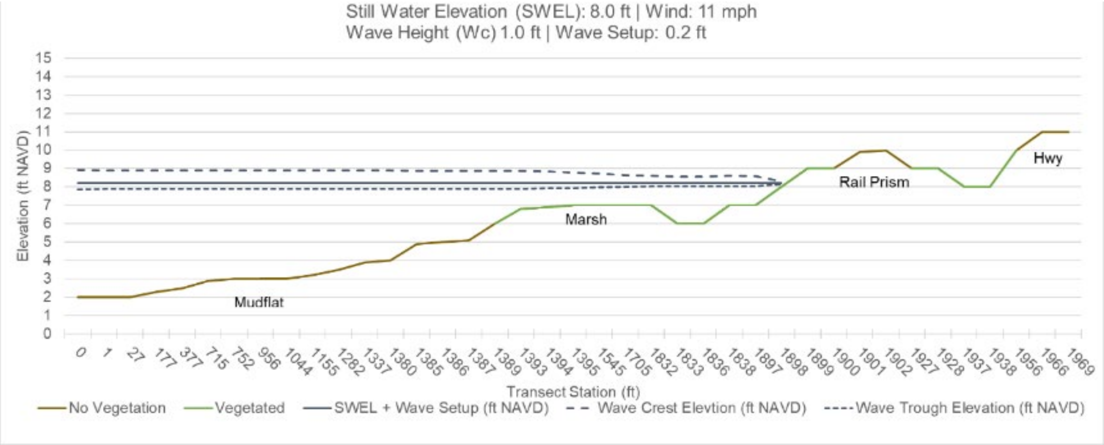


Figure 31 WHAFIS results for wave attenuation as a function of marsh width, where incident wave heights are A) 2 feet and B) 3 feet NAVD88 (ESA, 2012).

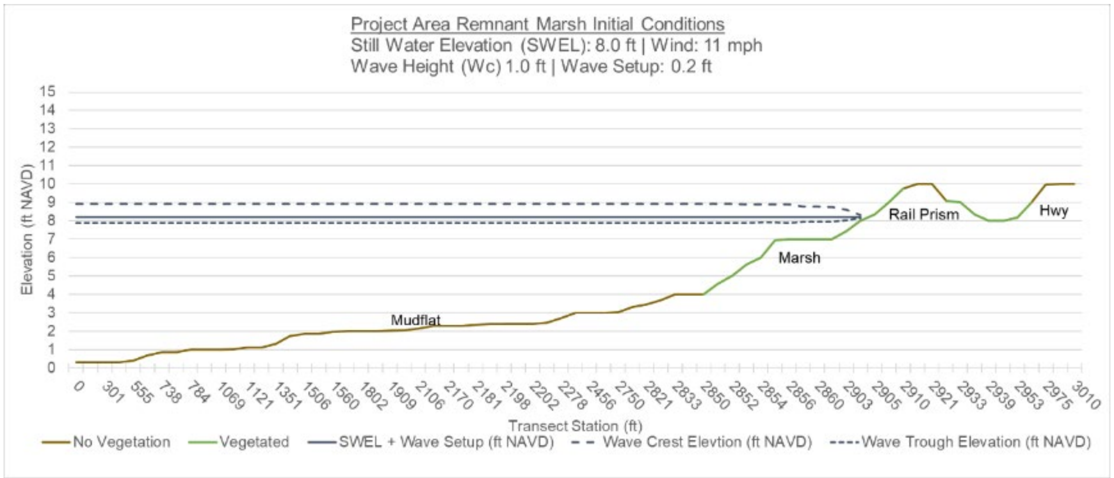
The results for each of the four model scenarios are shown below in (Figure 32, Figure 33, Figure 34, Figure 35). The still water elevation level (SWEL) and wave setup, along with wave crest and wave trough elevation are shown along each transect. In shallow water, approximately 30% of the wave height is located below the reference water level (SWEL + wave setup) and 70% above. Wave height is affected by wind speed, depth of water and the presence of vegetation. Wave height is limited to 78% of the local mean water depth.

In the scenarios involving the 8-ft SWEL and initial 1-foot wave height and 11 mph wind (Figure 32), the wave height is maintained along the mudflat and is first reduced when encountering a transect elevation of 7 feet and with the presence of vegetation. Along the reference reach transect, the wave height is reduced to 0.5 feet over 400 feet, then travels an additional 70 feet before breaking onto the rail prism. The wave height along the project area remnant marsh transect is initially reduced to 0.8 feet over 50 feet, before breaking onto the rail prism. Where no marsh is present, the wave breaks directly onto the rail prism.

When the initial wave height is increased to 2.4 feet, and wind to 45 mph, the wave height increases along the mudflat and is first reduced when encountering a transect elevation between 5 and 6 feet (Figure 33). Along the reference reach transect, the wave height is rapidly reduced to less than 1 foot over 200 feet of marsh, continues to reduce a small amount over the next 300 feet of marsh, then begins to build an equal amount across the marsh plain before breaking on the rail prism. The wave height along the project area remnant marsh transect is initially reduced to 1 foot over 40 feet of marsh and 10 feet of rail prism, before breaking onto the higher elevations of the rail prism. Where no marsh is present, the wave breaks directly onto the rail prism.



Still Water Elevation (SWEL): 8.0 ft | Wind: 11 mph
Wave Height (Wc) 1.0 ft | Wave Setup: 0.2 ft



Project Area Remnant Marsh Initial Conditions
Still Water Elevation (SWEL): 8.0 ft | Wind: 11 mph
Wave Height (Wc) 1.0 ft | Wave Setup: 0.2 ft

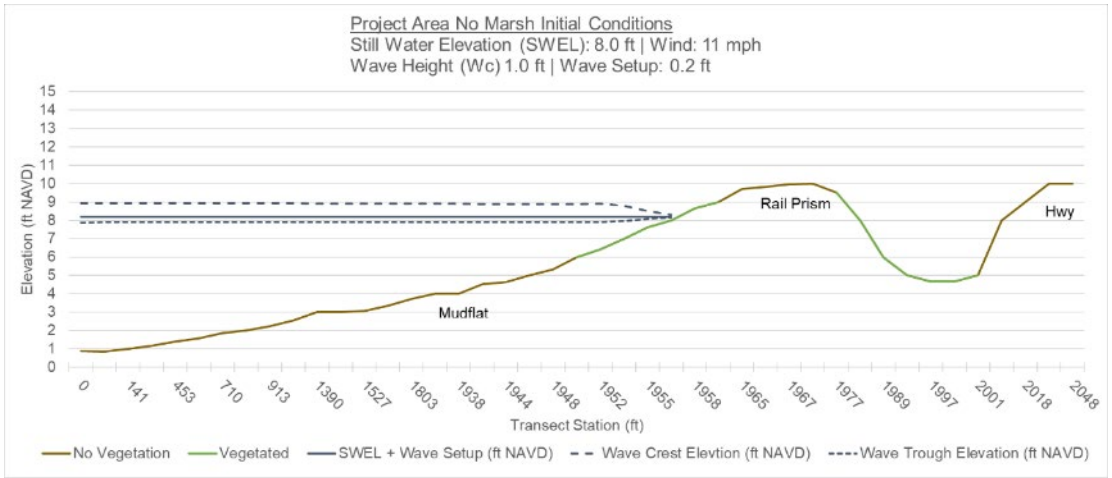
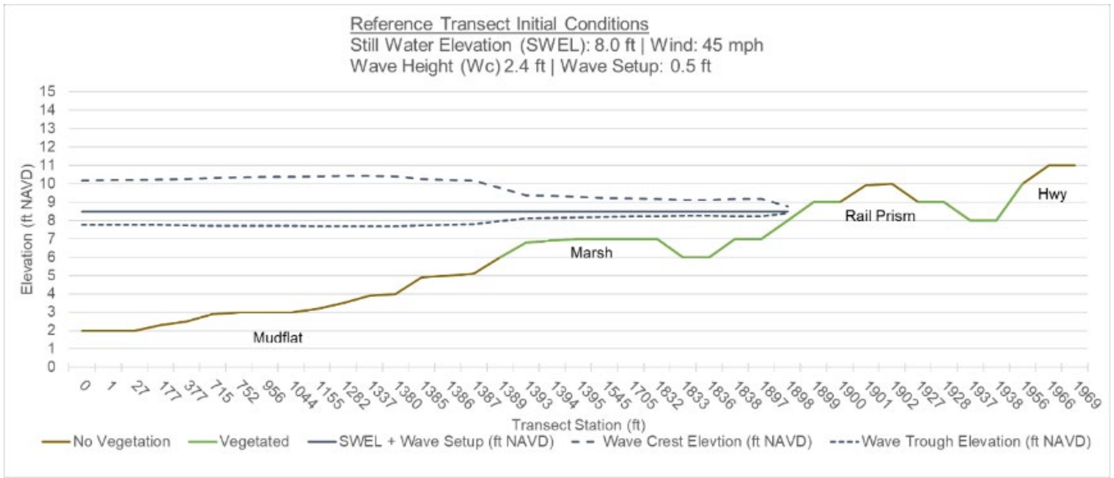
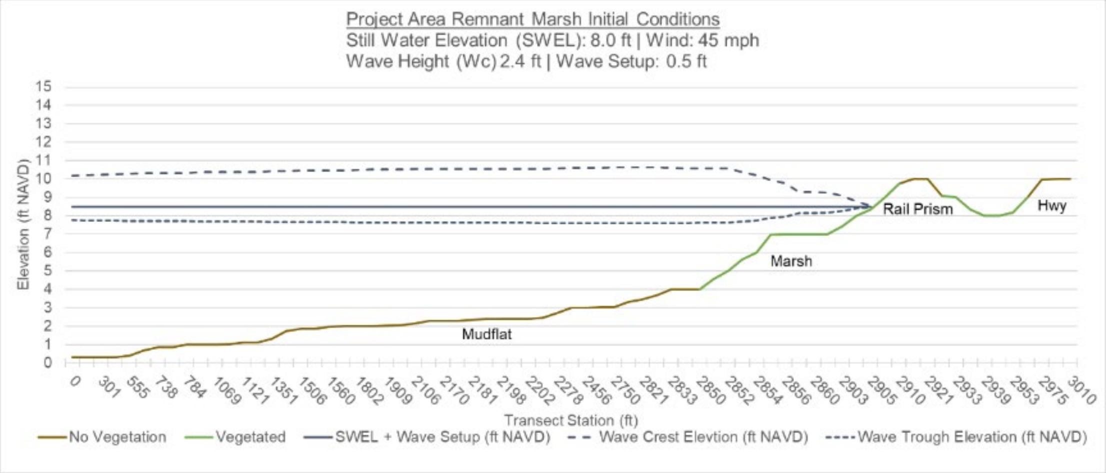


Figure 32 Initial conditions with water elevation 8.0 feet and wave height of 1.0 feet.





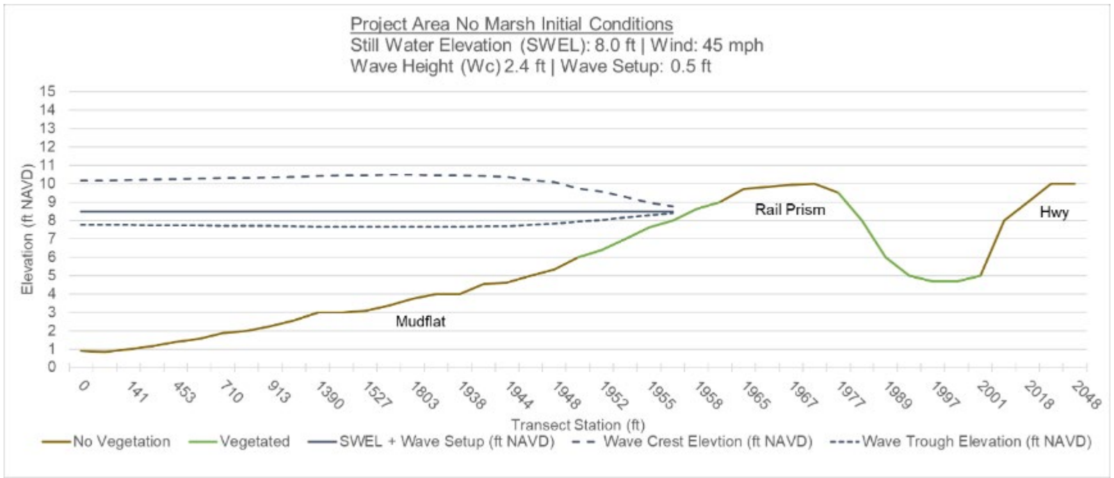


Figure 33 Initial conditions with water elevation 8.5 feet and wave height of 2.4 feet.

Increasing the water level to the 100-year SWEL of 10.6 feet represents a lower frequency event, where the SWEL is approximately 3.5 feet above the marsh plain and overtops the rail prism. The 1 foot wave height is maintained across the mudflat and marsh plain and is not reduced until encountering a transect elevation between 9.5 and 10 feet near the top of the rail road prism (Figure 34). The wave height is reduced to 0.5 to 0.6 feet and propagates over the rail prism and to the roadway.

When the initial wave height is increased to 2.4 feet, and wind to 45 mph, the wave height increases along the mudflat and is first reduced when encountering a transect elevation of 7 feet (Figure 35). Initial height reduction is limited to less than 0.5 feet. More significant wave height reduction occurs when the transect elevation is between 9.5 and 10 feet.

The comparison of the Eureka Slough marsh and project area transects demonstrates that the wave height and wave crest elevation is most significantly reduced by topography or water depth. The most significant reduction occurs at abrupt changes in elevation, provided the depth is shallow enough and vegetation rough enough to affect the wave. As stated in the ESA Corte Madera study, abrupt changes in elevation and depth contribute to plunging wave conditions that exhibit higher erosive forces that may result in migration of the marsh edge. The marsh edge configuration created by 1890s leveeing would likely have contributed to this erosive condition. Wave crest height continues to decrease along the marsh plain in lighter winds but higher wind speed increases the height of the wave, both across the mudflat and following the initial reduction at the marsh edge or other topographic feature.

The geometry of the shoreline affects where the wave breaks and with how much erosive force. An abrupt change in elevation creating a plunging wave is more erosive than a gradual change creating a spilling wave. The wave break location is dependent on water level and shoreline elevation. Wave height may continue to be reduced with the presence of vegetation creating roughness, or increase due to wind speed. Further investigations into changes to geometry and vegetation may demonstrate increased resiliency options.

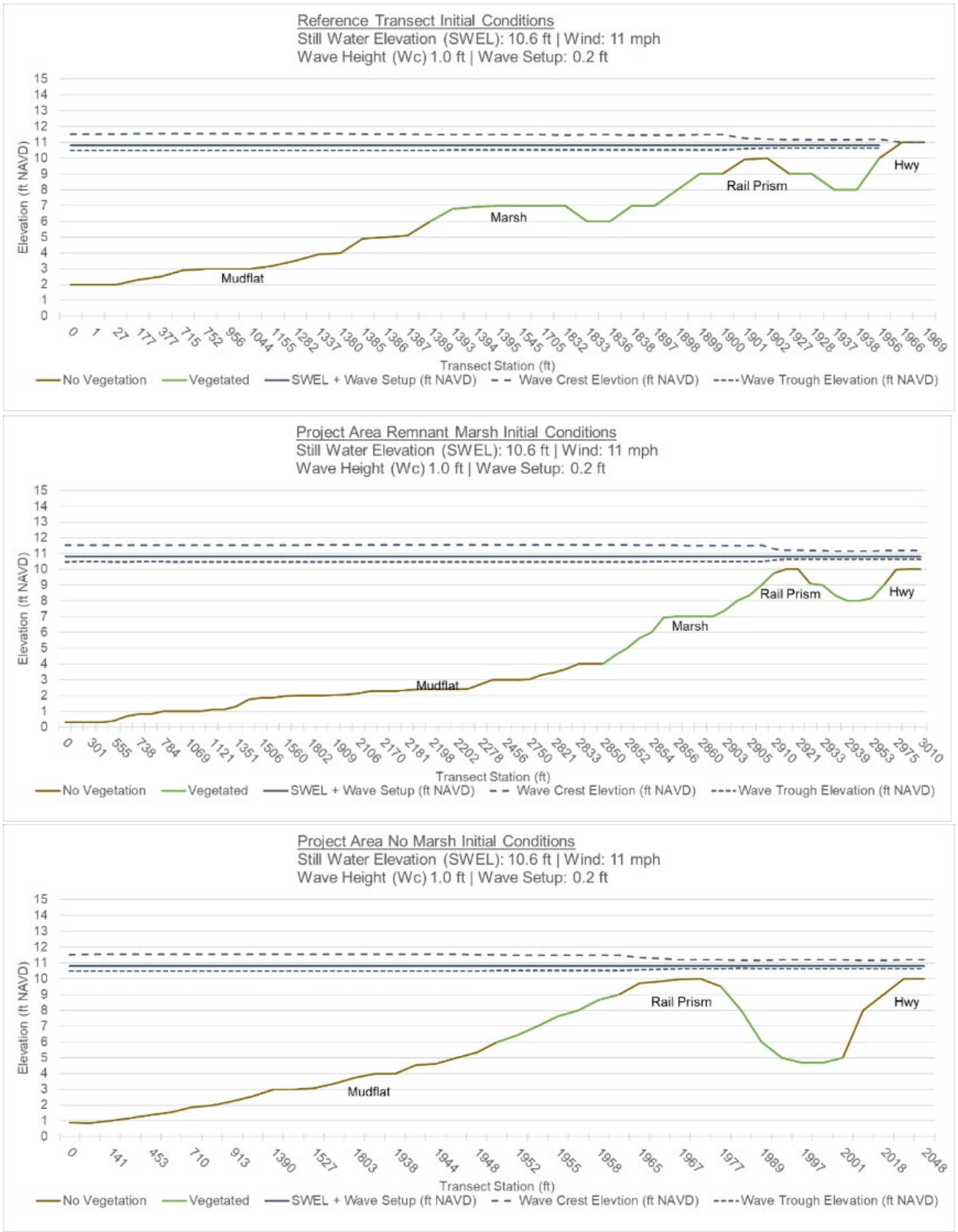


Figure 34 Initial conditions with water elevation 10.6 feet and wave height of 1.0 feet.

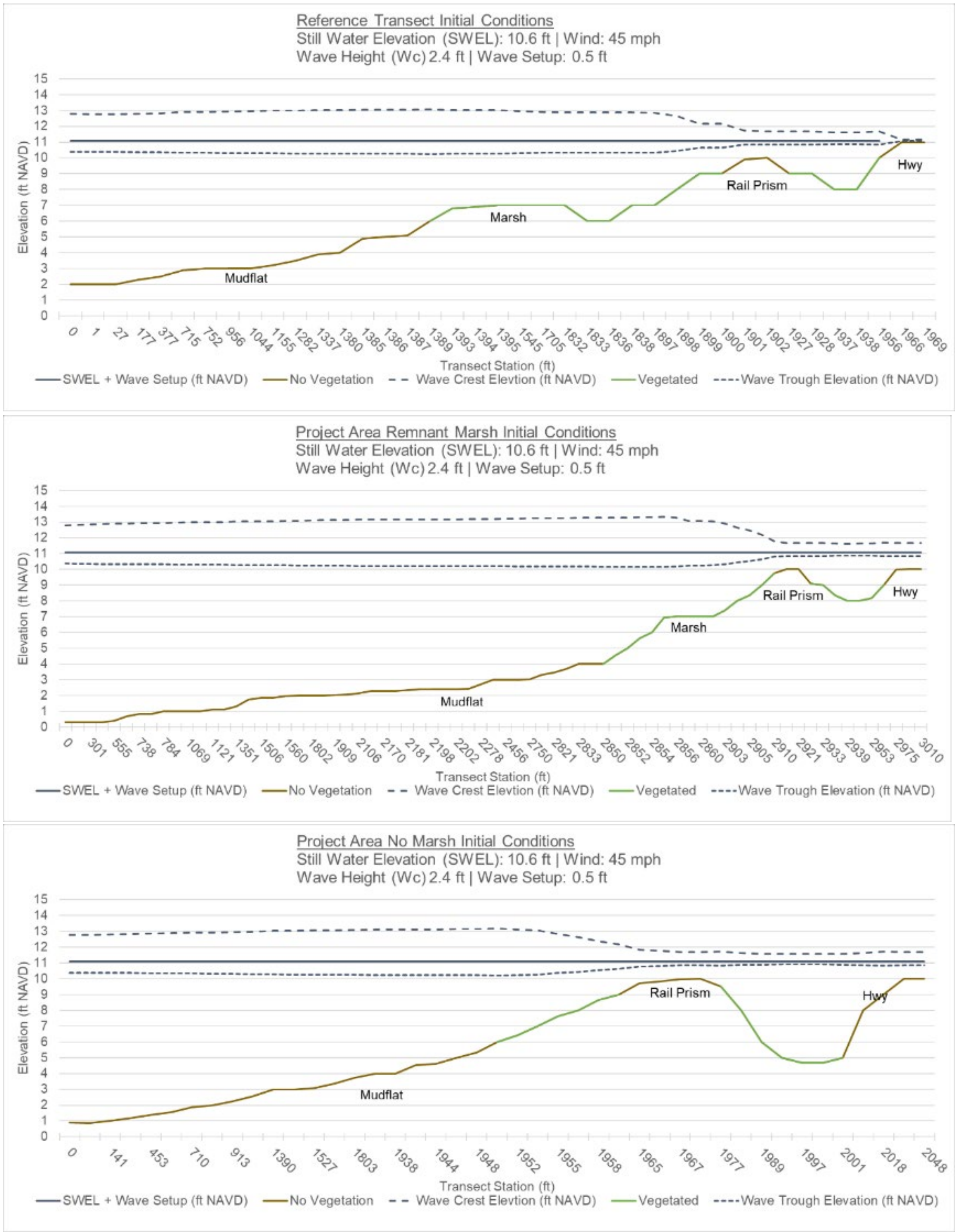


Figure 35 Initial conditions with water elevation 11.1 feet and wave height of 2.4 feet.

Wind Wave Effects on Tidal Currents

Wind blowing over the water surface and wind-generated waves can alter water levels and tidal currents. Wind-generated waves are further described in the subsequent section of this report. To develop an understanding of the effects of wind and waves on tidal currents within the project area, the NSI Model simulated four different wind conditions including no wind, and a 10 mps (22 mph) wind coming from the northwest, north, and southwest directions, respectively (Figure 36 and Figure 37). Both figures show water conditions near the peak (slack tide) of an approximate 2-yr extreme water level, which also represents the approximate mean annual maximum water level (Table 4).

Figure 36 shows that a 10 mps (22 mph) wind can have a significant effect on water levels, currents, and circulation patterns in Arcata Bay over the no wind condition. Wind from the northwest creates a wind setup across Arcata Bay with lower water levels on the west boundary, and higher water levels on the east boundary (project shoreline). A north wind pushes water out of Arcata Bay towards Entrance Bay and lowers water levels, while a south wind pushes water into Arcata Bay raising water levels, compared to the no wind condition. Bay wide currents and circulation patterns are significantly affected by the wind and wind-wave direction compared to the no wind condition. Near slack tide under the no wind condition currents are generally flowing into Arcata Bay, although a small amount of flow is beginning to reverse and flow south near Eureka Slough. The northwest wind creates two apparent circulation zones (eddy or gyre) with reversed flows along the westerly and easterly bay edges, with the strongest flow along the westerly shoreline. Wind from the north creates three apparent circulation zones in the bay, with stronger reversed currents along the easterly edge (project shoreline) than a northwest wind. The southwest wind creates two circulation zones, with single reversed current in the center of the bay and increased northward flow along both easterly and westerly shorelines.

Figure 37 shows the velocity magnitude and vectors at the project shoreline approximately 45 minutes before the conditions shown in Figure 36, to better emphasize the velocity field. The north and southwest winds create strong alongshore currents (longshore currents) compared to the velocity field from the no wind and northwest wind conditions. It is interesting to note that the northwest wind does not create a significant along-shore current at the project shoreline compared to the north and southwest wind conditions. This is largely due to the wind direction and wind generated incident waves approaching normal (perpendicular) to the project shoreline which creates minimal alongshore currents from the transfer of wave momentum flux through radiation stresses. Higher alongshore currents are generated from radiation stress forcing by the obliquely incident wind-waves from north and southwest wind directions. Thus, the wind conditions that produce the highest wind-wave heights at the project shoreline (northwest winds), also produce the lowest alongshore currents. Although simulation results are presented for only one high water level and wind-speed, current and circulation patterns are similar for different water levels and wind speeds from the same general wind directions.

This simple assessment demonstrates the important role wind waves have on the tidal circulation within Arcata Bay and along the project shoreline. The gravel patterns observed between the rail prism and fringe marshes corroborate the model results indicating an along-shore velocity sufficient to remove finer grained sediments and leave a gravel/sand layer along the shoreline during a high tide and high wind event. However, the gravel/sand gradation patterns, with coarser material at higher elevations grading to finer material at lower elevations, may be better explained by wave action than along-shore velocities.

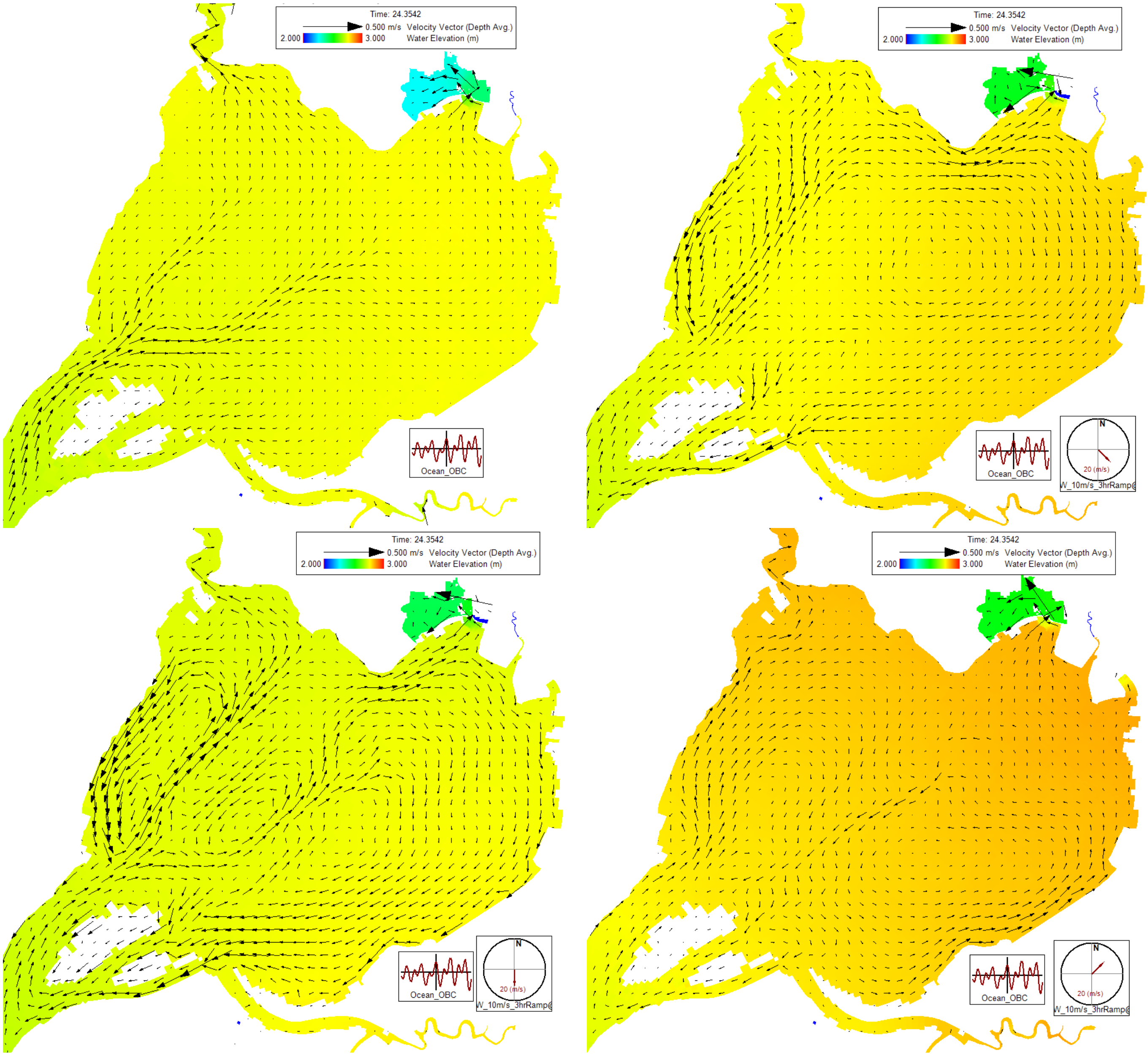


Figure 36 Water surface elevations and velocity vectors of tidal currents predicted during an approximate 2-year extreme water level in Arcata Bay with no wind (top left), a 10 mps (22-mph) northwest wind (top right), a 10 mps (22-mph) north wind (bottom left), and a 10 mps (22-mph) southwest wind (bottom right).

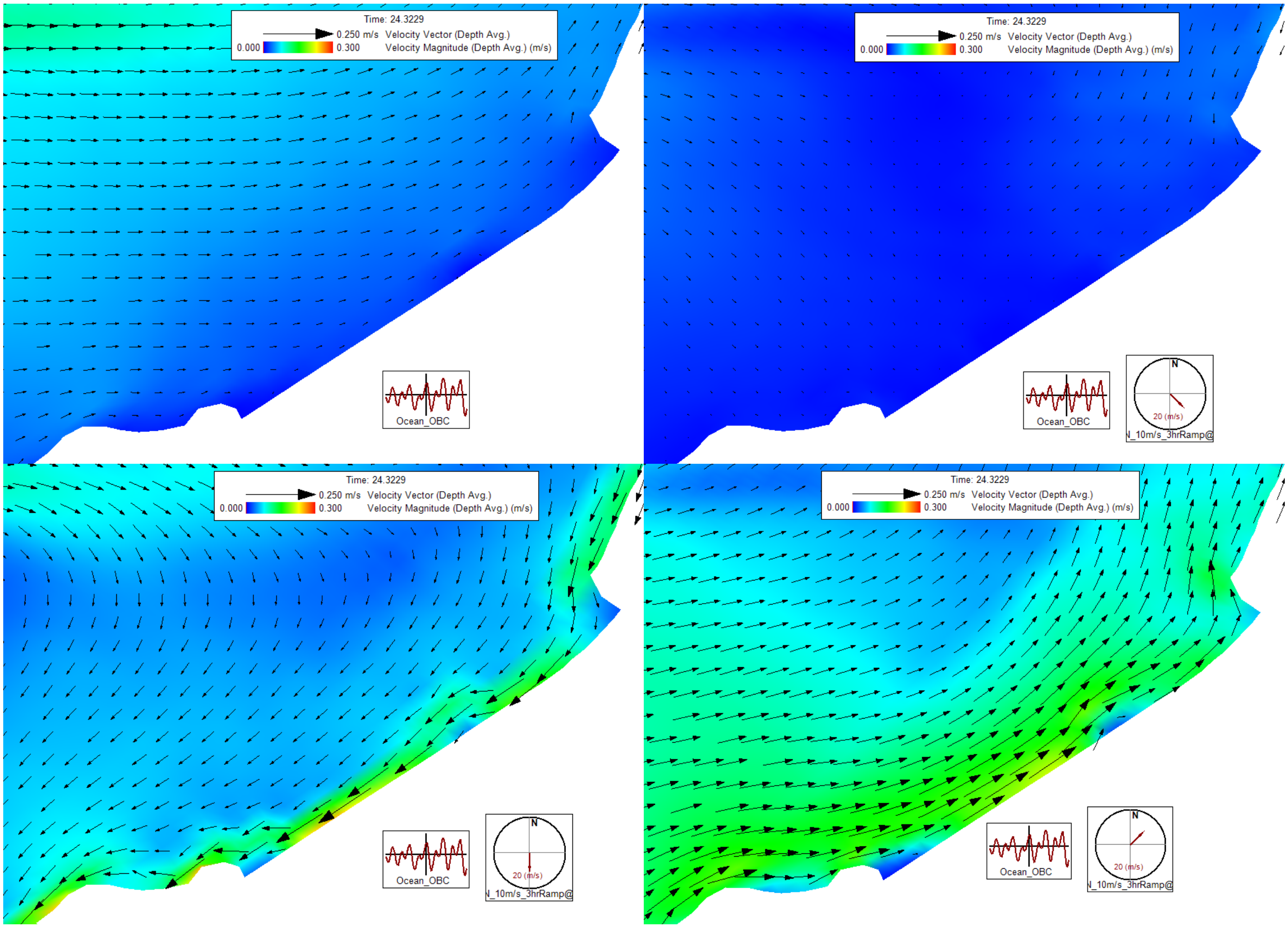


Figure 37 Velocity vectors (magnitude and direction) of tidal currents predicted during an approximate 2-year flood tide along the project shoreline, with no wind (top left), a 10 mps (22-mph) northwest wind (top right), a 10 mps (22-mph) north wind (bottom left), and a 10 mps (22-mph) southwest wind (bottom right).

5.4.4 Driver: Sediment Supply (Marine and Fluvial)

The sediments in Humboldt Bay are derived from three main sources: fluvial runoff, oceanic (marine) input, and biological activity which is the least important of three (Barnhart, 1992). Thompson (1971) estimated a yearly marine sediment input of 540,000 to 670,000 m^3 and only 90,000 m^3 of sediment per year from the fluvial rivers and creeks tributary to the Bay. Most of this oceanic sediment would be derived indirectly from river sources within the Eureka Littoral cell including the Eel and Mad Rivers. During periods of high river discharge, the nearshore currents trend northerly carrying the Eel River plume into the bay during flood tides as observed from satellite imagery (Barnhart, 1992 and Carlson, 1973) and some of these sediments settle in the Bay during slack tides. The Mad River probably also contributes sediments in the same fashion during periods of southward-flowing nearshore currents however sediment load of the Mad is only about 10% of that of the Eel, and because the periods of southward flow do not tend to coincide with periods of high river discharge, Mad River source sediments to the Bay are understood to be relatively low (Barnhart, 1992).

Tidal dynamics and wind-driven waves within Humboldt Bay distribute fine sediments such as clays and silts and are generally carried to higher elevations on tidal mudflats and salt marshes. Fine sediments such as colloidal clays, contributed from fluvial and marine sources, can remain in suspension for extended periods of time (Figure 38). Sediment deposited on mudflats can be resuspended when current velocities exceed approximately 10 cm/sec. Mudflats are thus often reshaped by tides (Bird, 2000).

Figure 38 Suspended sediment distribution in Eureka Slough and mouth of Jacoby Creek following rainfall runoff event, photos courtesy of Brad Finney.

As described in the Humboldt Bay Spartina Eradication Programmatic EIR, discrete suspended sediment concentration (SCC) sampling was conducted by the Wiyot Tribe at three locations in Humboldt Bay (Indian Island, Mad River Slough and the Bay Entrance) between 2005 and 2011 and resulted in an SSC range from 5.6 to 83 mg/L (H.T. Harvey & Associates and GHD, 2013). These ranges are similar to SCC observed at the USGS Mad River Slough gage (Curtis 2019). Coarser sediments such as fine sands are generally moved to lower intertidal and shallow subtidal zones near small channels. Coarser sands, gravels and larger shell debris are generally deposited in larger channels where fine sediments can be carried out by more competent flows (HBHRCD 2006). A study conducted by Borgeld and Stevens (2004) suggests that the sand-dominated marine sediments, characteristic of the channels in the lower reaches of Humboldt Bay, have propagated both northward and southward in the main tidal channels and away from the Entrance Bay.

Construction and ongoing maintenance of the navigation channels from the Humboldt Bay entrance and toward Arcata Bay affect the distribution of sediments and likely the tidal hydraulics (Thompson 1971; Costa and Glatzel 2002). The Humboldt Bay inlet evolution over the last 150 years including modifications and associated physical changes are addressed by Costa and Glatzel (2002). Dredging of interior Bay channels for navigation started around 1881 and entrance modifications were initiated around 1889, and the existing entrance was constructed in the 1970s. Arcata Bay is connected to the entrance via the dredged North Bay, Eureka and Samoa Channels. The report implies that the navigation works have affected the Bay. For example, the sediment delivered by Freshwater Creek reportedly deposits in the Eureka and North Bay navigation channels, and therefore is removed from the system via maintenance dredging.

Between 1975 and 2016, maintenance dredging of the federal navigation channels by the USACE remove approximately a total of 690,000 m^3/year and consistent with the approximate total volume of sediment input described above. Of the total dredged volume removed, 90% is of sand size and larger and less than 10% being fine-sediment. Starting in 1990, all of that dredged material was placed outside of the Littoral Cell at the Humboldt Open Ocean Disposal Site (HOODS), the center of which is approximately 3.5 mi from the channel entrance (USACE, 2017). Repeated testing has shown that sediment from the Bar and Entrance Channel and the North Bay Channel is greater than 95% sand and gravel. Sediment from the Samoa Channel and its Turning Basin is greater than 85% sand and gravel. Sediment from the Eureka Channel and the Fields Landing Channel and its Turning Basin is between 25 and 80% sand and gravel (USACE 2017).

While a sediment budget has not been completed for Humboldt Bay, climate change models have predicted an increase in suspended-sediment delivering to the Eureka Littoral Cell and Humboldt Bay. This increase in fine sediment supply and deposition throughout the Bay has the potential to partially offset impacts from sea level rise and subsidence (Curtis 2021).

5.5 Physical Processes and Response

The second component of the conceptual model includes the physical processes such as erosion or deposition throughout the project area and is specifically assessed with respect to the following landscape features:

1. Mudflat Deposition and Resuspension
2. Salt Marsh Edge Lateral Progradation and Recession
3. Salt Marsh Vertical Accretion and Degradation

5.5.1 Process: Mudflat Deposition and Resuspension

The mudflats fronting the project area extend over 3,000 feet bayward and are exposed during low tides and are inundated during high tides. The mudflats have evolved from sediment deposition and hydraulic shaping. Hydraulic shaping is typically accomplished by waves which initialize sediment entrainment, and tidal currents which then transport the sediment. In Arcata Bay, the waves are wind-generated waves, rather than ocean swell waves and boat wake waves exposure in the Entrance Bay. Currents generated by tides, winds, and waves “sweep” the mudflats, affecting the geometry (slope and extents) of the flats, which in turn affects the residual wave exposure at the landward edge of the mudflats.

The sediment type and size in the mudflats are largely affected by the sediment source and its proximity, with coarser sediments near creek mouths and recent nearshore deposits, and finer sediments typically in other locations where the greater range of suspended sediment transport dominates. The type of sediment, combined with the energy level of waves and currents, control the slope of the mudflats and shores. For a given sediment size, a higher wave exposure results in a relatively flatter slope. The lateral extent of the mudflats is primarily affected by the slope and the tide range extended by the depth of wave-induced water motion and the wave runup on the shore. The mudflats in Arcata Bay steepen above low tide (Barnhart and others 1992).

Mudflats may also transgress similar to sand flats and beaches. However, it is more likely that the finer sediments will migrate away from the profile due to the greater range of suspended sediment transport. Also, it is more likely that the eroded, suspended sediments will migrate into sediment sinks such as marshes. Therefore, the response of these finer sediment flats is often more dependent on suspended sediment supply to sustain the lower elevations of the profile.

Eelgrass and macro algae are prevalent on the mudflats of Arcata Bay (Barnhart and others 1992; Schlosser, S., and A. Eicher. 2012; Merkel & Associates 2017). They can reduce sediment resuspension from currents by processes that aggregates fine particles into clumps, which increases the critical shear stress required for resuspension. Over time, sediment deposited on mudflats becomes more cohesive as pore water escapes, and organic and electrolytic binding occurs.

Long-term sediment erosion and deposition trends in Arcata Bay mudflats have not been studied nor correlated with rate of sediment supply. Former deforestation from former logging and quarrying in Arcata Bay watersheds in late 1800's and early 1900's would have greatly increased the quantity of sediment delivered to Arcata Bay which likely contributed to mudflat deposition. During this same period, large scale leveeing and draining of the tidal marshes occurred which would have reduced this sediment sink, thereby making more sediment available to the mudflats. In sediment limited systems, mudflats fronting marshes can create a sediment sink that reduces sediment flux potential shoreward towards the marsh, whereas mudflats with sufficient sediment supply can increase flux potential to the marsh during wind-induced erosion (Mariotti and Carr 2014). The timescale of the mudflat-marsh system response to change in sediment loading is unknown in Arcata Bay.

To better understand mudflat erosion and deposition characteristics at the project area, SEDFlume analyses were conducted on three (3) cores fronting the project shoreline. SEDFlume analyses evaluate the erodibility of mud flat sediment to determine what tidal and wave forces (depth and speed) are necessary to break up and transport mudflat sediment. Cores were obtained in the upper 30cm of the mudflat and eroded using SEDFlume to determine erosion rates as a function of depth and shear stress (Integral 2021). This information provides insight on mudflat erodibility that can be correlated with depth and energy resulting from tidal currents and wind waves. The three SEDFlume core locations are shown in Figure 39 and a description of the SEDFlume analyses and results are presented in Appendix F. Given the sensitivity of erosion rates to sample density, some error may have been introduced in the results due in part to consolidation during the handling and transporting of the core samples. Sampling, handling and transporting procedures provided by Integral Consulting were followed and included transporting the samples in an upright, padded container via a freightliner truck to the SEDFlume laboratory in Santa Cruz, California. The coring, handling, transporting and standard laboratory procedures could have resulted in erosion rate error on the order of 10 to 30% of which typically less than 10% is attributed to transporting effects (Integral 2021 and per comm 2022).

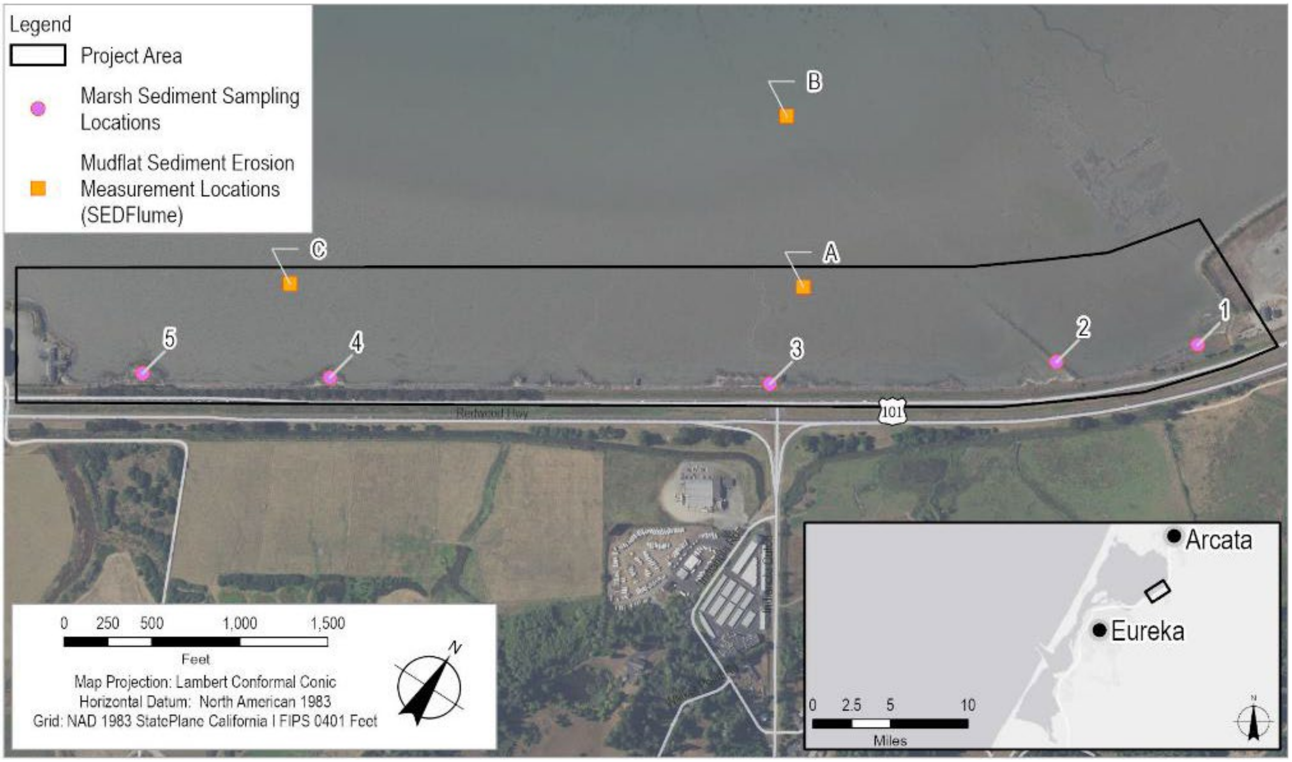


Figure 39 Sediment sampling locations in and adjacent to project area.

The erosion rates, particle size and bulk density by depth for each core are shown below in Figure 40. In core A, the sediment grain size was predominantly silt and ranged from clay to coarse silt. The sediment size decreased slightly with depth and both bulk density and critical shear stresses increased with depth. In core B, sediment grain size was predominantly silt and ranged from clay to very fine sand. The sediment size increased slightly with depth as did the bulk density and critical shear stresses. In core C, sediment grain size was predominantly silt and ranged from clay to coarse silt. The sediment size and bulk density slightly decreased with depth however the critical shear stresses increased. The increase in shear stress with depth observed in all cores, indicates that the surface sediment has higher erosion rates (are more erodible) relative to the deeper sediments. Relative to one another, the critical shear stresses were similar between cores A and B, however core C critical shear stresses were higher, indicating lower erosion potential compared to cores A and B. In core B, a layer of organic debris and shell fragments was detected at 18cm below ground surface. This could have been a historic mudflat surface with 18cm of deposition. However, this sample was collected at the location of remnant dike[2] which may have directly or indirectly disturbed the mudflat in this vicinity altering the erosion and depositional patterns.

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[2] The dike was constructed in 1960 as part of an attempt to expand the shoreline fill at Bracut. The project was abandoned before it was completed. Traces of the dike remain above water and can be seen in Figure 39 at the location of marsh sediment sampling location 2.

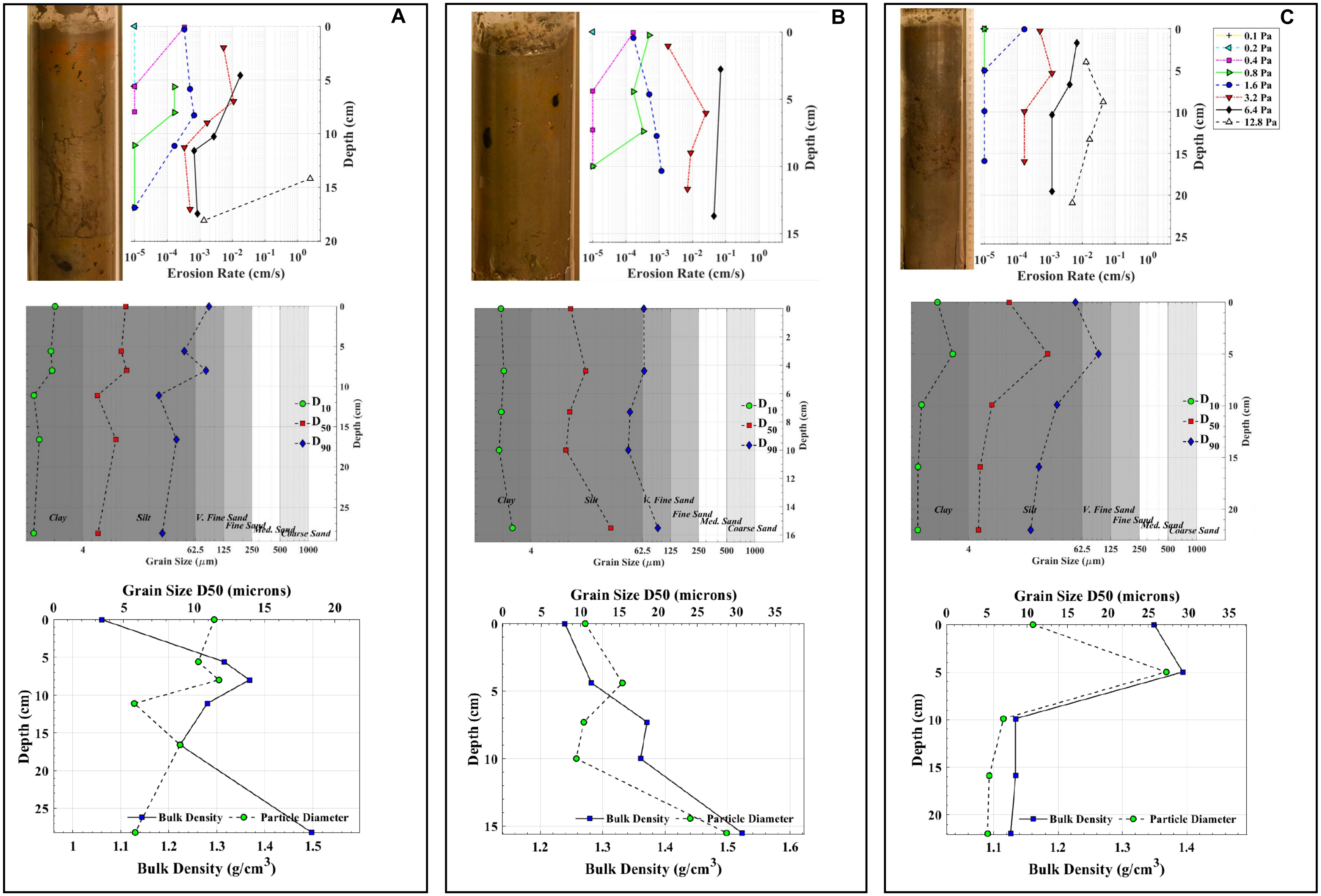


Figure 40 SEDFlume cores with photograph at top aligning vertically with the corresponding erosion rates. Particle size distribution is shown in the middle and bulk density on the bottom.

To better understand the potential for erosion and/or deposition at the project area, the NSI model was used to simulate hydrodynamics for eight (8) cases which included tidal currents with no wind and combined tidal and wind-wave currents for a range of tidal elevations, and wind speeds from the two dominant wind directions. As previously discussed, the tidal boundary condition was for a 10-day period that included a range of tidal elevations from MHHW to above the 1% annual chance extreme high-water level event. The wind speeds were 5 mps (~ 11 mph), 10 mps (~22 mph), 15 mps (~34 mph), and 20 mps (~45 mph), and the two wind directions were from the NW and SE.

The erosion/deposition potential analysis consisted of comparing the range of critical shear stress for erosion (critical shear stress) values from the top ~5 cm of bed material for the 3 SEDflume samples (Samples A, B and C), to the predicted total bed shear stress (total stress) from the NSI model. The critical shear stress of the top ~5 cm ranged from 0.27 (Sample A) to 1.3 N/m^2 (Sample C). This range indicates that the top ~5 cm layer for Sample A is more prone to erosion than Sample C.

Following are general assumptions for the erosion/deposition analysis:

- Predicted total bed shear stress (total stress) consisted of the combined current-induced and wave-induced shear stresses from wind waves. If wind waves were not simulated (no wind), then the total stress consisted of current-induced shear stresses from tidal flows only.
- The potential for erosion occurs when total stress exceeds the critical shear stress range from the SEDflume samples. The critical shear stress range indicates the potential range of shear stresses when erosion from the bed is likely to begin. For this analysis, some of the bed top layer will begin to erode when total stress exceeds the lowest critical shear stress of 0.27 N/m^2, and most of the bed will begin to erode when the highest critical shear stress of 1.3 N/m^2 is exceeded.
- The potential for deposition occurs when shear stresses are below the lowest critical shear stress of 0.27 N/m^2. However, this deposition condition only applies to this erosion/deposition potential analysis. Actual fine-grained sediment deposition is probabilistic in nature, and can occur at shear stresses above the critical shear stress depending on different factors (e.g. floc size, soil mineralogy, salinity, etc.). In fact, it is possible to have sediment eroding and depositing at the same time and same general location.
- The erosion/deposition potential analysis only applies to the mudflat areas. The sand/cobble shoreline consists of non-cohesive grain sizes and will have different critical shear stresses (lower and/or higher) based on particle size. The tidal wetland areas will have higher critical shear stresses due to the vegetation roots increasing the shear strength of the soil.

For this analysis, the general project and offshore areas were delineated into four (4) zones (Figure 41) representing a gradient of combined upper elevation mudflat and tidal marsh areas (Zone 1), to zones that are lower elevation mudflat areas that are typically exposed at low tides (Zones 2, 3 and 4). In general, submergent mudflat areas were not included in the individual zones. Zone 1 represents the general area of the proposed NSI project, has an average bed elevation of 1.3 m (4.3 ft), and consists of a combination of mudflat, sand/cobble shorelines, and tidal wetlands. Zone 2 is immediately offshore of Zone 1, has an average depth of 1.0 m (3.3 ft), and contains SEDflume samples A and C. Zone 3 is west and slightly larger than Zone 2, contains SEDflume sample B, and has an average bed elevation of 0.77 m (2.5 ft). Zone 4 is the largest and most offshore zone with an average bed elevation of 0.33 m (1.1 ft).

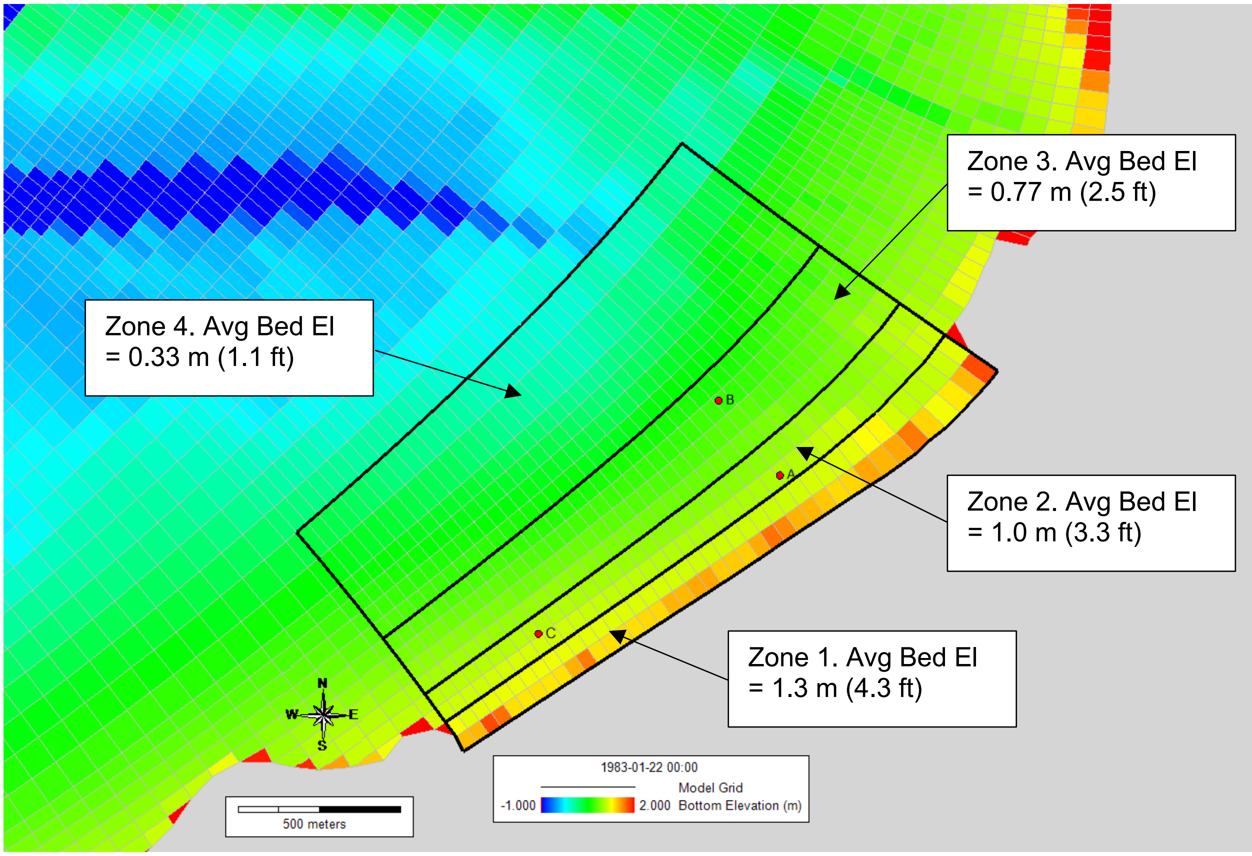


Figure 41 Model grid within the Project Area showing delineated Zones and average bed elevations for each Zone in meters (m) or feet (ft) (NAVD88). Red circles indicate location of SEDflume samples.

For each simulated case predicted depth and total stress were extracted from each grid cell over the 10-day simulation period and analyzed within the 4 zones. The average and minimum/maximum range of depth and total stress were determined for all grid cells within each zone at each model time step (15-min).

It should be noted that the erosion/deposition potential analysis is not a sediment transport analysis. It only provides an indication when erosion and deposition from the bed (or incipient motion), based on the assumptions above, may occur. It does not account for the fate and transport of sediments, and deposition and/or erosion patterns, rates, or depth, which can be assessed with a sediment transport modeling analysis.

Summary results of the erosion/deposition analysis for each of the 8 simulated cases are provided in Figure 42 to Figure 50. The top graph in each figure is the average and range of depths within Zone 1, which represents the ebb and flood of tides in this zone. The four lower graphs in each figure are the total stress average and range within each of the 4 zones for the simulated case. Also provided on each of the total stress figures are the minimum and maximum critical shear stress values from the SEDflume samples.

For the no wind case (Figure 42), total stress in Zone 1 is below the lowest critical shear stress threshold over all simulated tides indicating that the erosion potential is low, and deposition is possible in this zone. Moving offshore from Zone 1, the total stress and the potential for erosion incrementally increases in each zone as the zone bed elevations decrease (depth increases). Zones 3 and 4 have the highest potential for erosion from tidal currents only. This gradation of total stress from Zone 4 to Zone 1 demonstrates that the potential exists for sediment to be eroded from offshore and if transported towards the shoreline deposition is possible due to the lower total stresses. Results also indicate that total stresses tend to be highest during rising and falling tides and decrease during slack tide. This process further promotes the potential for sediment to be eroded from deeper water and transported to the shoreline where deposition is possible.

Winds blowing from the northwest (NW) generate the largest wind waves and create the most energetic wave conditions and highest total stresses near the project area, indicating a high potential for erosion (Figure 43 to Figure 46). As the wind speed increases, the total stress and potential for erosion increases in all zones. In general, Zones 2, 3 and 4 show similar total stress responses and a narrow stress range for each wind speed indicating that the erosion potential is similar in the offshore zones for wind-waves generated from NW winds. Zone 4 has a larger range in total stress compared to Zones 2 and 3, which is likely due to greater a variation in Zone 4 bed elevations that creates greater depth and wave-induced stress variation. For all NW wind speeds, Zone 1 shows the widest range in total stress indicating that the potential for both erosion and deposition are possible in the nearshore zone. Similar to the tide only case, the potential exists for sediment to be eroded from offshore zones and if transported towards shore, deposition may occur due to lower shear stresses.

Winds blowing from the southeast (SE) also create energetic wave conditions at the project area, but the resulting total stresses are lower than winds from the NW for all simulated wind speeds (Figure 47 to Figure 50). The project area is more sheltered from SE winds with shorter fetch lengths that result in smaller wind waves than winds from the NW. Wind waves generated from SE winds also produce a wider range of total stresses for all wind speeds compared to NW winds. The zone responses for SE winds are similar to NW winds, with Zones 2, 3 and 4 having the highest total stress and potential for erosion. Zone 1 has the widest total stress range indicating that the potential for erosion and deposition in the nearshore zone.

The erosion/deposition potential analysis demonstrates that tidal-induced currents alone can erode sediment from deeper water areas (Zones 3 and 4), but in general the total stresses and the potential for erosion is low. However, wave-induced stresses from winds from the NW and SE and wind speeds greater than 5 mps (~11 mph) generate total stresses high enough to erode sediment from all zones, demonstrating that wind-waves are the likely dominate driver for mudflat erosion and deposition in the project area. Model results also indicate that the nearshore zone (Zone 1) has the largest range of total stresses indicating the potential for both erosion and deposition within this zone from wind waves. During wind-wave events the potential exists for sediment to be eroded from offshore mudflat areas and transported to the project area where deposition could occur due to a wider range and lower total stresses.

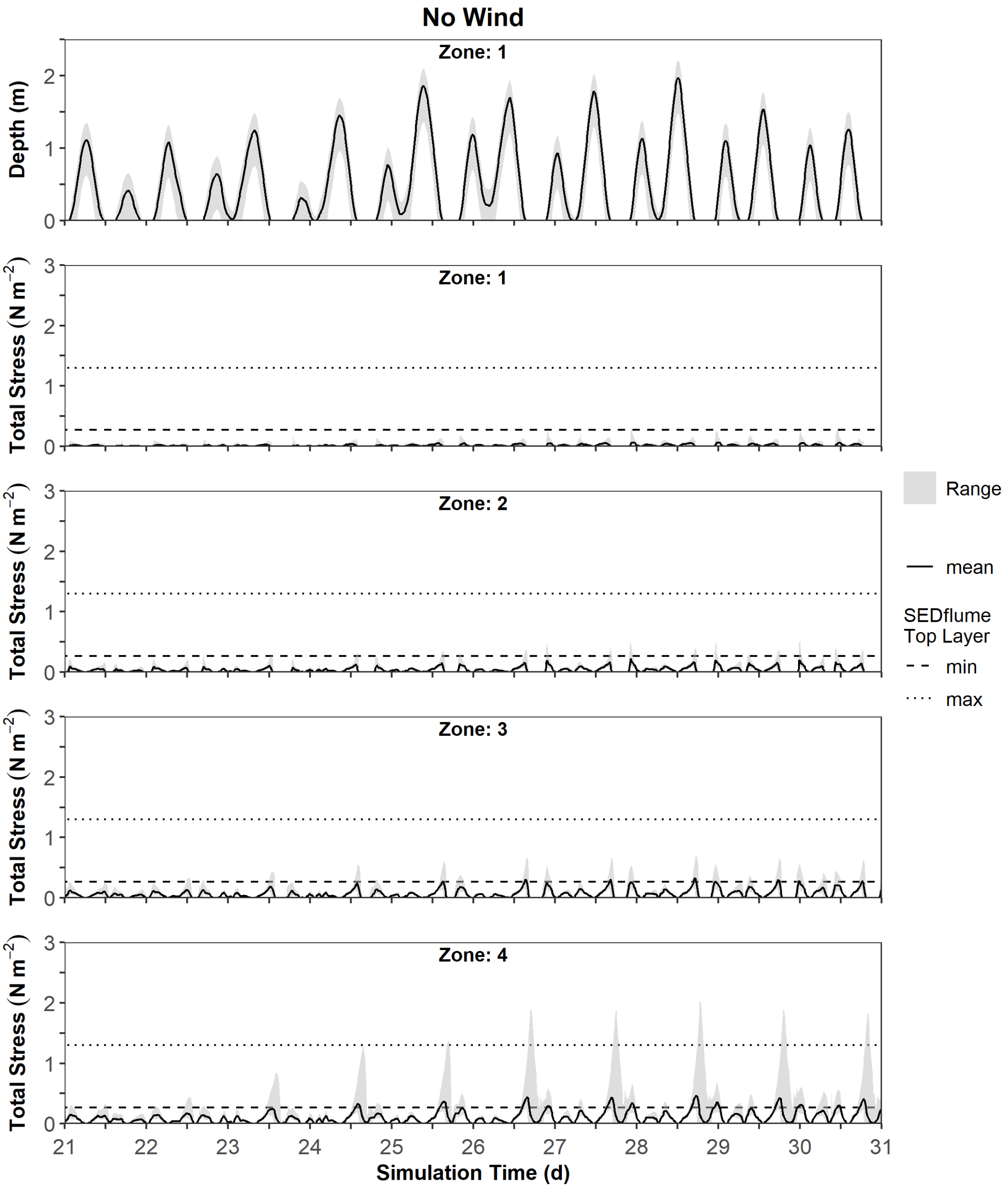


Figure 42 Predicted depth and total bed shear stress (total stress) by Zones with No Wind for the simulation period. Depth is provided for Zone 1 only (top figure), and total stress is provided for all Zones. Total stress is from current-induced shear stress only. Solid black line is the mean; gray band is the min/max range; and the dotted and dashed lines are the minimum and maximum SEDflume top layer critical shear stress for erosion, respectively.

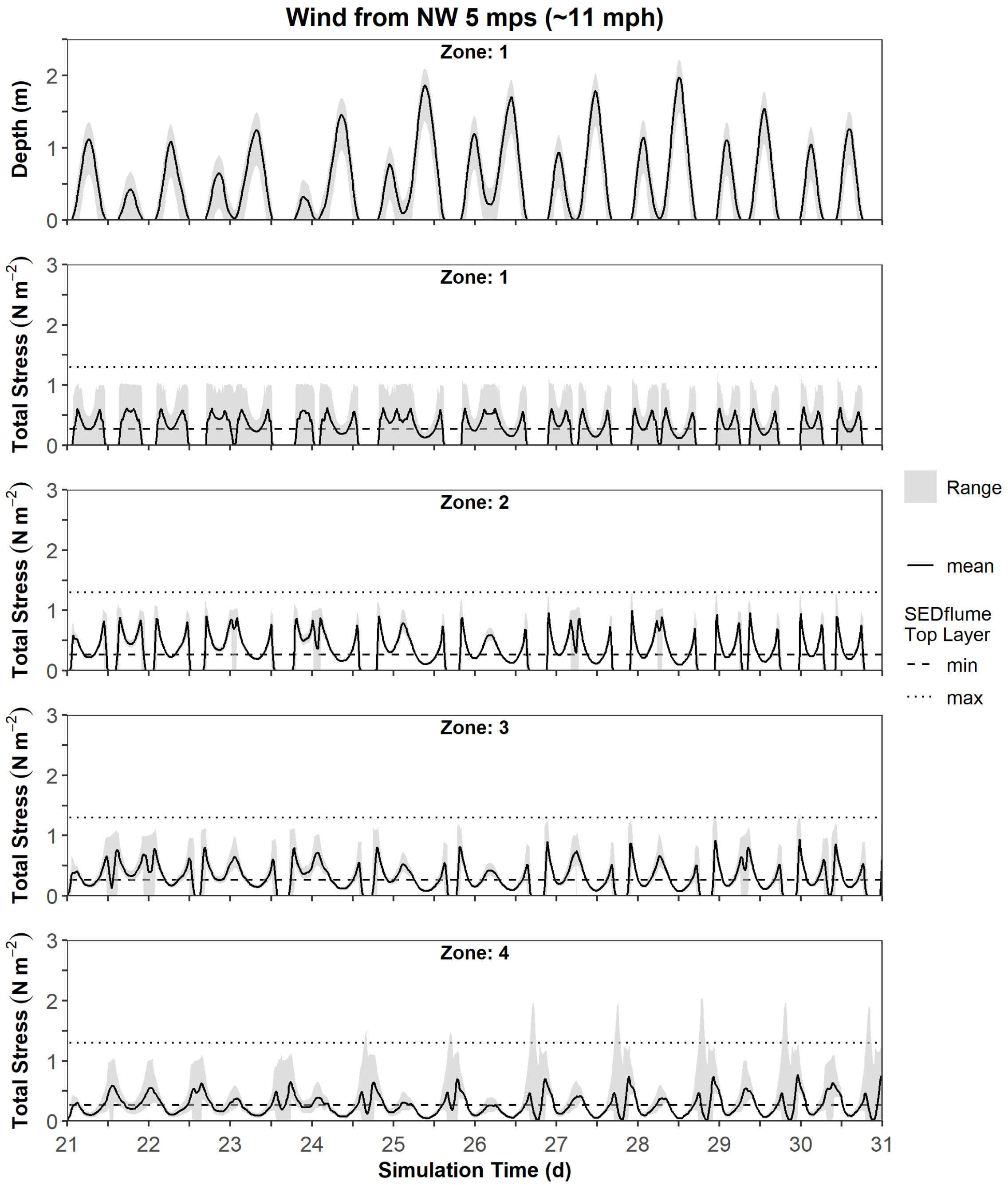


Figure 43 Predicted depth and total bed shear stress (total stress) by Zones with a northwest (NW) wind at 5 mps (~11 mph) for the simulation period. Depth is provided for Zone 1 only (top figure), and total stress is provided for all Zones. Total stress accounts for current-induced and wave-induced shear stresses. Solid black line is the mean; gray band is the min/max range; and the dotted and dashed lines are the minimum and maximum SEDflume top layer critical shear stress for erosion, respectively.

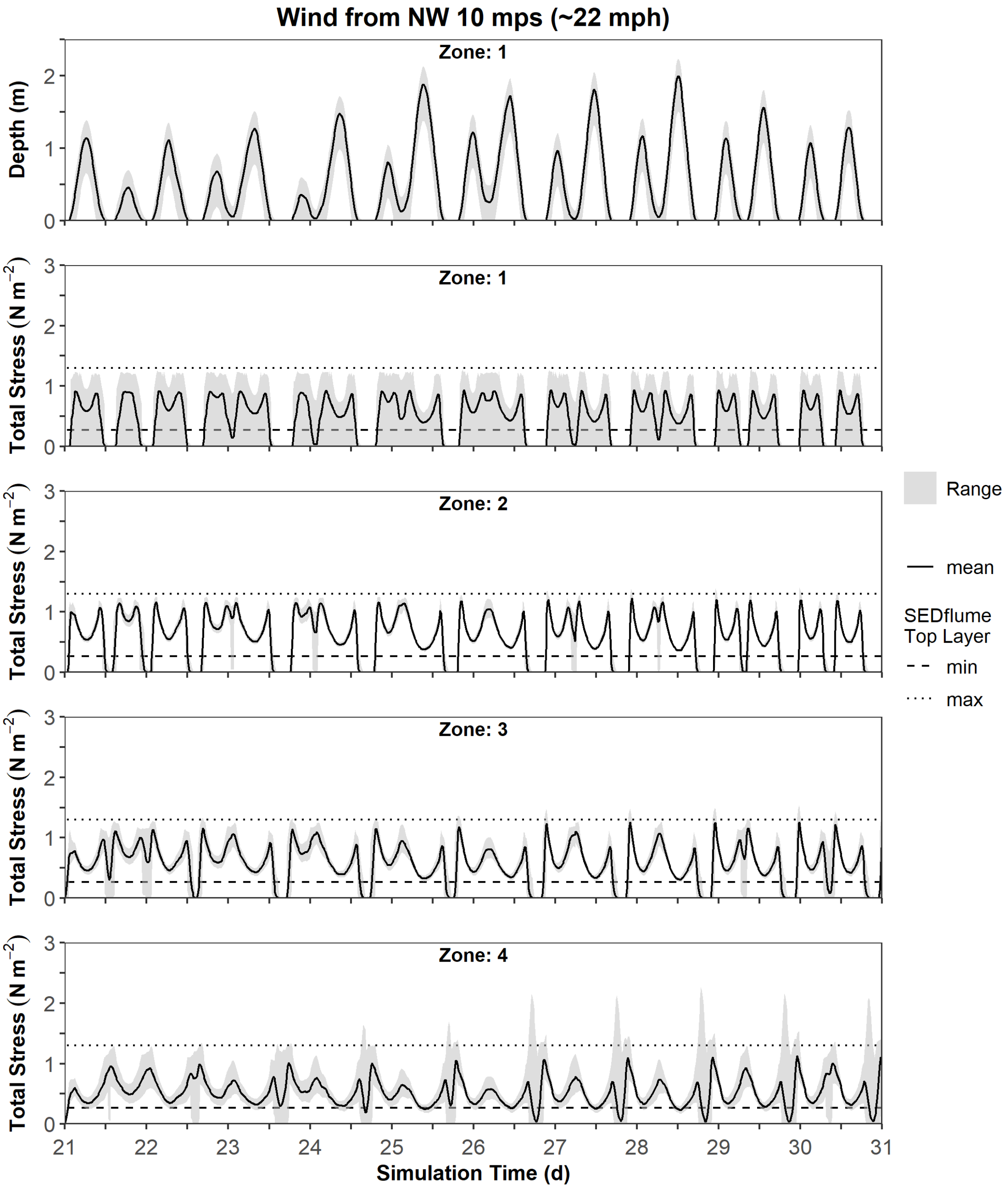


Figure 44 Predicted depth and total bed shear stress (total stress) by Zones with a northwest (NW) wind at 10 mps (~22 mph) for the simulation period. Depth is provided for Zone 1 only (top figure), and total stress is provided for all Zones. Total stress accounts for current-induced and wave-induced shear stresses. Solid black line is the mean; gray band is the min/max range; and the dotted and dashed lines are the minimum and maximum SEDflume top layer critical shear stress for erosion, respectively.

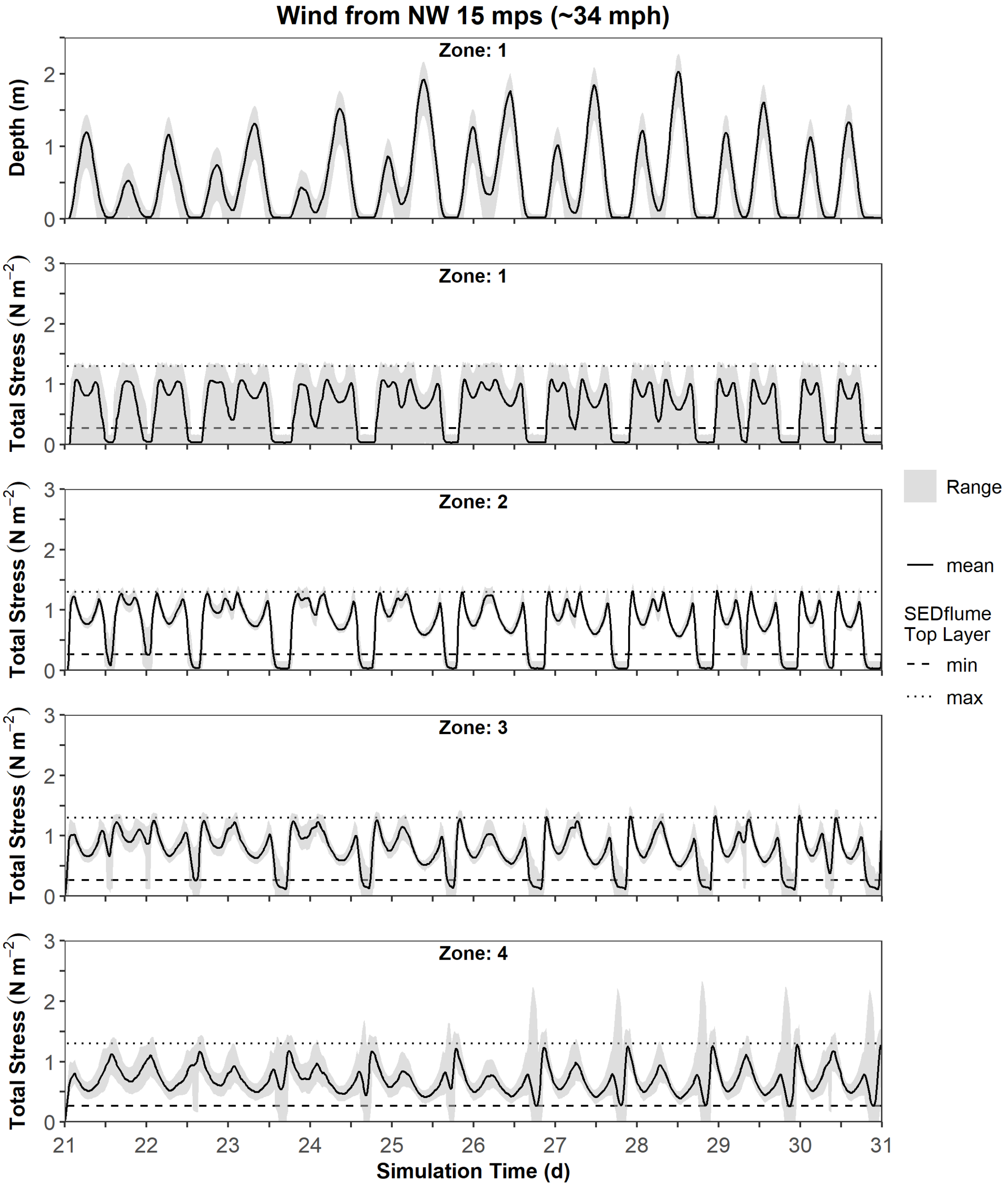


Figure 45 Predicted depth and total bed shear stress (total stress) by Zones with a northwest (NW) wind at 15 mps (~34 mph) for the simulation period. Depth is provided for Zone 1 only (top figure), and total stress is provided for all Zones. Total stress accounts for current-induced and wave-induced shear stresses. Solid black line is the mean; gray band is the min/max range; and the dotted and dashed lines are the minimum and maximum SEDflume top layer critical shear stress for erosion, respectively.

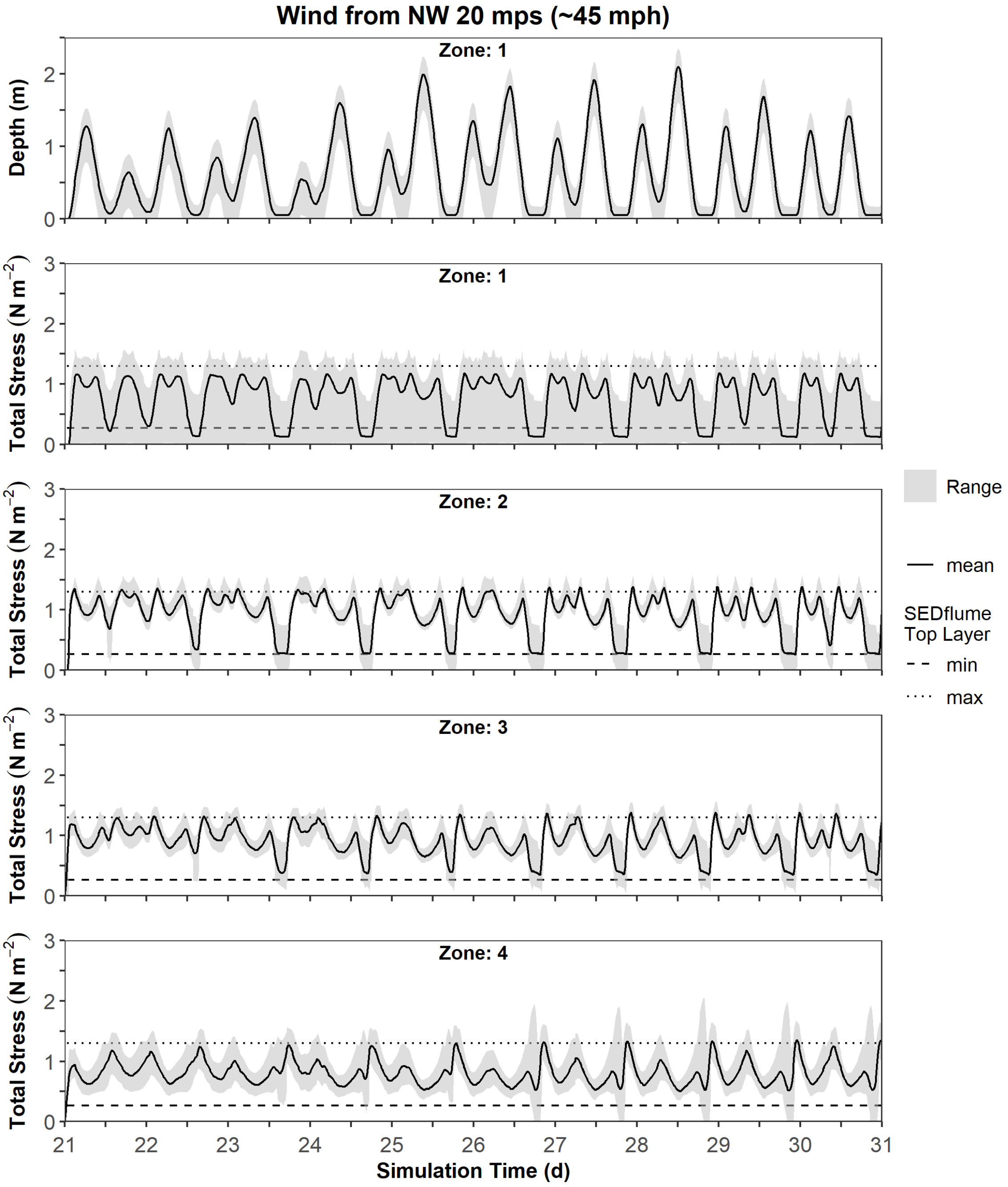


Figure 46 Predicted depth and total bed shear stress (total stress) by Zones with a northwest (NW) wind at 20 mps (~45 mph) for the simulation period. Depth is provided for Zone 1 only (top figure), and total stress is provided for all Zones. Total stress accounts for current-induced and wave-induced shear stresses. Solid black line is the mean; gray band is the min/max range; and the dotted and dashed lines are the minimum and maximum SEDflume top layer critical shear stress for erosion, respectively.

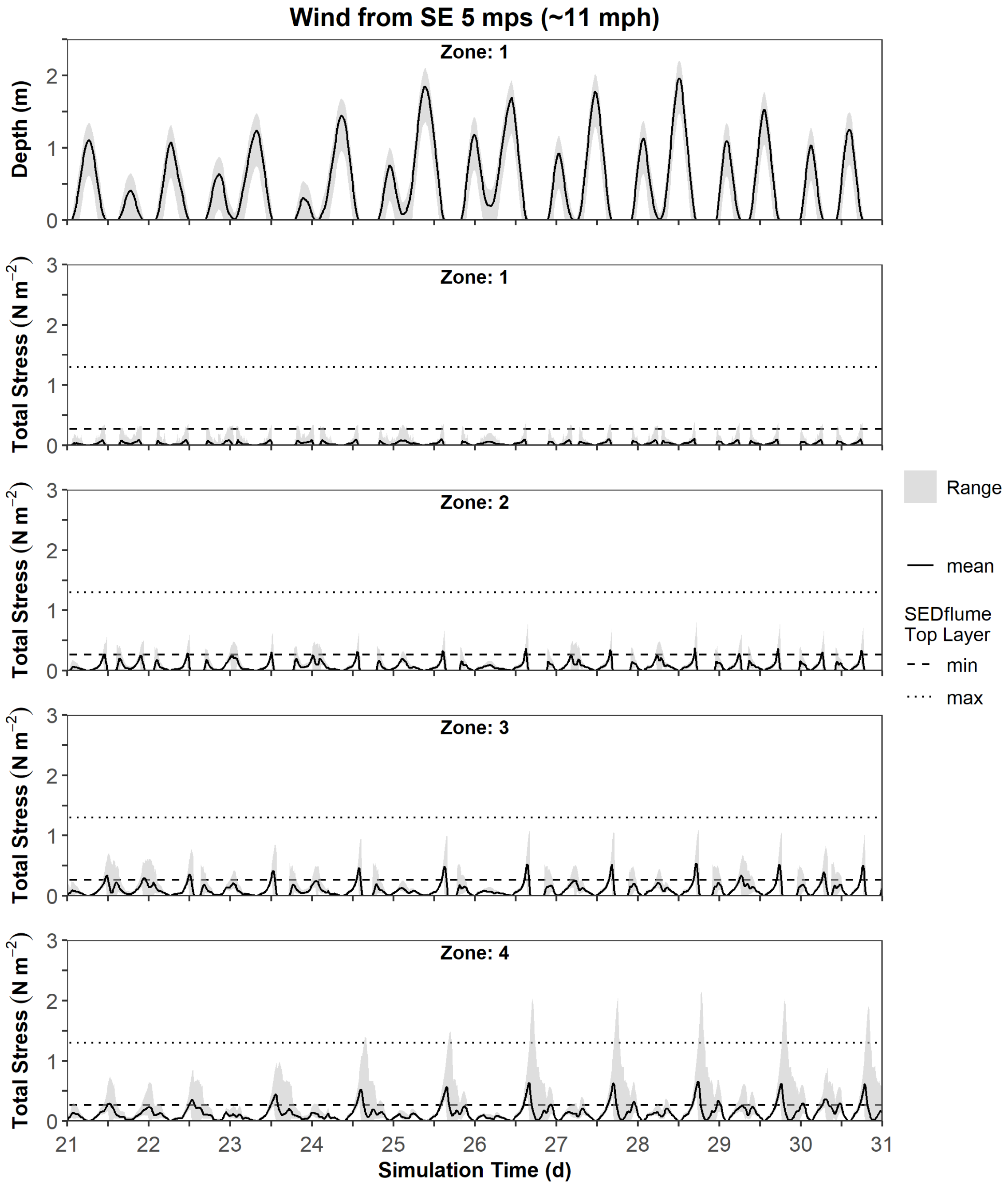


Figure 47 Predicted depth and total bed shear stress (total stress) by Zones with a southeast (SE) wind at 5 mps (~11 mph) for the simulation period. Depth is provided for Zone 1 only (top figure), and total stress is provided for all Zones. Total stress accounts for current-induced and wave-induced shear stresses. Solid black line is the mean; gray band is the min/max range; and the dotted and dashed lines are the minimum and maximum SEDflume top layer critical shear stress for erosion, respectively.

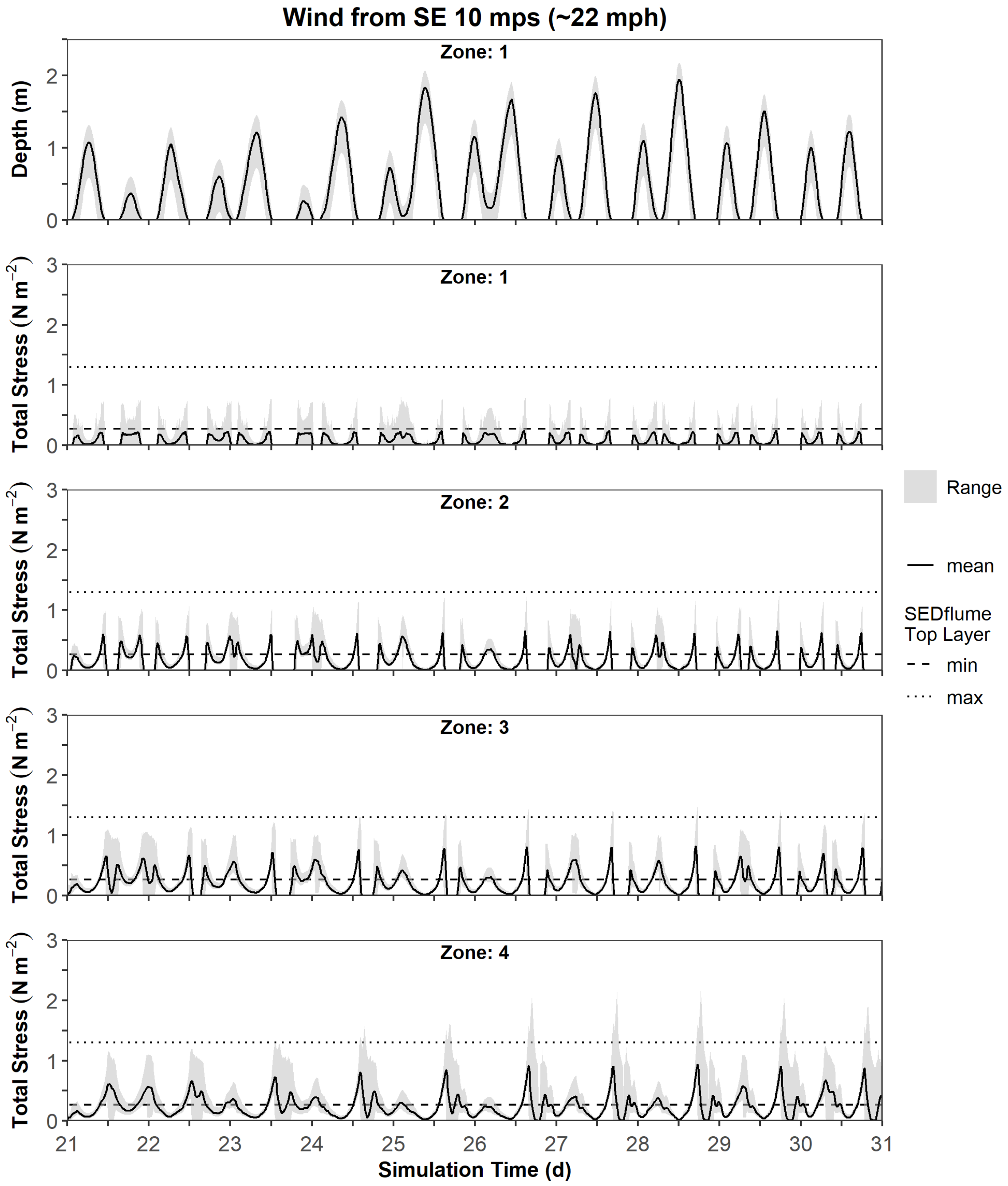


Figure 48 Predicted depth and total bed shear stress (total stress) by Zones with a southeast (SE) wind at 10 mps (~22 mph) for the simulation period. Depth is provided for Zone 1 only (top figure), and total stress is provided for all Zones. Total stress accounts for current-induced and wave-induced shear stresses. Solid black line is the mean; gray band is the min/max range; and the dotted and dashed lines are the minimum and maximum SEDflume top layer critical shear stress for erosion, respectively.

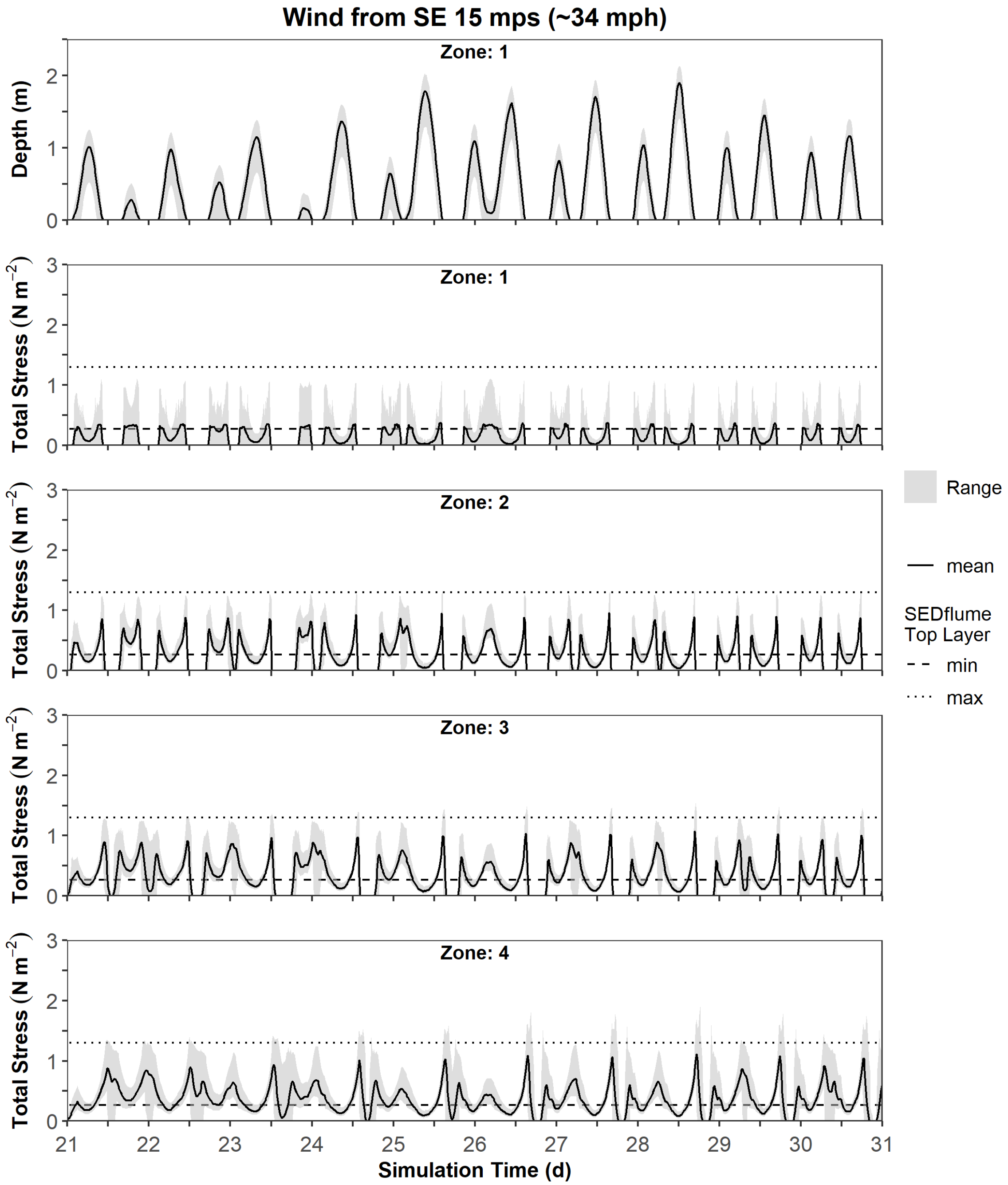


Figure 49 Predicted depth and total bed shear stress (total stress) by Zones with a southeast (SE) wind at 15 mps (~34 mph) for the simulation period. Depth is provided for Zone 1 only (top figure), and total stress is provided for all Zones. Total stress accounts for current-induced and wave-induced shear stresses. Solid black line is the mean; gray band is the min/max range; and the dotted and dashed lines are the minimum and maximum SEDflume top layer critical shear stress for erosion, respectively.

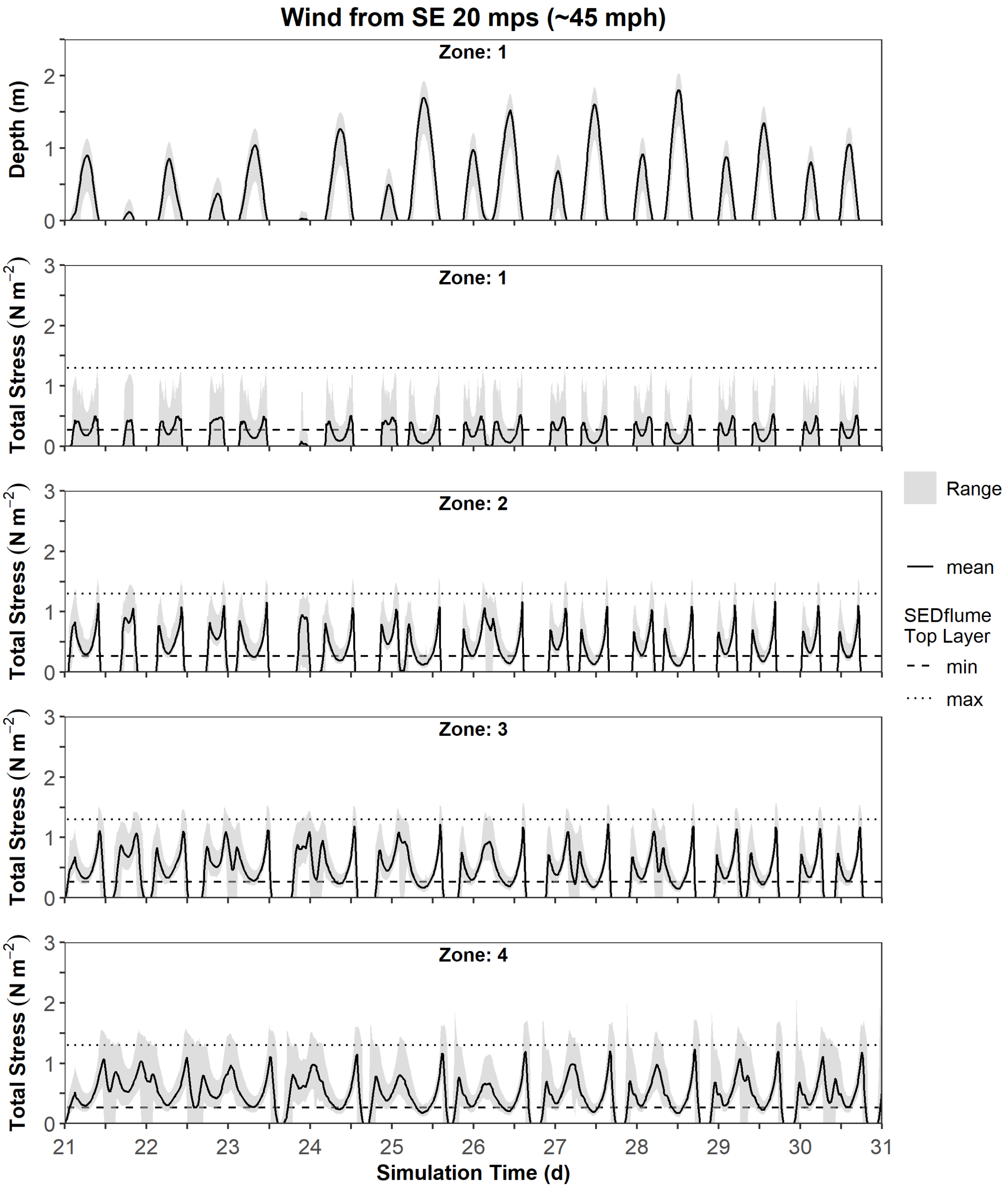


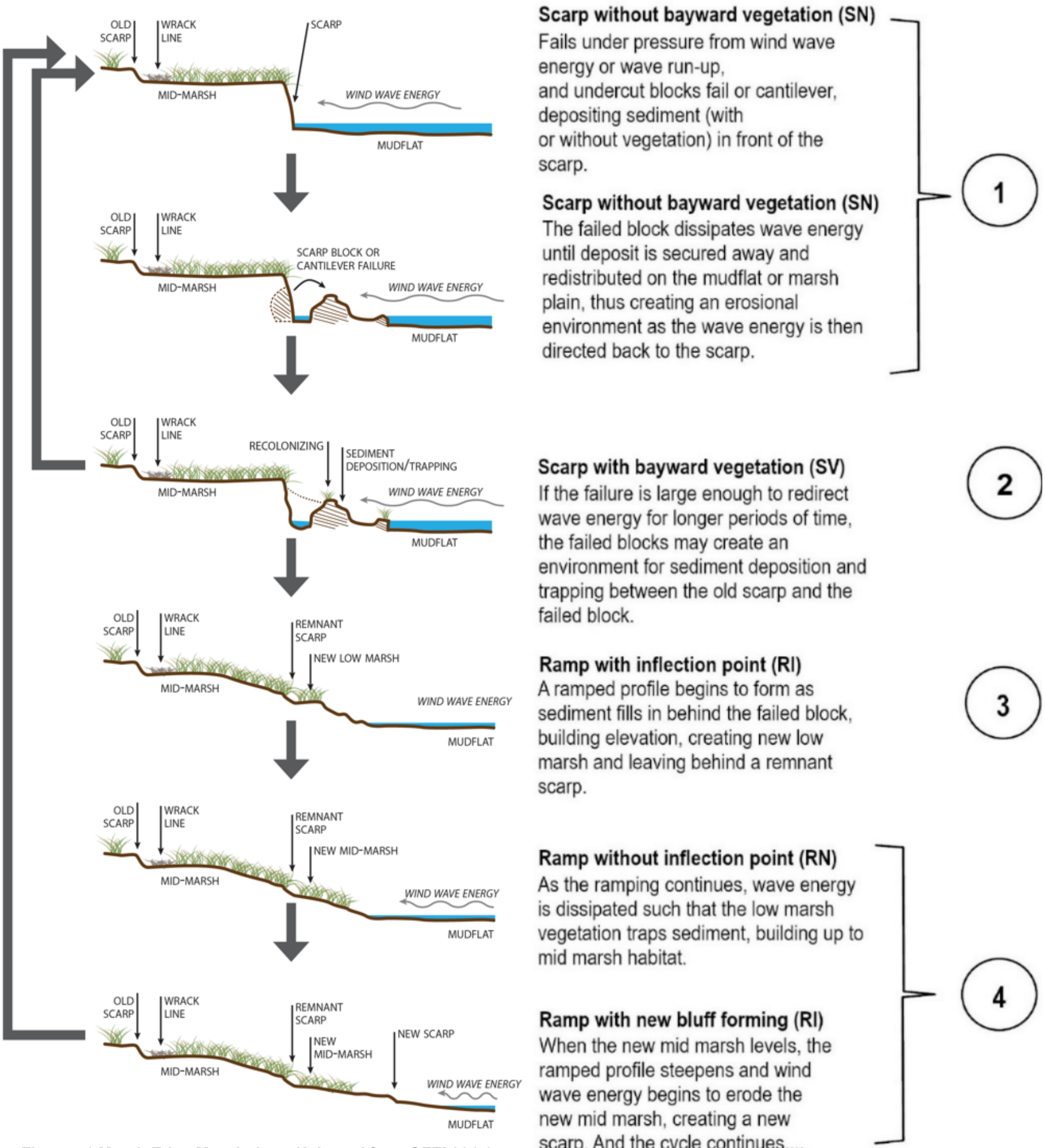
Figure 50 Predicted depth and total bed shear stress (total stress) by Zones with a southeast (SE) wind at 20 mps (~45 mph) for the simulation period. Depth is provided for Zone 1 only (top figure), and total stress is provided for all Zones. Total stress accounts for current-induced and wave-induced shear stresses. Solid black line is the mean; gray band is the min/max range; and the dotted and dashed lines are the minimum and maximum SEDflume top layer critical shear stress for erosion, respectively.

5.5.2 Process: Salt Marsh Edge Lateral Progradation and Recession

Marsh edge morphology and the change in lateral position over time can provide insight on the processes contributing to the expansion and retreat along the shoreline. The marsh edge along the eastern shoreline of Arcata Bay has variable geometry, ranging from steep vertical and undercut scarp banks to gradual ramping slopes. Vertical scarps, with as much as 4-foot difference between the top and toe of the marsh bank, indicates erosion that has created a scarp along the marsh plain, whereas gradual slopes indicate ongoing deposition (prograding) in the transition zone between the mudflat and marsh plain. Wave attack causing undercutting and notching of the scarp face occurs during tidal stages between Mean Sea Level (approximate mudflat elevation) and Mean High Water, which is below the crest of the scarp; over-marsh tides dissipate over the marsh surface vegetation and occur infrequently (above Mean Higher-High Water). The irregularity of scarps is due to variability in soil shear strength, vegetation, and orientation to incident wind-wave attack which are further described in subsequent sections of this report.

San Francisco Estuary Institute (SFEI 2015) categorized marsh edges in San Francisco Bay into four different marsh edge types to explain the cycle of shoreline position change. The four marsh edges types are described below in Figure 51. SFEI found scarps on prograding marshes and determined that the marsh edge profile (scarp or slope) is not necessarily a strong indicator of shoreline change (retreat/progradation). Figure 51 also suggests the classification was developed for marshes that are not restricted by anthropogenic interventions (i.e. the marsh extends back from the shore farther than the reach of significant wave action). The processes depicted in Figure 51 may differ some for narrower marshes with backshore barriers such as fill/rail prisms in close proximity to the marsh edge.

Following methods described by SFEI 2015, marsh edge types were mapped along the marsh edges within the project area, Eureka Slough marsh and Jacoby Creek marsh using UAV photography and verified by ground observations (Appendix A, Exhibits 2-7, 2-8, 2-9 and 2-10). The purpose of the mapping was to document the current marsh edge morphology and examine relationships between marsh position, marsh edge type and geomorphic setting. The different marsh edge morphologies reflect differing responses to a variety of drivers, including sediment supply, wave energy dissipation, mudflat shape and size, plant colonization patterns and orientation to the Bay (SFEI 2015). There is feedback between the hydrodynamic conditions, shoreline orientation and marsh edge type. The configuration of marsh edges on Arcata Bay are also reflect responses to shoreline development which are different than the responses for undeveloped shorelines with the same set of physical drivers. The variation in shoreline types may represent different points along a cycle of marsh edge evolution. The timing of this cycle is undetermined and may be on a yearly, or more likely, decadal scales. While the mapping can provide insight on the hypothetical linkages between the marsh edge types, additional monitoring would be necessary to validate these linkages over time and with respect to other drivers. An interpretation of the marsh edge morphology and position mapping are provided below for the project area, Eureka Slough marsh and Jacoby Creek marsh.



Scarp without bayward vegetation (SN)
Fails under pressure from wind wave energy or wave run-up, and undercut blocks fail or cantilever, depositing sediment (with or without vegetation) in front of the scarp.

Scarp without bayward vegetation (SN)
The failed block dissipates wave energy until deposit is secured away and redistributed on the mudflat or marsh plain, thus creating an erosional environment as the wave energy is then directed back to the scarp.

Scarp with bayward vegetation (SV)
If the failure is large enough to redirect wave energy for longer periods of time, the failed blocks may create an environment for sediment deposition and trapping between the old scarp and the failed block.

Ramp with inflection point (RI)
A ramped profile begins to form as sediment fills in behind the failed block, building elevation, creating new low marsh and leaving behind a remnant scarp.

Ramp without inflection point (RN)
As the ramping continues, wave energy is dissipated such that the low marsh vegetation traps sediment, building up to mid marsh habitat.

Ramp with new bluff forming (RI)
When the new mid marsh levels, the ramped profile steepens and wind wave energy begins to erode the new mid marsh, creating a new scarp. And the cycle continues....

Figure 51 Marsh Edge Morphology (Adapted from SFEI 2015).

5.5.2.1 Project Area Marsh Edge

The marshes within the project area are predominantly comprised of scarp edges with and without bayward vegetative blocks. The scarp edges are indicative of an erosive wave energy environment. The project area marsh edge is directly exposed to prevailing northwest wind generated waves and has a long fetch length. Further, because of shore armoring and very narrow marsh width, wave energy is not dissipated but reflected to scour along the shoreline. The exception to this dominant marsh edge morphology is the low pickleweed marsh on the lee (south) side of the remnant levee which exhibits a ramping marsh edge. This morphology is consistent with low wind wave exposure given the sheltering from the remnant levee.

5.5.2.2 Eureka Slough Marsh Edge

The Eureka Slough marsh edge is characterized predominantly by scarps; however, short segments of ramps are also prevalent. The ramps do correlate in some areas of marsh edge progradation; however, orientation also appears to be a factor. The marsh edge has a sinuous planform relative to the rail prism with variable marsh width extending out as much as 500 feet. Unlike the project area marsh, railroad and highway construction were set back from the edge of the marsh in order to maintain a smoothly curving alignment and long over-water crossings. This left a remnant marsh seaward of the railroad that varied between 200 and 600 feet in width. Railroad and highway construction blocked several distributary channels from Eureka Slough that fed sediment to the marsh. Review of mapping and aerial photos indicate that both progradation and recession occurred. Most recession of the marsh edge appeared to have occurred prior to 1958. During the same period, borrow ditches and abandoned channels infilled with sediment and were colonized by salt marsh. Since 1958, the marsh edge position has remained fairly stable relative to current position, with recession and progradation differences less than 1 foot per year during this period. Similar to the project area, this area is also exposed to long fetch lengths from prevailing northwest winds. The leveeing and rail prism construction in 1900 likely altered the sediment routing from Eureka Slough distributary channels into the marsh. This could have explained the predominant recession trend along the marsh edge between 1870 and 1958 and the trend slowing following 1958 as a new equilibrium was established.

5.5.2.3 Jacoby Creek Marsh Edge

The marsh edge fronting the Jacoby Creek mouth is characterized as prograding ramps indicative of a deltaic marsh from deposited fluvial derived sediments. This area is also less exposed to long fetch lengths from prevailing northwest and south winds with resulting lower incident wave heights. The Jacoby Creek marsh has expanded approximately 1,000 feet from the position of the creek mouth indicated on the 1870 bay map. The amount of sediment supplied by Jacoby Creek is thought to have been elevated significantly by development through construction of stream-side levees to prevent flooding and logging of the headwaters (Murray and Wunner, 1988). South of the Jacoby Creek mouth the marsh plain edge transitions from a ramp typology to scarps with and without bayward vegetation. The marsh width reduces in a southward direction towards Brainard Slough likely attributed to the increasing fetch length and resulting wave energy and further distance from the Jacoby Creek sediment source. The shoreline is absent of salt marsh at Brainard Slough mouth and comprised of rocky intertidal shoreline with an armored rail prism.

5.5.3 Process: Salt Marsh Vertical Accretion and Degradation

Salt marsh vertical accretion is driven by mineral suspended sediment delivered to the marsh surface during high tides, accumulation of organic matter supplied from marsh vegetation, subsurface expansion driven by root growth, and local rates of land movement driven by tectonic processes (Cahoon et al. 2021). The rate of vertical accretion must keep pace with, or exceed, the rate of relative sea level rise to avoid marsh degradation and drowning. Direct measurements of marsh accretion rates have not been conducted within the project area marshes; however, historic and current accretion rates have been assessed in other Arcata Bay marshes, including Jacoby Creek marsh. Historic accretions rates were estimated using chronological and carbon dating techniques conducted by UCLA from sediment cores obtained from five Humboldt Bay marshes including Mad River Slough and Jacoby Creek marshes in Arcata Bay. The results show historic accretion rates ranging from approximately 2.9 mm/year to 8.4 mm/year, which exceeds the eustatic sea level rise rates of 1-2 mm/year (Gerwein, 2019 and Brown, 2019). More recent accretion rates were measured by USGS (Curtis 2019) between 2015 and 2017 at five marsh sites on Humboldt Bay, two in South Bay and three in Arcata Bay including Mad River Slough, Manilla and Jacoby Creek marshes. Accretion rates were measured using surface elevation tables (SETs) and feldspar marker horizon (MH) and correlated with suspended sediment concentrations (SSC) from continue water quality sampling. Elevation change measured by the SETs averaged 2.28 mm/year for the two South Bay marshes, and 0.89 mm/year for the three North Bay marshes. Sediment accretion as measured by the MHs measured 4.41 mm/year for the South Bay marshes and 0.71 mm/year for the North Bay (Curtis 2019). SET measurements reflect the combined elevation changes created by plant growth, sediment deposition, and tectonic land movement. The MH measurement reflect only the accretion due to deposition of sediment and organics on the surface. These accretion rates are lower relative to net sea level rise rates (combination of sea level rise and local tectonic subsidence) of 5 mm/year and would suggest Arcata Bay marshes are not keeping pace with relative sea level rise. However, the rate is based on a limited three-year data set and additional data is needed to confirm this hypothesis. Based on climate change modeling, an increase in fine-sediment delivery to Humboldt Bay from future increased precipitation intensity is predicted. The increase in sediment delivery is anticipated to partially or wholly meet the future sediment demand of mudflats and marshes caused by subsidence, sea level rise, and tidal prism expansion within Humboldt Bay (Curtis 2021). The study applied a Bay-wide mass-balance approach to compare future sediment supply and demand, however sediment distribution patterns within Humboldt Bay are complex given the spatial and temporal varying erosional and depositional characteristics.

There are also feedback mechanisms between salt marshes and sea level rise which promote marsh accretion to an equilibrium elevation relative to sea level that maintains the marshes. Marshes that are flooded by increasing sea level can recover equilibrium marsh elevation through increased organic production and increased accretion (Cahoon et al. 2021). Rates of sediment deposition increase because the extended duration of flooding allows more sediment to settle out of the water column. These feedbacks support marsh accretion and return to an equilibrium elevation, but only if the rate of sea level rise is not rapid enough to suppress primary plant production. If primary production is suppressed, then the marsh vegetation will die off and the marsh will drown.

5.5.3.1 Salt Marsh Sediment Characterization

Sediment properties within the project area marshes were characterized by SHN (2021) at five (5) hand augured borings to target depth of 6 feet (Figure 39). Soil texture, organic content and salinity concentrations were documented for each boring with the results presented in Appendix G and summarized below. The soil texture in all borings were predominantly silts, consistent with the mudflats. Borings 1 and 3 reached the full 6-foot depth and encountered distinct horizons characterized by concentrations of buried roots and organics. SHN inferred that these horizons represent formerly exposed marsh surfaces that have been subsequently buried. Borings 2, 4 and 5 were absent of buried root/organic horizons which appeared to have contributed to the “soupy” texture, deeper samples were not retrievable, and the hand auger could be pushed to the full 6-foot depth under body weight. For all samples, the upper one foot of the marsh soils was collected for laboratory testing of organic content and salinity. Salinity concentrations generally increased from boring 1 to 5 (north to south), which corresponds with longer fetch lengths and potentially higher incident wave heights and greater splash frequency onto the marsh surface. Organic content appears to be higher in areas where wrack and accumulation of organic debris from wave overtopping was observed.

Extensive sediment probing was conducted to depths of 0 to 4 feet through the marsh plain and mudflat surfaces fronting the marsh edge. Differing materials such as shell fragments were not detected or layers of noticeable varying density. Uniform resistance was encountered throughout the marsh surface for the exception of interior marsh channels and depositional areas with unconsolidated sediments in the locations of former borrow ditches between the former rail prisms that are now filled with sediment. In these areas, the probing resistance was relatively low and observable surface depositional patterns of fine-grained sediments were noticeable. These characteristics indicate recent deposition and a net onshore sediment flux direction and were most noticeable in the marsh fronting Indianola Cut-off.

5.6 Summary of Marsh Disturbance and Recovery

The fragmented marsh patches in the project area are remnants of the pre-disturbance marsh depicted in the 1870 Bay Map. Anthropogenic interventions directly along the shoreline inhibited the physical processes, sediment flux, and flow that maintain marshes. A conceptual cross-section of marsh geomorphic dynamics under pre-disturbance and present conditions is depicted in Figure 52. This cross-section was developed through field investigations and the analysis of wave dynamics described above.

5.6.1 Pre-disturbance Conditions

The 1870 U.S. Coast and Geodetic Survey map indicates that the marsh extended for approximately 2,000 feet from the shoreline to the high ground on the eastern edge of the marsh. The marsh appears well developed in the map. During the period from 1854-2006, NOAA estimates sea level at San Francisco rose at a rate of 2.0 mm/year (NOAA, 2009). It's also assumed that during this period tectonic subsidence created additional rise in relative sea level.

We hypothesize that prior to disturbance by diking, physical and organic processes supported vertical accretion of the marsh surface to maintain a stable elevation relative to sea level (Figure 52a). The marsh received sediment inputs from:

- direct upland erosion processes;
- transport of sediment from upland areas by streams, especially via Fay Slough;
- transport of suspended sediment into the marsh through the network of tidal channels and overbank tidal flooding; and
- wave-transported suspended sediment.

Organic processes in the marsh captured and trapped the sediment. Physical roughness of marsh vegetation slowed flows velocities and allowed sediment to settle. Biological activity helped to bind the captured sediment into larger particles. Vegetation feedback allowed a variable response (Cahoon et al. 2021). If water levels rose too quickly or insufficient sediment was available, vegetation productivity would increase expanding the soil column and raising the marsh surface. Conversely, if too much sediment was captured and the marsh plain rose above optimal levels, vegetation productivity would slow until sea level rise caught up.

It is unclear if the marsh edge was eroding, stable or expanding under pre-disturbance conditions. The mudflats and marshes act as a system and exhibit collective behavior with dynamic recruitment and exchange of sediment. Dynamic exchange allows the marsh edge to expand and recede in time as a function of sediment flux, inundation period and hydraulic conditions (Mariotti and Carr, 2014). There is not sufficient direct evidence to draw a conclusion. Wave processes would have caused toe erosion, but it's possible for marshes to expand the edge by colonizing block failures. It is thought that prior to wide-spread logging and agricultural clearing, the sediment supplies were lower than present day. Lower sediment supplies may have inhibited marsh growth, but the tidal and freshwater drainage network that delivered soil to the marsh and to the mudflats was much more robust and efficient. The marsh may also have still been in a state of adjustment following the 1700 Cascadia earthquake (Valentine et al, 2012) in which the marsh edge was expanding.

5.6.2 Present Day Conditions

The major anthropogenic interventions of railroad and highway construction on the marsh edge greatly interfered with the processes that maintained a stable marsh (Figure 52b). The developments separated the marsh into two zones: an interior marsh and an exterior marsh. Embankment construction fragmented the exterior marsh into strips separated by borrow ditches and dredge channels (Figure 18). The embankments also blocked tidal channels that fed the interior marsh and diverted dendritic channels that delivered sediment to the exterior marsh and mudflats. Fay Slough was re-directed so that it no longer discharged into Humboldt Bay near the project area, but instead became a tributary to Eureka Slough, and thence to Entrance Bay.

The interior marsh within the project area was converted primarily to agricultural use and cut off from most sediment sources. This land has subsided and is now at risk from sea level rise. Sediment from tidal flooding and wave overwash, and from tidal flooding of Fay Slough no longer reaches the former marsh. Stream-side levees prevent sediment from fluvial sources reaching the former marsh. Agricultural practices converted the marsh vegetation to shallow rooted grasses. Organics stored in the soil column decayed and the marsh root zone collapsed. Total ground subsidence has been approximately three feet since pre-disturbance conditions.

The historical construction of the rail prism during the early development of the Humboldt Bay shoreline was a significant disruption of the high marsh-to-upland ecotone. The upper high marsh-to-upland transitional zone, which would have occurred along a gradual elevational gradient prior to development, now occurs in a patchy narrow elevational band along the steep rail prism and artificial berms. With widespread erosion undercutting the salt marsh and the rail prism itself in some areas, native high marsh habitat in the project area and the rare plant species it supports are particularly at risk of disappearing as they are pinched between rising seas and the rocked rail prism. Restored salt marshes to the north around the mouth of Jacoby Creek and south at the mouth of Eureka Slough have a steady influx of sediment from upstream and may be able to accrete sediment at a rate that allows them to keep pace with sea level rise, with relevant studies ongoing (i.e. Curtis et al. 2019). In contrast, the fringe marsh between Bracut and Brainard has no direct sediment sources, and no potential to translate inland with the current rail prism position.

Under pre-disturbance conditions, the marsh edge extended approximately 200-300 feet beyond the present position. Much of this lost marsh was removed during the construction of the railroad and highway embankments. Additional marsh may have been removed by passage of a dredge. Initially following construction, there was a narrow strip of marsh left at the original marsh edge. The strip was unable to survive the wave climate and the marsh vegetation died-off.

The viability of the remaining exterior marsh is challenged by the current physical setup. The position and orientation of the project area shoreline exposes it to a harsh wave environment that creates relatively high amounts of erosive energy. Where present, the marsh patches are very narrow, which limits the ability of the marsh to dissipate wave energy and thus trap wave-transported suspended sediment. The marsh has minimal tidal drainage network that has been simplified and thus has altered tidal-flooding sediment supply. There is no supply of upland sediment as dendritic channels were diverted away from the marsh to highway drainage ditches.

Despite the harsh environment, the marsh appears to have prograded slightly in some locations and to have developed some resistance to wave erosion. Portions of the borrow ditches left between the armored railroad embankment and the exterior marsh have filled with fine sediment. The fine sediment has been colonized by marsh vegetation. The fill areas are still unconsolidated and have low erosion resistance. They are protected by the remnants of the original marsh. The marsh edge has developed gravel shingle beaches[3] in some locations. The gravel is suspected to consist of railroad ballast. The shingle beach consists of a thin layer of gravel approximately 2 D_{100} [4] thickness which overlays fine sand and silts. Edge erosion is limited in areas possessing the gravel shingle beach.

The anthropogenic interventions have created conditions on the exterior marsh that allow the marsh to persist, but not to thrive. The remnant marshes may be able to keep pace with sea level rise through organic and mineral sediment accretion. The ability to persist is challenged by deprivation of pre-disturbance sediment supplies and the poor ability to trap wave transported sediment. Wave energy is not dissipated at the shoreline and runup and runoff strips the sediment that is delivered creating lateral rills and gullies that bifurcate the marsh plain.

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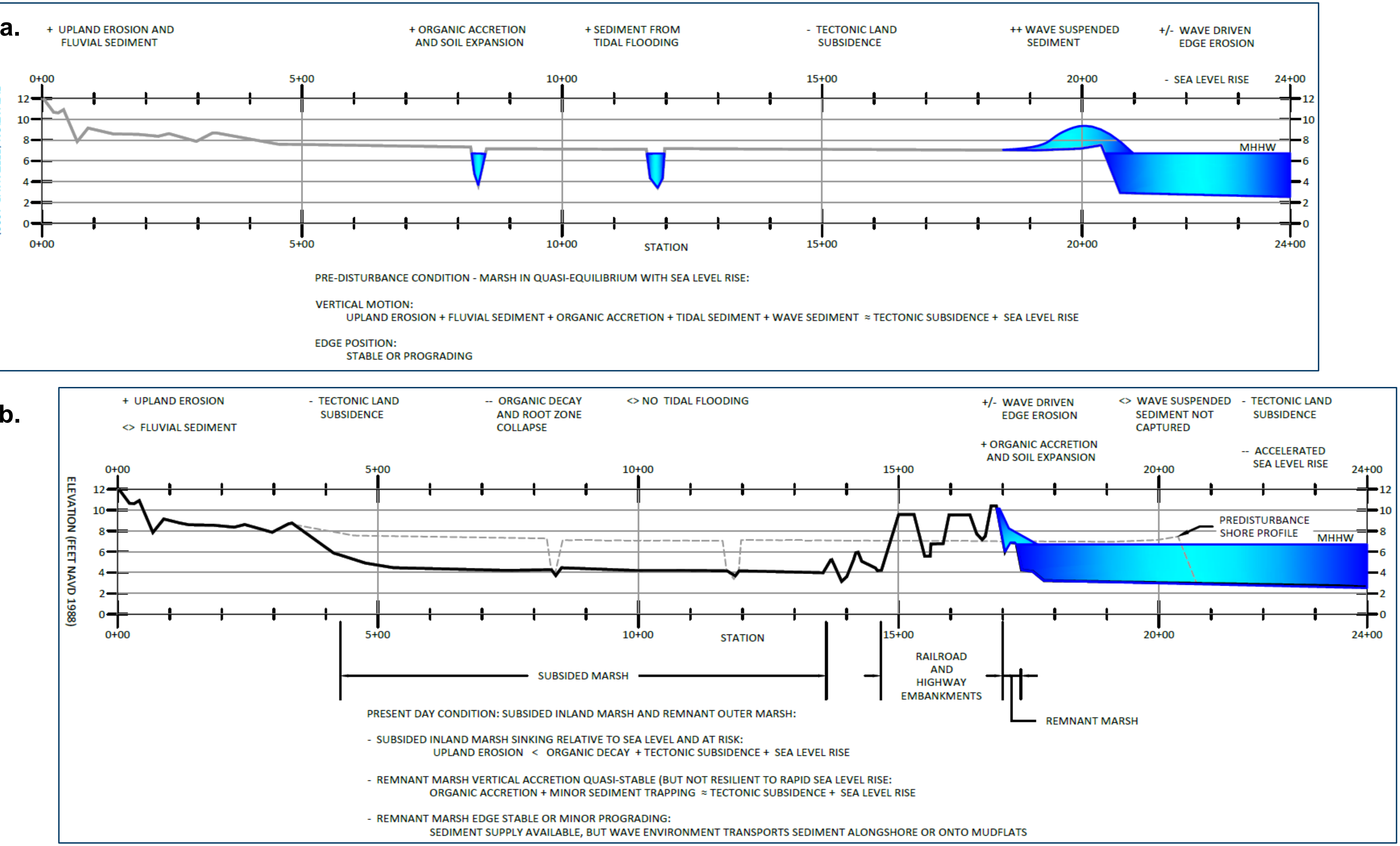
[3] A shingle beach is characterized as a shoreline beach comprised of stones, pebbles and other small rocks

[4] D_{100} is the maximum intermediate diameter of the gravel.



PRE-DISTURBANCE CONDITION - MARSH IN QUASI-EQUILIBRIUM WITH SEA LEVEL RISE:

VERTICAL MOTION:
UPLAND EROSION + FLUVIAL SEDIMENT + ORGANIC ACCRETION + TIDAL SEDIMENT + WAVE SEDIMENT ≈ TECTONIC SUBSIDENCE + SEA LEVEL RISE

EDGE POSITION:
STABLE OR PROGRADING

PRESENT DAY CONDITION: SUBSIDED INLAND MARSH AND REMNANT OUTER MARSH:

- SUBSIDED INLAND MARSH SINKING RELATIVE TO SEA LEVEL AND AT RISK:
  UPLAND EROSION < ORGANIC DECAY + TECTONIC SUBSIDENCE + SEA LEVEL RISE
- REMNANT MARSH VERTICAL ACCRETION QUASI-STABLE (BUT NOT RESILIENT TO RAPID SEA LEVEL RISE:
  ORGANIC ACCRETION + MINOR SEDIMENT TRAPPING ≈ TECTONIC SUBSIDENCE + SEA LEVEL RISE
- REMNANT MARSH EDGE STABLE OR MINOR PROGRADING:
  SEDIMENT SUPPLY AVAILABLE, BUT WAVE ENVIRONMENT TRANSPORTS SEDIMENT ALONGSHORE OR ONTO MUDFLATS

Figure 52 Conceptual project area cross-section showing (a) pre-development conditions and (b) current conditions.

5.7 Summary of Geomorphic Assessment

Anthropogenic interventions have influenced the physical and biological characteristics of the eastern shoreline of Arcata Bay by modifying the landscape response to physical drivers including tidal currents, relative sea level rise, wind-generated waves, and sediment supply. All drivers (tides, relative sea level rise, wind, and sediment supply) play an important role in intertidal habitat form and function. The temporal variation in these drivers and anthropogenic interventions can alter the rate of physical processes which are complex to quantify and predict. The temporal and spatial landscape changes observed in this assessment indicate the important role of each driver and the interconnectedness. Below is a summary of findings from the geomorphic assessment including an explanation of observed differences between project area and the Eureka Slough and Jacoby Creek marshes.

1. Previous studies have identified the project shoreline as having higher vulnerability to coastal flooding and erosion relative to the balance of shoreline protecting critical resources within Cell A. These critical resources include Highway 101, Murray Field Airport, Fay Slough Wildlife Area and multiple Jacobs Avenue businesses and residents (Humboldt County 2021). Where salt marsh is absent, the shoreline within the project area will remain vulnerable to wind-wave attack, overtopping and inundation of Cell A critical resources. Planned projects including the Humboldt Bay Trail South project will reduce coastal flood risk for areas east of the trail by elevating the existing rail prism to elevation11.5 feet (NAVD) and repairing rock armoring within the project area (see section 1).
2. A total of 90% of the pre-disturbance salt marsh has been lost within the project area. While most of the remaining salt marsh is dominated by invasive *Spartina densiflora*, rare salt marsh plants have been observed and can serve as an analog and seed source for future marsh restoration efforts. The remnant marsh that remained after development of the railroad and highway embankments is in an impaired state. The marsh is cut off from upland sediment supplies, exposed to wave attack, fronts an expansive mudflat and is too narrow in width to effectively trap sediment. The impairment created by anthropogenic interventions restricts the ability of the marsh to regenerate through natural processes (see section 2 and 3).
3. The landforms that comprise the project area including intertidal mudflats and salt marshes that provide habitat for rare plants, aquatic species and avian species that are unique to Humboldt Bay and regionally significant. Mudflat habitat dominates the project area disproportional to salt marsh, limiting shorebird use throughout much of the project area when water levels are above mean tide level (50% of time) (see section 4).
4. Initial leveeing of the marsh edge and rail prism construction in the project area altered shoreline hydraulic conditions and marsh drainage, causing marsh degradation in an area exposed to high-wind wave energy. The railroad and highway development left only a narrow strip of marsh seaward of the railroad prism. Much broader remnant marshes were left in the adjacent Eureka Slough and Jacoby Creek marshes. Sufficient marsh widths were left in the Eureka Slough and Jacoby Creek marshes that the marshes were able to maintain themselves and recover from the railroad and highway development impacts. The project area marsh was significantly damaged and the outer marsh edge left behind after dredging subsequently eroded away (see section 3).
5. There has been a limited amount of salt marsh recovery in the project area, primarily by vegetation colonization of sediment trapped in borrow ditches. In isolated areas of the project area, marsh expansion and accretion through natural processes has occurred following the 1950s suggesting availability of suspended sediment delivered to depositional areas. Sediment deposition on existing marsh surfaces is evident and emphasizes important role of wind waves for transporting sediment onto the marsh surface. The ability of the existing marsh to trap sediment is hindered by its narrow width and exposure to a harsh wave environment (see section 3).
6. The marsh edge morphology in the project area primarily consists of scarps indicating a marsh edge subjected to wave driven erosion. Scarps form where there is sufficient vegetation rooting depth to slow erosion and strengthen the soil column (Mariotti and Fagherazzi 2010). Scarping was also observed at Eureka Slough and Jacoby Creek marshes, but also with ramping. The marsh edge positions on the adjacent marshes are fairly static indicating an ongoing process of scarp block failure followed with sediment trapping behind the block and accretion for recolonization of vegetation. The general marsh edge morphology appears to be primarily a function of shoreline orientation. Ramping morphology is strongly correlated to edges that are prograding, observed at

both Eureka Slough and Jacoby Creek marshes. Ramping edge morphology is most prevalent at the Jacoby Creek deltaic fan, however short segments of ramping and progradation are also present throughout the Eureka Slough marsh in areas exposed to long north-northwest wind fetch. Ramping in these areas suggest ample sediment supply from adjacent mudflats (see section 5).

7. Wind-generated waves can alter circulation patterns, tidal currents, and increase velocity along the project shoreline. Depositional patterns of gravels and the gravel shoreline sourced from the rail prism erosion corroborate the model results showing an increase in velocity and shear stresses from the dominate north-northwest wind direction resulting in a north-south circulation pattern. The erosion/deposition potential analysis demonstrates that tidal-induced currents alone can erode sediment from deeper water areas (Zones 3 and 4), but in general the total stresses and the potential for erosion is low. However, wave-induced stresses from winds from the NNW and S and wind speeds greater than 5 mps (~11 mph) generate total stresses high enough to erode sediment from all zones, demonstrating that wind-waves are the likely dominate driver for mudflat erosion and deposition in the NSI project area. Model results also indicate that the nearshore zone (Zone 1) has the largest range of total stresses indicating the potential for both erosion and deposition within this zone from wind waves. During wind-wave events the potential exists for sediment to be eroded from offshore mudflat areas and transported to the NSI project area where deposition could occur due to a wider range and lower total stresses (see section 5).
8. The WHAFIS wind-wave model quantified wind-wave propagation and dampening from salt marsh and adjacent mudflat in the project area and at Eureka Slough marsh given the similar wind-fetch exposure. The Eureka Slough marsh plain (approximately 500 feet) reduced the wave height more significantly than the project area marsh plain (approximately 0 and 40 feet). The wider, vegetated marsh plain provided the increased wave height reduction. However, in higher wind conditions the wider, flat marsh plain allows waves height to increase. The model can be utilized for design to assess minimum marsh width and geometry needed to dampen various wave heights occurring at different tidal elevations and assess the benefits from a transition zone. Wind wave heights and fetch length are not anticipated to increase with sea level rise, however extreme storm events may increase with climate change thereby increasing wind speeds and frequency of episodic events (see section 5).
9. Accretion rates and chronological dating have not been measured in the project area marshes but have in other Arcata Bay marshes including Jacoby Creek marsh (Curtis el al., 2019 and Brown 2019). Recent measured accretion rates appear to be lower than relative sea level rise (Curtis et al., 2019) while historic measured accretion rates appear to have kept pace or slightly greater than relative sea level rise (Brown, 2019). Visual observations and sediment probing have identified areas of deposited sediment located between the former rail prisms near Indianola Cut-off. These depositional characteristics in sheltered areas indicate a sediment supply/availability that could support a net onshore sediment flux if the sediment can be trapped and retained (see section 5).
10. Sediment delivery to Humboldt Bay is estimated to increase over time with climate change (Curtis, 2021), and while sediment distribution patterns in Arcata Bay are not well studied, depositional areas may accrete in conjunction with sea level rise (see section 5).

PART III – BASIS OF DESIGN

6. Alternative Development, Evaluation and Selection

The alternative development, evaluation, and selection process is guided by the project goals and objectives and existing sea level rise adaptation planning and natural infrastructure design guidelines. The goals and objectives, as detailed in Section 1.5, focus on the creation, diversity and resiliency of native intertidal coastal marsh habitat; using the natural flood-risk reduction properties of salt marsh to protect transportation infrastructure; and creating opportunities for innovation and learning to enhance our understanding of nature-based sea level rise adaptation while providing beneficial reuse of local sediment sources. These goals and objectives highlight the need and application of natural ecological systems and processes to develop natural shoreline infrastructure design alternatives. As an initial step in developing alternatives, a review of Natural Shoreline Infrastructure design guidelines was completed and are summarized below.

6.1 Overview of Natural Shoreline Infrastructure

For protection against flooding and erosion caused by rising sea levels and extreme storms, California is emphasizing natural infrastructure. The state of California has defined natural infrastructure as:

…the preservation and/or restoration of ecological systems, or utilization of engineered systems that use ecological processes, to increase resiliency to climate change and/or manage other environmental problems. This may include, but is not limited to, floodplain and wetland restoration or preservation, combining levees with restored ecological systems to reduce flood risk, and urban trees to mitigate high heat days. (CGC §65302(g)(4)(C)(v)(SB379))

This approach is prioritized in the California Coastal Commission's Sea Level Rise Policy Guidance (2018). Similarly, the Federal Highway Administration (2018) encourages "nature-based solutions" to prevent coastal highway flood damage and/or disruption by implementing approaches that mimic characteristics of natural features and protect or improve the built environment while maximizing the habitat value associated with the natural system.

In 2018 the California Natural Resources Agency published a refined working definition for Natural Shoreline Infrastructure to clarify the setting and intention of the term:

'natural shoreline infrastructure for adaptation' means using natural ecological systems or processes to reduce vulnerability to climate change related hazards while increasing the long-term adaptive capacity of coastal areas by perpetuating or restoring ecosystem services (Newkirk et al, 2018).

Natural Shoreline Infrastructure also possesses the following qualities (Newkirk et al. 2018):

- Provides ecosystem services and benefits
- Is/features a "healthy ecosystem"
- Provides economic benefits and/or is cost-effective
- Includes specific types of projects/features, including forests, saltmarsh, eelgrass beds, oyster reefs, beach and dunes, fish and wildlife habitat, etc.
- Projects include preservation of biodiversity as a specific outcome

6.2 Guidance Documents for Sea Level Rise Adaptation Planning and Natural Shoreline Infrastructure Design

Sea level rise adaptation planning requires both qualitative and quantitative analyses to identify long-term benefits that balance multiple objectives. Much of the time, these objectives are competing. One of the first steps in adaptation planning is to develop an understanding of the vulnerability of an asset or system (i.e., collection of assets) to existing and future environmental conditions. The OPC (2018) Guidance defines vulnerability as "the propensity or predisposition to be adversely affected; vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt." Evaluating vulnerability is often a combination of high-level planning and more detailed risk-based approaches:

- High-level planning approach: used to determine what might be impacted and when, often without attention to potential damages and consequences
- Detailed risk-based approach: engineering assessment to determine the likelihood of a damaging event and the consequences of damages

Both of these approaches rely on developing an understanding of how the hazards will change over time, which often requires using detailed hydrodynamic and geomorphic modeling.

After characterizing the vulnerability of a system to sea level rise hazards, the adaptation planning process is used to determine measures and strategies that will reduce the vulnerabilities and risk. Adaptation planning requires developing both asset-specific and system solutions to address known vulnerabilities. System solutions can be addressed using different combinations of adaptation approaches. Therefore, the adaptation plans often take on a scenario or thematic approach that lean toward a specific strategy (e.g., protect, retreat), although the ultimate solution is likely a hybrid of multiple strategies over time. Adaptation alternatives can be evaluated using economic analysis of the systems over time and compared to a defined baseline condition to inform solution selection.

Several guidance documents have been prepared by state and federal agencies, and other interested parties, to establish standardized approaches to conducting vulnerability assessments and planning for sea level rise adaptation. The following sections provide brief summaries of selected reference documents.

6.2.1 California Ocean Protection Council 2018

Since 2010, the State of California has issued a series of guidance documents related to addressing sea level rise in projects and planning. Although the first sea level rise guidance documents were intended primarily for state agencies, recent policy and legislative directives and mandates have been focused on both the state and local levels. Therefore, the 2018 *Sea level Rise Guidance* issued by the Ocean Protection Council (OPC) "aims to respond to the needs for guidance that can help cities, counties and the State prepare for, and adapt to sea level rise" (OPC 2018). The California Coastal Commission (CCC) adopted updated guidance in 2018 that uses the projections of Griggs et al. (2017) and OPC (2018). The CCC (2018) Guidance focuses solely on the high emission scenarios but recommends using the range in sea level rise projections by risk level for a particular time horizon.

6.2.2 California Coastal Commission Guidance

A Public Review Draft of the CCC's *Critical Infrastructure at Risk: Sea Level Rise Planning Guidance for California's Coastal Zone* was issued in August 2021. The draft guidance promotes resilient coastal infrastructure and protection of coastal resources by providing local governments, asset managers, and other stakeholders with policy and planning information to help inform sea level rise adaptation decisions that are consistent with the Coastal Act (CCC 2021). Draft guidance focuses on water and transportation infrastructure and builds on previously adopted guidance documents.

Adopted technical methods and guidance for using the OPC (2018) projections as part of an adaptation planning process are included in the California Coastal Commission (CCC) *Sea level Rise Policy Guidance*, with Original

Guidance adopted in 2015 and Science Update adopted in 2018 (CCC 2018). The CCC (2018) Guidance provides a basis for selecting the time horizon and the risk level of the project, which are used to define the appropriate sea level rise amounts, and recommends technical topics to be assessed, such as projected coastal flooding, wave runup, and coastal erosion associated with sea level rise. Many of the analysis methods used to address the technical questions are described in the *FEMA Coastal Flood Hazard Analysis and Mapping for the Pacific Coast of the United States* (FEMA 2005).

The CCC (2018) Guidance includes a stepwise process for addressing sea level rise and adaptation planning for Coastal Development Permits and for new and updated Local Coastal Programs (LCPs). Our interpretation of the Guidance is that preparation of this Study most closely resembles the CCC (2018) process for LCPs, with some changes.[5] These steps are as follows:

1. Determine a range of sea level rise projection relevant to the planning area/segment using best available science
2. Identify potential physical sea level rise impacts in the planning area/segment, including inundation, storm flooding, wave impacts, erosion, and/or saltwater intrusion into freshwater resources
3. Assess potential risks from sea level rise to coastal resources and development in the planning area/segment, including those resources addressed in Chapter 3 of the Coastal Act
4. Identify adaptation measures and policy options to include in the plan

The CCC (2018) Guidance includes detailed chapters on addressing sea level rise in LCPs (Chapter 5) and for developing adaptation strategies (Chapter 7). Appendix B of the CCC (2018) Guidance describes additional resources and methods to develop local hazard conditions based on regional or local sea level rise using best available science. The Coastal Commission's sea level rise guiding principles include:

- Use a precautionary approach by planning and providing adaptive capacity for the higher end of the range of possible sea level rise.
- Design adaptation strategies according to local conditions and existing development patterns, in accordance with the Coastal Act.
- Avoid significant coastal hazard risks to new development where feasible.
- Minimize hazard risks to new development over the life of the authorized development.
- Minimize coastal hazard risks and resource impacts when making redevelopment decisions.
- Account for the social and economic needs of the people of the state, including environmental justice; assure priority for coastal-dependent and coastal-related development over other development.
- Provide for maximum protection of coastal resources in all coastal planning and regulatory decisions.
- Maximize natural shoreline values and processes; avoid expansion and minimize the perpetuation of shoreline armoring.
- Recognize that sea level rise will cause the public trust boundary to move inland. Protect public trust lands and resources, including as sea level rises. New shoreline protective devises should not result in the loss of public trust lands.
- Address potential secondary coastal resource impacts (to wetlands, habitat, agriculture, scenic and visual resources etc) from hazard management decisions, consistent with the Coastal Act
- Address the cumulative impacts and regional contexts of planning and permitting decisions.

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[5] The steps presented in this section were modified to remove the relevance to the application to LCPs, and focuses on the process for sea level rise planning for an area that includes multiple types and classes of assets. Steps related to LCP certification and implementation have been excluded.

The CCC (2018) Guidance recognizes that adaptation planning likely requires a hybrid approach to the Protect, Accommodate, and Retreat strategies commonly used to characterize sea level rise planning. Adaptation strategy policies carry specific design implications that could influence adaptation project alternatives and selection. They articulate a framework the conservation of natural resource areas and leveraging of natural processes to mitigate hazards; interim maintenance of existing shoreline protection within existing footprints; anticipation of future shoreline, natural resource areas and public access based on sea level rise and encroachment; and processes for eventual retreat from hazard areas.

The CCC (2018) Guidance is a key document for developing vulnerability and adaptation planning consistent with other areas within the State of California, although significant judgment and decisions are required by project team and owner.

6.2.3 Caltrans Guidance on Incorporating Sea level Rise

Caltrans provides information for incorporating sea level rise considerations during all phases of project delivery at a website titled "Sea Level Rise and the Transportation System in the Coastal Zone" (Caltrans, 2022a). Chapter 880 of the Caltrans Highway Design Manual addresses procedures, methods, devices, and materials commonly used to mitigate the damaging effects of wave action on transportation facilities and adjacent properties (Caltrans, 2020). Caltrans recently published a complementary resource to Chapter 880 of the Highway Design Manual that provides design guidance focused on nature-based adaptation strategies (2022b).

6.2.4 Natural Infrastructure Design Guidance

Guidance for use of natural infrastructure to manage shore response to sea level rise in California is provided to support consideration of alternatives to traditional coastal armoring (Newkirk et al. 2018; ESA 2018a). The Natural Infrastructure Guidance consists of several reports developed as part of California's Fourth Climate Assessment. Guidance is provided for five natural infrastructure shore elements:

- Vegetated dunes – range from sand embankments to natural dune fields,
- Course sediment berms – range from cobble / gravel berms to cobble – boulder lag deposits; beach nourishment was not included because adequate guidance already exists;
- Tidal benches – relatively flat slopes that provide transition from intertidal to supra-tidal elevations to provide habitat, wave dissipation, erosion protection and accommodation space; tidal benches are similar to horizontal levees[6] and living levees[7];
- Marsh sills – rock revetments that are placed on sediment flats in front of tidal marsh scarps to dissipate waves and maintain the marsh; and,
- Oyster reefs and eel grass beds – restoration of low-intertidal and submerged structures to help stabilize estuarine shores.

Methods to assess suitability for a particular location are provided, based on setting, exposure and space requirements. The concept level guidance is intended to identify natural infrastructure typologies that are worthy of further evaluation.

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[6] https://www.sfestuary.org/wp-content/uploads/2013/03/EstApr2013FINAL-web.pdf

[7] http://www.wp.sustainablesv.org/the-living-levee-a-win-win-scenario-for-the-bay-area-community/

6.3 Alternative Development and Evaluation

6.3.1 Resilient Salt Marsh Design Criteria

The substantial anthropogenic interventions along the eastern shore of Arcata Bay make restoration of salt marsh to pre-disturbance conditions challenging. The disturbance to tidal channel and fluvial drainage networks, interior marsh subsidence, and existing infrastructure preclude restoring the pre-disturbance salt marsh footprint. The enhancement project proposes to restore physical and vegetation processes that support and maintain stable marshes in the project area. Based on the project goals and objectives, the following design criteria were established and used to preliminarily screen alternatives.

- Salt Marsh Geometry and Mudflat
    - Sufficient salt marsh width and elevation to dissipate wave energy, enhance sediment trapping, promote deposition and colonization of native salt marsh species.
    - Mudflat fronting the salt marsh edge to provide sediment storage and break wind waves between mean tide and mean high tide levels.
- Stability
    - Provide initial stabilization of salt marsh edge to accommodate marsh vegetation establishment and consolidation of placed sediment.
    - Reduce susceptibility of long-term marsh edge erosion to wave energy.
    - Minimize lateral marsh edge erosion tidal and wind generated currents at the interface with existing Bracut (north) and Brainard (south) levee rock slope protection.
- Tidal Channel Network
    - Restore tidal exchange, sediment delivery and improve marsh drainage.

6.3.2 Alternative Evaluation

Six design alternatives, listed below, were developed and described below in the context of the design criteria and project goals and objectives. Many of these concepts were developed based on the existing conditions assessment, inter-tidal habitat restoration design and construction experience within the Humboldt Bay region, review of publications cited above in addition to multiple San Francisco Estuary Institute (SFEI) publications.

1. Horizontal Levee: Low, Mid, and High Salt Marsh Creation
2. Horizontal Levee: High Salt Marsh Creation with and without Armored Toe
3. Breakwater Reef with Passive and Active Salt Marsh Creation
4. Barrier Island Breakwater with Passive and Active Salt Marsh Creation
5. Groins with Passive and Active Salt Marsh Creation

    Coarse Sediment Shore (sand/gravel/oyster hash)

Alternative 1 - Horizontal Levee: Low, Mid, and High Salt Marsh

The horizontal levee alternative would be comprised of imported fill to establish geometry and elevation to accommodate low, mid and high marsh and a transition zone to the existing rail prism (Figure 53 and Figure 54). Geometry provides wave energy dissipation across the length of the imported fill, promoting deposition of sediment on the marsh plain and erosion protection for the rail prism. The variable marsh plain elevations would restore tidal flooding and promote sediment delivery. Stabilization is achieved through natural recruitment of native vegetation on the low- and mid-marsh is anticipated whereas active planting on the high-marsh and transitional zones would be necessary to reduce infestation of non-natives and invasive species. Tidal channel networks would be integrated into the marsh planform design to provide marsh plain drainage and sediment exchange. The horizontal levee, with low-, mid- and high- marsh achieves many of the project goals and objectives with the creation of extensive salt marsh, wave energy dissipation, and potential beneficial reuse of dredged sediment. However, based on observations in the project area and around Humboldt Bay, the persistence of low and mid marsh is extremely limited. Given the potential lack of the horizontal levee being in dynamic equilibrium, erosion of much of the landform and diminished ability to meet the goals and objectives is expected. Additionally, placement of unconsolidated sediment along the low-marsh transition would likely be highly unstable resulting in long-term scarping and limited natural recruitment of marsh vegetation.

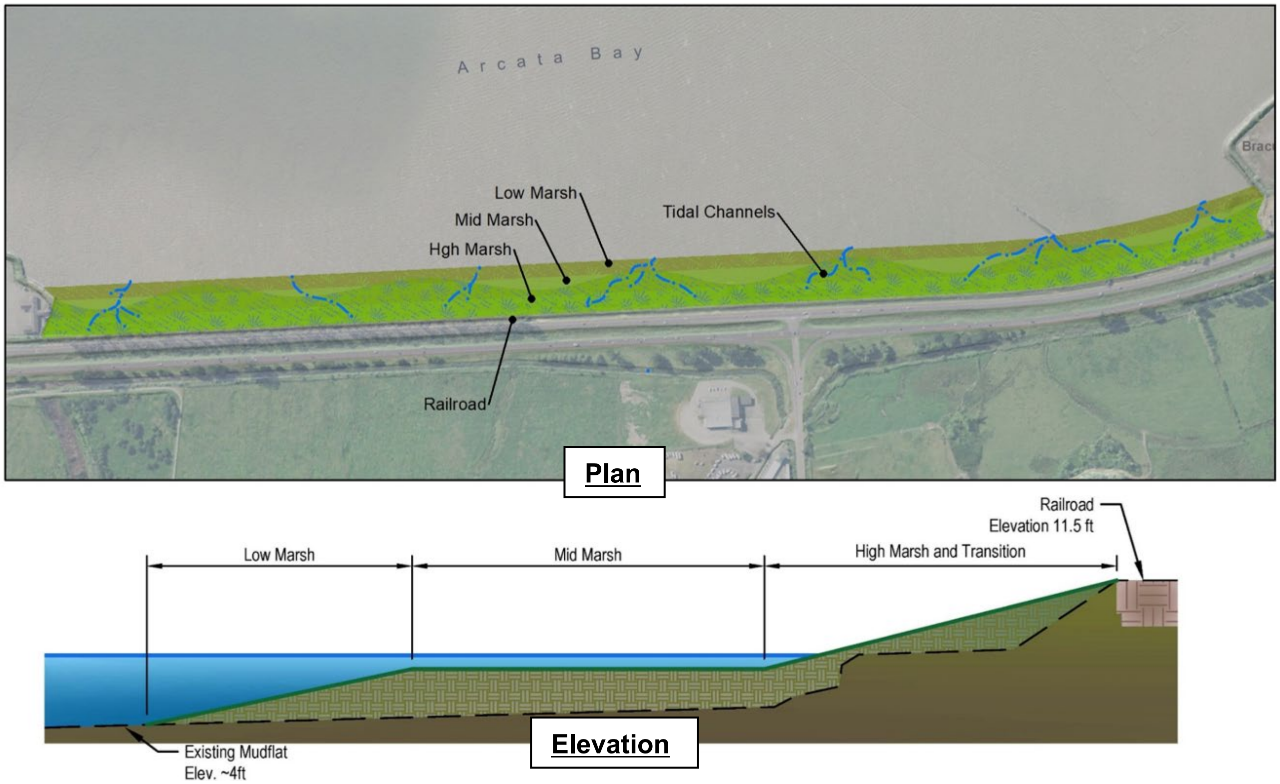


Figure 53 Plan and Elevation of Horizontal Levee: Low-, Mid- and High-Salt Marsh

Figure 54 Example photograph of shore profile at Manilla Community Park (former mill site) on Humboldt Bay constructed in circa 1900. The lateral shoreline has remained fairly static since construction and exhibits a ramping morphology with transition from mudflat to low-, mid- and high-salt marsh. This shoreline is sheltered from the dominant NNW winds which has likely allowed for the ramping morphology to persist.

Alternative 2 - Horizontal Levee: High Salt Marsh with or without Armored Toe

Based on observations of the presence of high marsh in the study area and other marshes of Humboldt Bay that lack low- and mid-marsh, a modification to the previous horizontal levee alternative (1) was developed to represent persistent habitats in reference areas. This alternative is the most comparable to natural marshes located in high energy wave environments where sediment supply is limited in Humboldt Bay. This horizontal levee alternative is similarly constructed of imported fill to establish geometry and elevation and is focused on the construction of high marsh and a transition zone (Figure 55). An optional cobble/stone toe at the transition between mudflat and marsh would provide initial and long-term stabilization benefiting vegetation colonization. The more abrupt change in elevation provides wave energy dissipation at the seaward edge of the marsh promoting deposition of sediment on the marsh plain and erosion protection for the rail prism. The high marsh is more limited in tidal flooding and erosion of the marsh scarp may promote sediment delivery. Optional stabilization of the marsh edge is provided with cobble/stone toe. Geometry and tidal channel networks would be integrated into the planform design to provide marsh plain drainage and sediment transport. The horizontal levee, with high marsh also achieves many of the project goals and objectives with the creation of extensive salt marsh, wave energy dissipation, and potential beneficial reuse of dredged sediment.

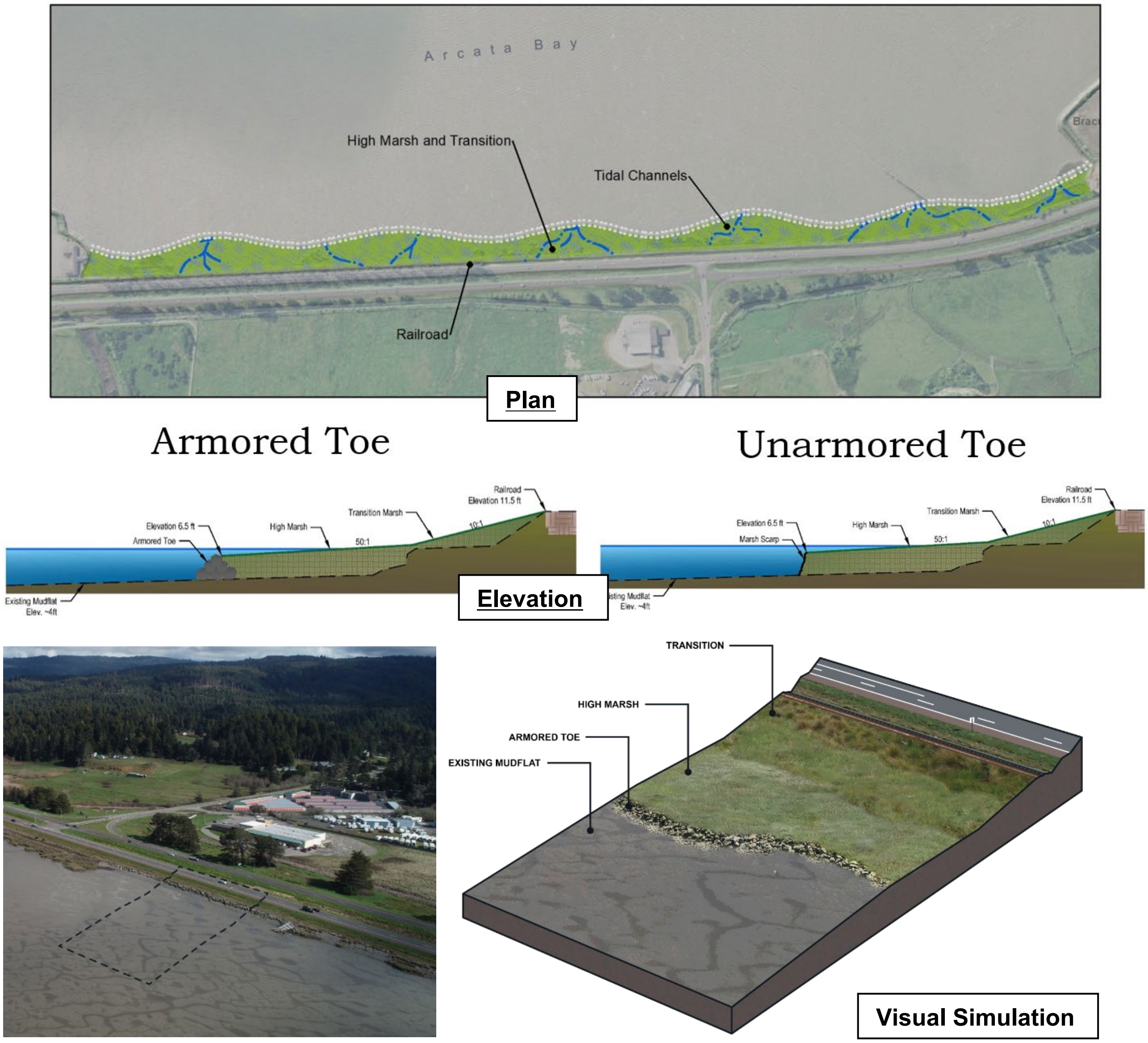


Figure 55 Plan, Elevation and Visual Simulation of Horizontal Levee: High Salt Marsh Creation with Armored Toe

Alternative 3 - Breakwater Reef with Passive and Active Salt Marsh

The breakwater reef alternative utilizes a rock breakwater and imported fill to promote conditions for the passive creation of salt marsh (Figure 56). A rock breakwater is constructed on the mudflat fronting the marsh intended to dissipate wave energy and promote deposition of sediment on the mudflat to passively create marsh habitat. Imported fill provides a transition marsh, from low to high adjacent to the rail prism to enhance erosion protection. Variations in tidal flooding occur along the length of the transition marsh. Geometry and tidal channel networks provide marsh plain drainage and sediment transport. Localized scour around the perimeter of breakwater reef would be expected and overtime the reef may settle vertically and loose effectiveness or require maintenance. During extreme high tides coincident with high wind waves, the reef would be inundated and loose some effectiveness of wind-wave attenuation. Reef configurations, orientation, openings and sediment accretion rates along the back shore are unknown and require further analyses. Concrete reef balls have been placed and monitored for effectiveness within sub-tidal areas of San Francisco Bay to create native oyster habitat, promote eel grass colonization and attenuate wind wave energy. This concept positions the reef at a higher elevation on inter-tidal mudflat relative to the Sub-tidal San Francisco Bay application and therefore offers limited commonalities.

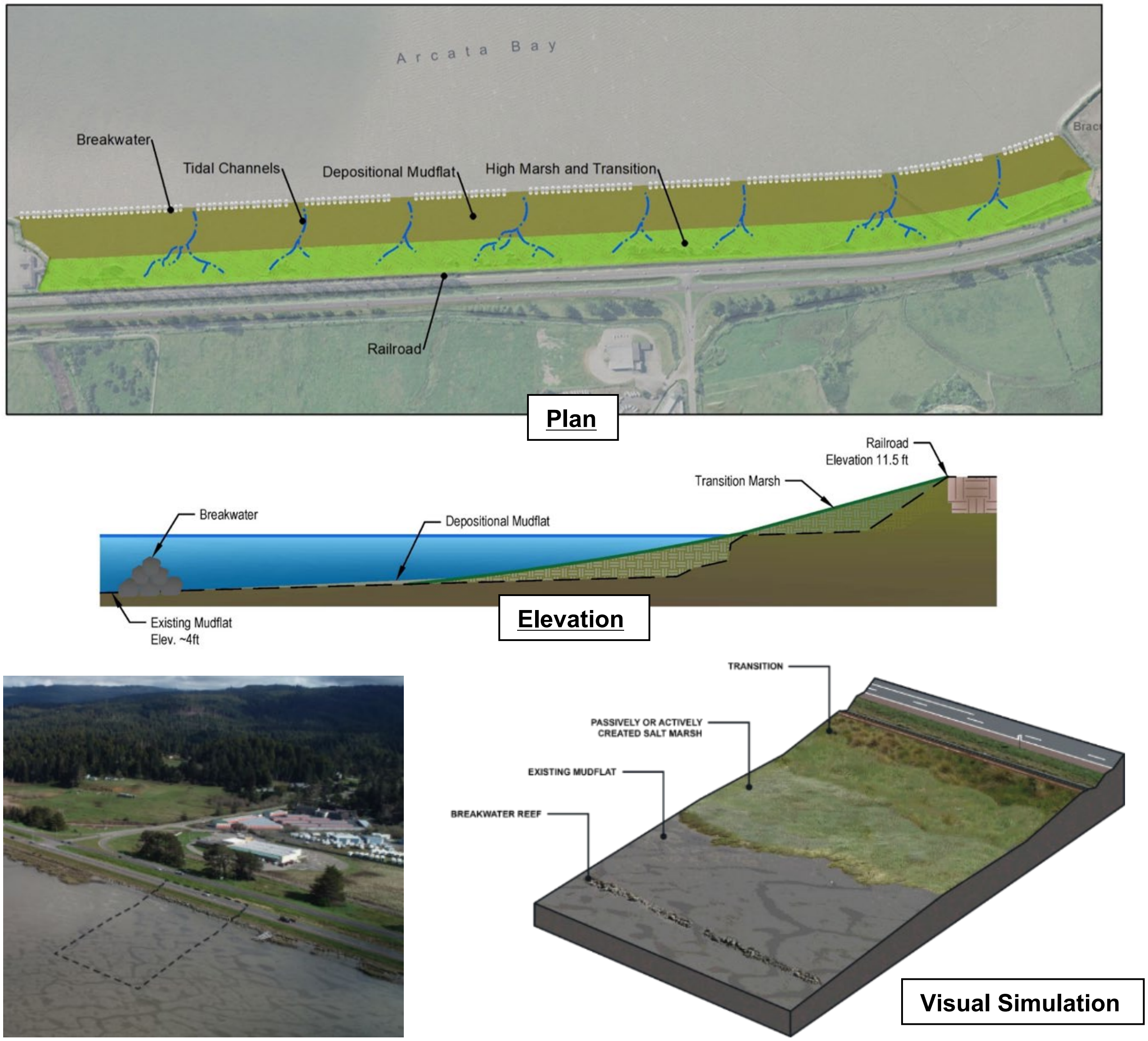


Figure 56 Plan, Elevation and Visual Simulation of Breakwater Reef with Passive and Active Salt Marsh Creation

Alternative 4 - Barrier Island Breakwater with Passive and Active Salt Marsh

Similar to the breakwater reef alternative, the barrier island breakwater alternative constructs an elevation barrier to promote conditions for the passive creation of salt marsh (Figure 57). This alternative utilizes imported fill as opposed to rock for the barrier. An earthen breakwater is constructed on the mudflat to dissipate wave energy and promote deposition of sediment on the mudflat to passively create marsh habitat. Imported fill provides a transition marsh, from low to high adjacent to the rail prism to enhance erosion protection. Stability of the barrier island breakwater is dependent on installed or natural recruitment of vegetation, fill properties, and erosion from wind waves. Variations in tidal flooding occur along the length of the transition marsh. Geometry and tidal channel networks provide marsh plain drainage and sediment transport. An example photo of a barrier island breakwater is provided in (Figure 58).

The barrier island reef concept originates from remnant earthen dikes constructed around the bay shoreline, and if remain intact could be breached to provide tidal exchange to the backshore. Dikes comprised of dredged spoils were constructed at the site as previously described and have eroded and therefore this concept would likely have limited resiliency at the project site.

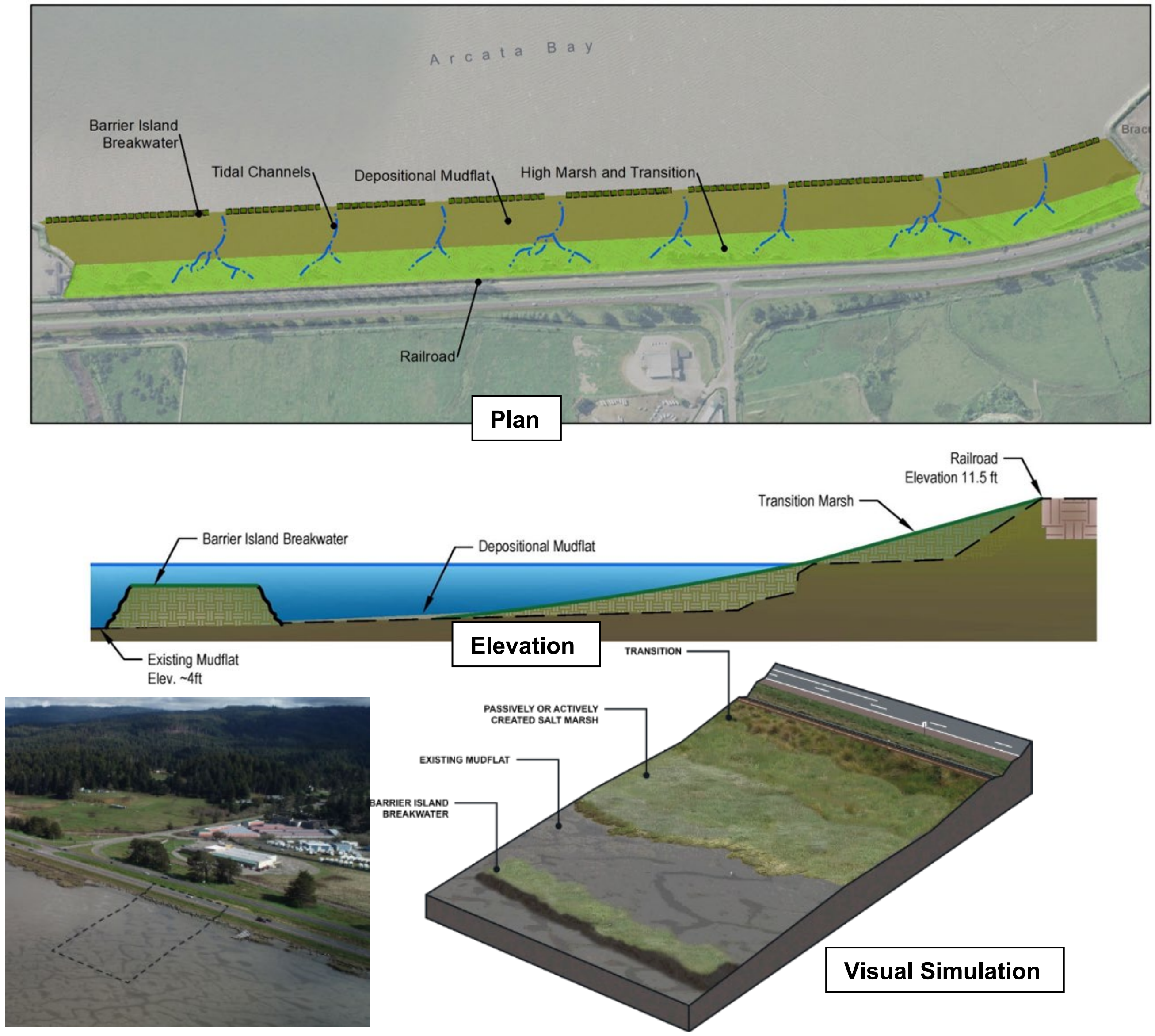


Figure 57 Plan, Elevation and Visual Simulation of Barrier Island Breakwater with Passive and Active Salt Marsh Creation

Figure 58 Example Photo of Barrier Island Breakwater at White Slough, HBNWR (Laird)

Alternative 5 - Groins with Passive and Active Salt Marsh

The groins alternative utilizes rock jetties and imported fill to mimic the form and function of the remanent dike that currently provides wave dissipation, traps long-shored transported sediment and creates salt marsh (Figure 59). Rock jetties would be constructed on the mudflat to dissipate tidal and wind currents, and wave energy and imported fill is placed on the leeward side and along the rail prism. Imported fill provides a transition marsh, from low- to high-marsh adjacent to the rail prism to enhance erosion protection. Variations in tidal flooding occur along the length of the transition marsh. Tidal channel networks would passively form to provide marsh drainage and sediment transport. While the existing remnant dike has created a groin-like feature, the passively accreted low marsh on the lee-side is restively small, vertically limited and remains vulnerable to south wind wave erosion. Groin configuration, orientation, and sediment accretion rates along the back shore are unknown and require further analyses. While long-shore sediment trapping would likely be enhanced, the marsh plain would remain vulnerable to wind-wave erosion from south winds, and erosion from long-shore currents at the down drift locations between groins.

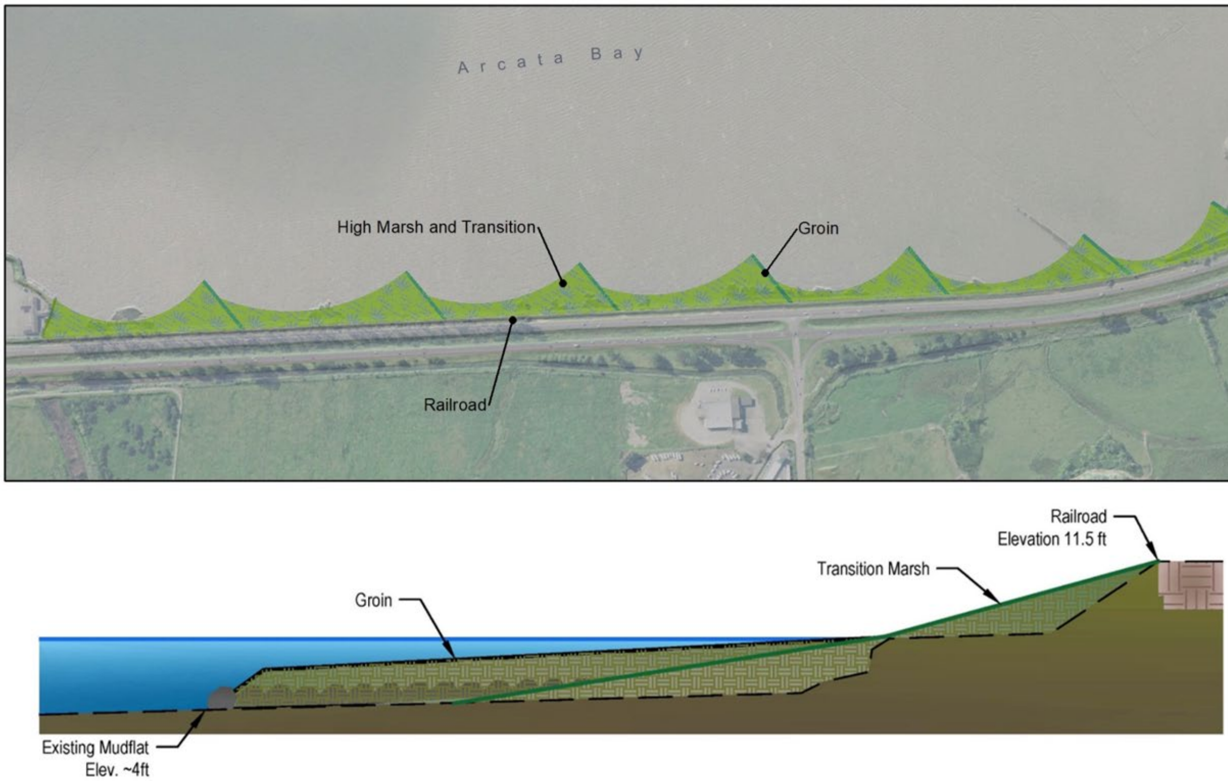


Figure 59 Groins with Passive and Active Salt Marsh Creation

Alternative 6 - Coarse Sediment Shore (sand/gravel/oyster hash)

The coarse sediment shore alternative utilizes imported sand, gravel, or oyster hash and imported large wood habitat groins or drift sills to dissipate wave energy adjacent to the rail prism and retain coarse sediment from long-shore drift (Figure 60). The coarse material is placed on the mudflat and wood structures embedded to dissipate wave energy and reduce the migration of placed gravels. Deposition of fine sediment within the coarse material promotes marsh vegetation. Examples of existing coarse sediment shorelines, also referred to as a gravel shingle are shown in Figure 60 and Figure 61. The coarse sediment shore proposed in this alternative is very similar to the portions of the existing shoreline within the project area that have been formed from the eroded railroad ballast. Where the fringing marsh does not exist and railroad ballast as eroded, the shoreline profile has equilibrated to a variable yet gradual slope (10-15%) based on the course gravel size. As described in the existing condition assessment the course sediment in most locations is several inches thick overlaying native fine sediment. This course sediment shore could be adapted to the existing project shoreline to preserve salt marsh where it currently exists or create new salt marsh where it does not already exist.

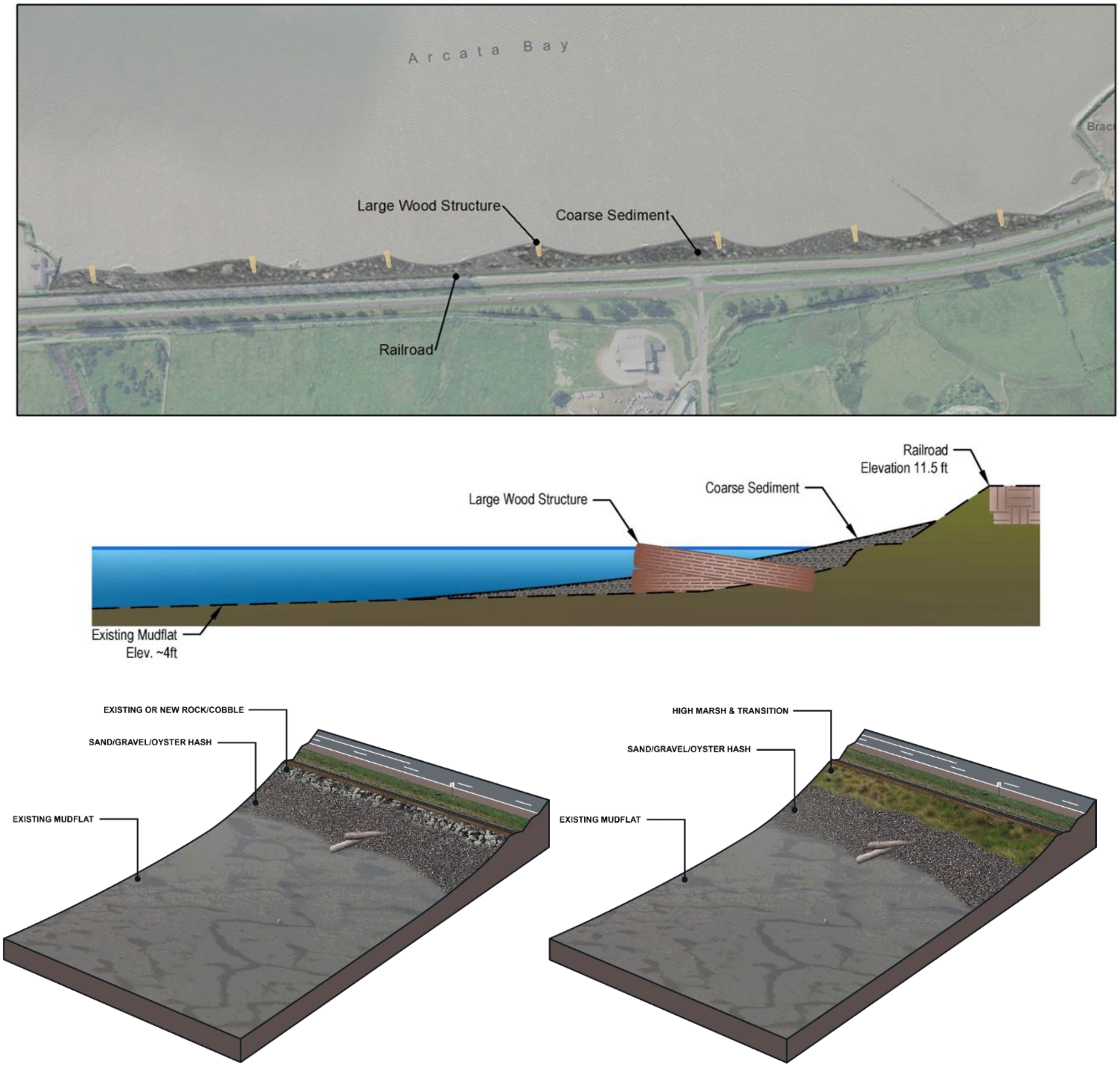


Figure 60 Visual Simulation of Coarse Sediment Shore with wood groins or drift sills (sand/gravel/oyster hash)

Figure 61 Example Photo of Coarse Sediment (Gravel Shingle) Beach at Brainard (left) and within project area (right)

Figure 62 Example photos of gravel beach with groins or drift sills of embedded, pinned logs along the Aramburu Island project shoreline in North San Francisco Bay used to trap updrift coarse sediment (A-C). Downdrift side of groins either remain stable or exhibit erosion where the drift beach sediment is obstructed locally (B-D). When gravel beach profiles retreat landward overtime, beach accretion on the updrift side reorient to face dominant wave approach (blue arrow), in contrast with the strongly oblique orientation of the main beach axis relative to the wave approach (SFEI 2020).

6.3.3 Alternative Selection

The alternatives presented above provide a range of concepts all with varying levels of uncertainty and ability to achieve the project goals. A relatively high degree of uncertainty is expected when applying nature-based design in a highly dynamic setting. Utilizing reference sites, whether natural or constructed, that remain in dynamic equilibrium with hydraulic and geomorphic processes can reduce uncertainty. The White Slough Wetland Enhancement Project at the Humboldt Bay National Wildlife Refuge has demonstrated that salt marsh vegetation will quickly colonize fill placed at appropriate marsh plain elevations (Pickart, 2020). Other recently completed salt marsh restoration projects throughout Humboldt Bay and adjacent Eel River estuary have also demonstrated similar success. These project sites do not, however, share similar wind-wave exposure and sediment dynamics as the project site. As previously described, wind-waves play an important role in suspension of sediments from the mudflat for deposition to the marsh plain, an important process for resilient marshes. However, wind-waves can also contribute to marsh erosion, particularly in early marsh development and vegetation colonization. Balancing these physical processes was considered in selection of the apparent best alternative.

Several factors contributed and influenced the selection of the apparent best alternative:

- Goal of restoring/enhancing intertidal marsh habitat resilient to sea level rise and in equilibrium with hydraulic and geomorphic processes.
- Goal of protecting infrastructure (Humboldt Bay Trail and Highway 101) from wind-wave runup and overtopping.
- Input from Technical Working Group (TWG) about minimizing the use of shoreline hardening, particularly from rock slope protection.
- Results and findings from the Geomorphic Assessment and Conceptual Model (Chapter 5).

Based on the above factors, a hybrid alternative was selected utilizing components of Alternatives 2 and 6 and employs components of the physical features found at reference locations. The apparent best alternative is comprised of a gravel shingle beach, salt marsh and transition zone. The gravel shingle beach is composed of a layer of coarse gravel placed below approximately MHHW at a gradual slope to the mud flat. The gravel shingle beach promotes breaking wave energy that can be dissipated by the flexible shoreline. Shoreline restoration projects such as the Aramburu Island project in Richardson Bay (North San Francisco Bay) have similar wind-wave heights and exposure relative to the project area. The Aramburu Island project incorporated salt marsh creation in combination with a gravel shingle beach and log groins (Figure 61 previously shown above). The project was constructed in 2011 and has served as a successful demonstration project (SFEI 2020).

The combination of these components restores the natural processes that maintain a stable or prograding marsh while providing toe stability for early vegetation colonization and fill stabilization. The natural recruitment of vegetation on the salt marsh is important for stabilization, sediment trapping, and vertical accretion. Thus, it is anticipated that placed fill at the project area would quickly vegetate and promote organic and mineral sediment accretion, maintaining pace with sea level rise into the future. A reference shoreline between Brainard Slough and Jacoby Creek Marsh exhibits similar characteristics comprised of a course sediment shore transitioning between mudflat and salt marsh as proposed in the apparent best alternative (Figure 63). Figure 64 and Figure 65 depict a visual simulation and conceptual design profile of the apparent best alternative. The design basis for this apparent best alternative including marsh plain geometry, width and channel network is presented in Section 7.

Figure 63 Shoreline north of Brainard Slough with example coarse sediment transition from mudflat to salt marsh. Salt marsh vegetation is dominated with invasive Spartina densiflora, sparse pickleweed and salt grass.

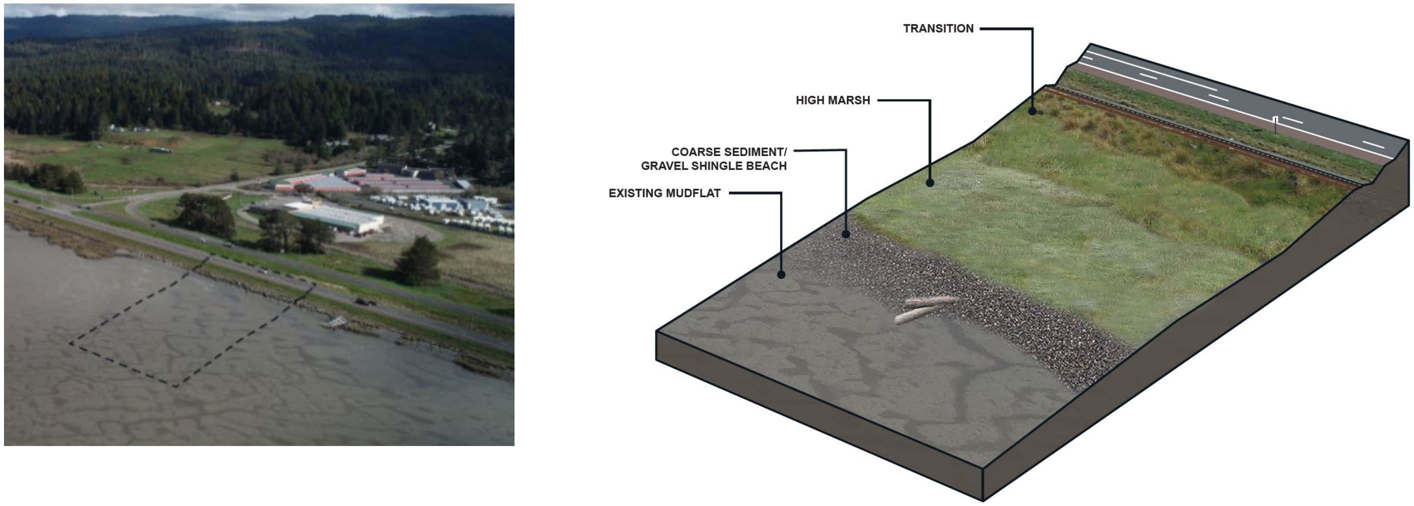


Figure 64 Conceptual visual simulation of apparent best alternative comprised of shingle beach, salt marsh and transition zone.

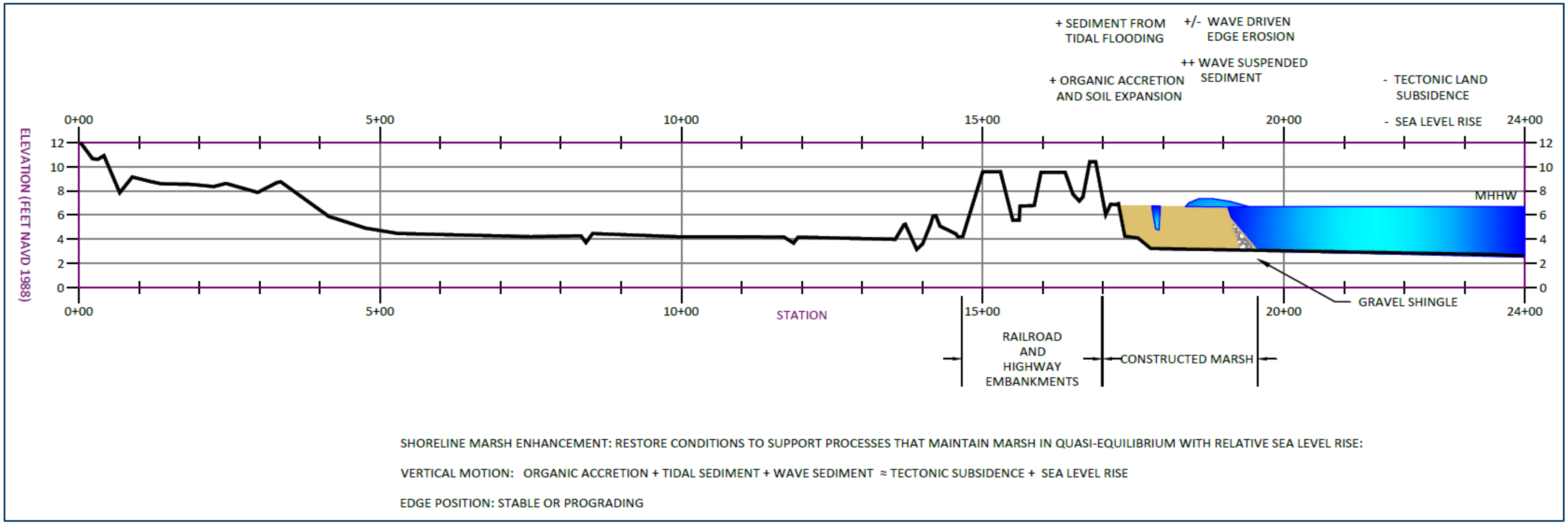


Figure 65 Conceptual project area cross-section showing apparent best alternative of gravel shingle beach and salt marsh

7. Concept Design Development

The apparent best alternative introduced in the previous section of this report is based on the fundamental concept to integrate natural flood-risk reduction properties of a salt marsh which historically existed within the project area. Creation of a salt marsh to achieve the project goals and objectives introduces constructability and logistical challenges that were considered early in the design development specifically related to construction phasing and material sourcing. The project will require import of locally sourced materials to construct the various features and while all materials are readily available, the source of fine-grained sediment to construct the salt marsh is currently undefined. The design has therefore been developed to accommodate implementation of the project in a single construction phase should all import material, including fine-grained sediment be available, or through multiple phases/years to accommodate incremental placement that could, for example, align with beneficial reuse of future sediment dredge cycles. The concept design is comprised of three primary components:

1. **Salt marsh plain with tidal channel network,**
2. **Coarse sediment shingle beach with large wood debris (LWD) groins**, that provides a transition from the constructed salt marsh to the existing mudflat, and
3. **Transition (High Marsh Ecotone) zone** that provides a transition from the salt marsh plain to the existing rail prism.

The basis of design for each of these three primary components is described below, shown in Figure 66 and presented on the 50% design plans (Appendix H). The 50% design plans assume the Humboldt Bay Trail South Project, scheduled to be constructed in 2023, is in-place when this project is constructed.

EXISTING CONDITIONS

FUTURE CONDITIONS

Figure 66 Visual Simulation of Proposed Project Components

7.1 Salt Marsh Plain and Tidal Channel Design

7.1.1 Design Objectives

The historic salt marsh within the project area depicted in the 1870 maps show a variable width extending beyond the current rail prism and is depicted on the 50% design plans and Figure 17. In the northern portion of the project area, the 1870 salt marsh edge aligned with the current rail prism alignment with an increasing width in a southward direction extending as much as 600 feet beyond the rail prism at the southern end of the project area. Restoring the salt marsh to the 1870 footprint would not necessarily satisfy the project goals given the variable width. The proposed salt marsh is intended to have sufficient width and elevation to achieve multiple objectives, such as to wave dissipation, sediment trapping, colonization of native salt marsh species, and a dendritic tidal channel network that would improve sediment delivery and marsh drainage. An additional design objective is to minimize the change in tidal and sediment circulation patterns fronting the project area. Restoring the salt marsh to a 600-foot width could affect tidal circulation, reduce mudflat as a sediment source/sink, pose additional construction challenges and be cost prohibitive. The following sections below describe the basis for developing the optimal salt marsh plain width and elevation.

7.1.2 Overview of Relevant Design Guidelines and Criteria

Design guidelines for salt marsh restoration are regionally specific and do not exist for Humboldt Bay however they do exist for San Francisco Bay and emphasize the use of analog systems (PWA 2004). Salt marsh restoration projects in Humboldt Bay have largely relied on analog sites to establish desired marsh plain elevations and tidal channel geometries. The design criteria and approach for the proposed salt marsh features are shown in Table 5 and rely on a combination of supporting analytical modeling tools and analog sites.

Table 5 Design Feature, Criteria and Approach for Salt Marsh and Tidal Channel

Design Feature	Design Criteria	Design Approach (described below)
Salt Marsh Width	Width sufficient to attenuate wind-waves	Wind-Wave Model Analyses
	Width sufficient to support tidal channel network	Analog: Jacoby Creek Marsh
Salt Marsh Elevation	Support naturally recruited native salt marsh vegetation	Analog: Project and Jacoby Creek Marshes
Salt Marsh Fill	Support naturally recruited native salt marsh vegetation	Analog: Project area salt marsh
Tidal Channels	Maximize tidal and sediment circulation	Analog: Jacoby Creek Marsh

7.1.3 Project and Analog Sites (Geomorphic Template)

7.1.3.1 Salt Marsh Width and Elevation

To identify target width and elevation of the proposed salt marsh, analog cross sections were established and surveyed within the nearby Jacoby Creek Marsh (Jacoby Marsh) located between Bracut and Jacoby Creek. The Jacoby Marsh serves as a geomorphic template and was selected as an analog marsh as it has shown edge position stability since 1870, has an established tidal channel network, is in close proximity to the project area, and has naturally recruited native salt marsh vegetation following Spartina treatment which last occurred in January 2019

(RCAA 2019). For comparative purposes, cross-sections were also surveyed in the project area salt marshes. The location of the project area and analog survey locations are shown in Figure 67.

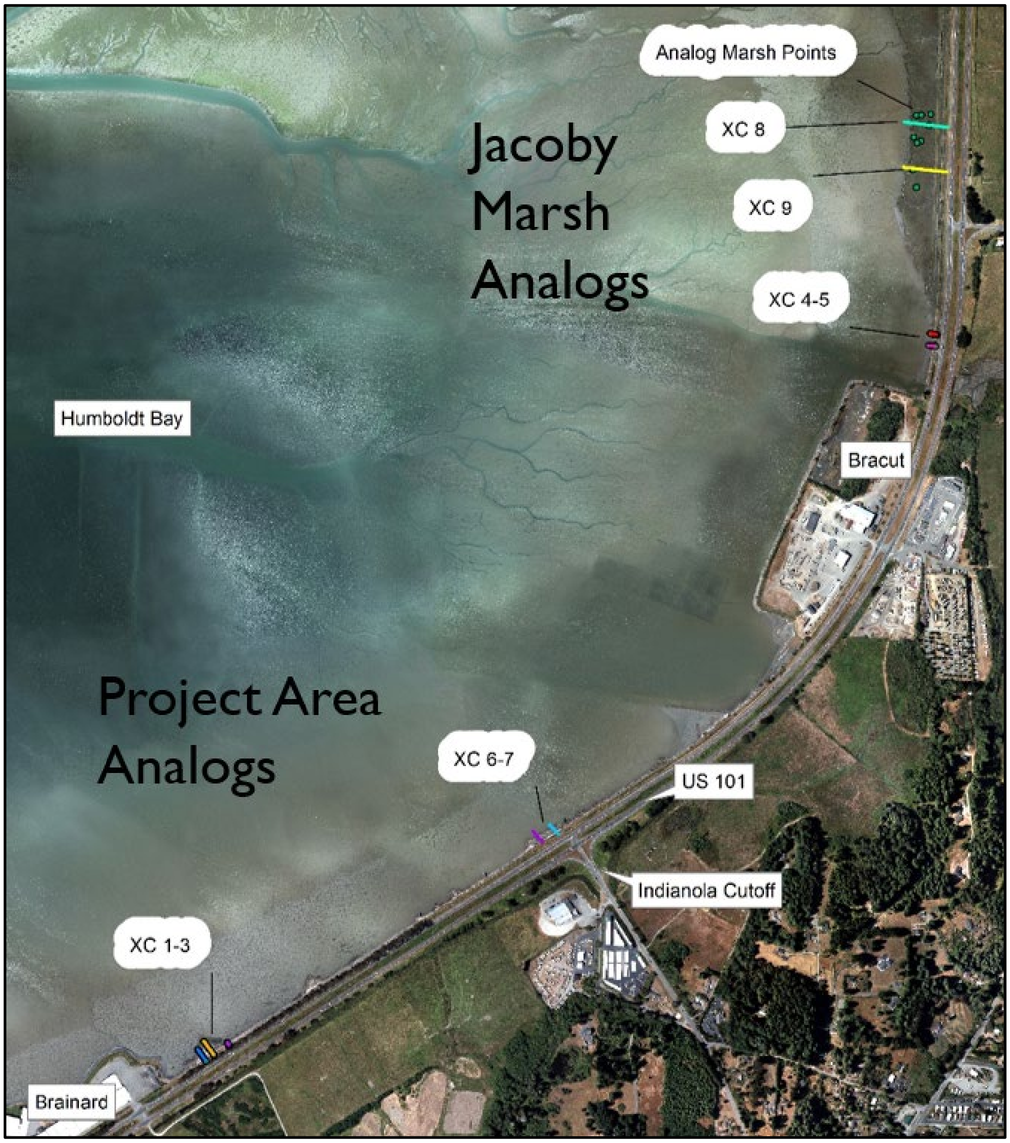


Figure 67 Project Area and Jacoby Marsh cross-section and channel geometry measurement locations.

Cross-sections were surveyed using a centimeter-grade Real Time Kinematics (RTK) GPS (Eos Arrow) for comparison to the available 2019 coastal LiDAR. The cross-sections show general agreement between the LiDAR and surveyed data with differences attributed to vegetation return from the LiDAR and GPS accuracy. Figure 68 and Figure 69 show marsh plain elevations ranging between 6 and 7 feet (NAVD88) within the project area.

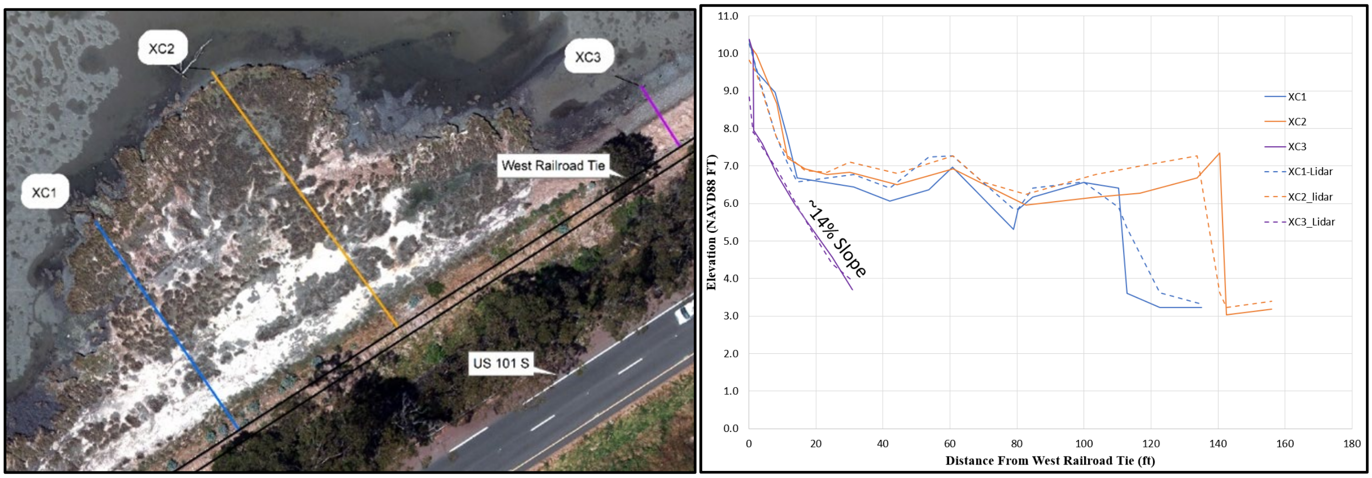


Figure 68 Salt Marsh cross-sections in southern portion of project area.

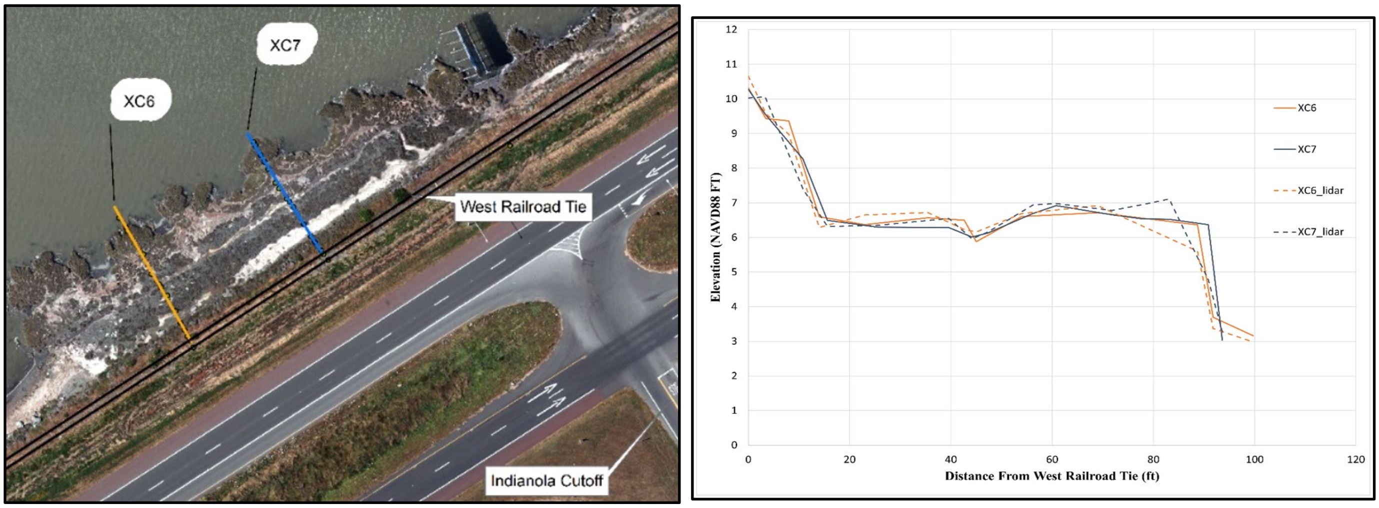


Figure 69 Salt Marsh cross-sections in project area (near Indianola Cutoff).

Additional salt marsh plain cross-sections (8 and 9) were surveyed at the Jacoby Marsh (Figure 70) and show a consistent near 7-feet elevation (NAVD88) consistent with Mean Higher-High Water (MHHW) and typical of an Arcata Bay mature salt marsh elevation. The Jacoby Marsh width fronting the former rail prism ranges between 150-250 feet and includes a dendritic tidal channel network. Construction of the rail prism in 1900 would have disconnected tidal exchange to the back marsh thereby reducing the tidal prism exchanged through the channels. Over the past 120+ years, the channels present today have likely equilibrated in size to the current marsh drainage area.

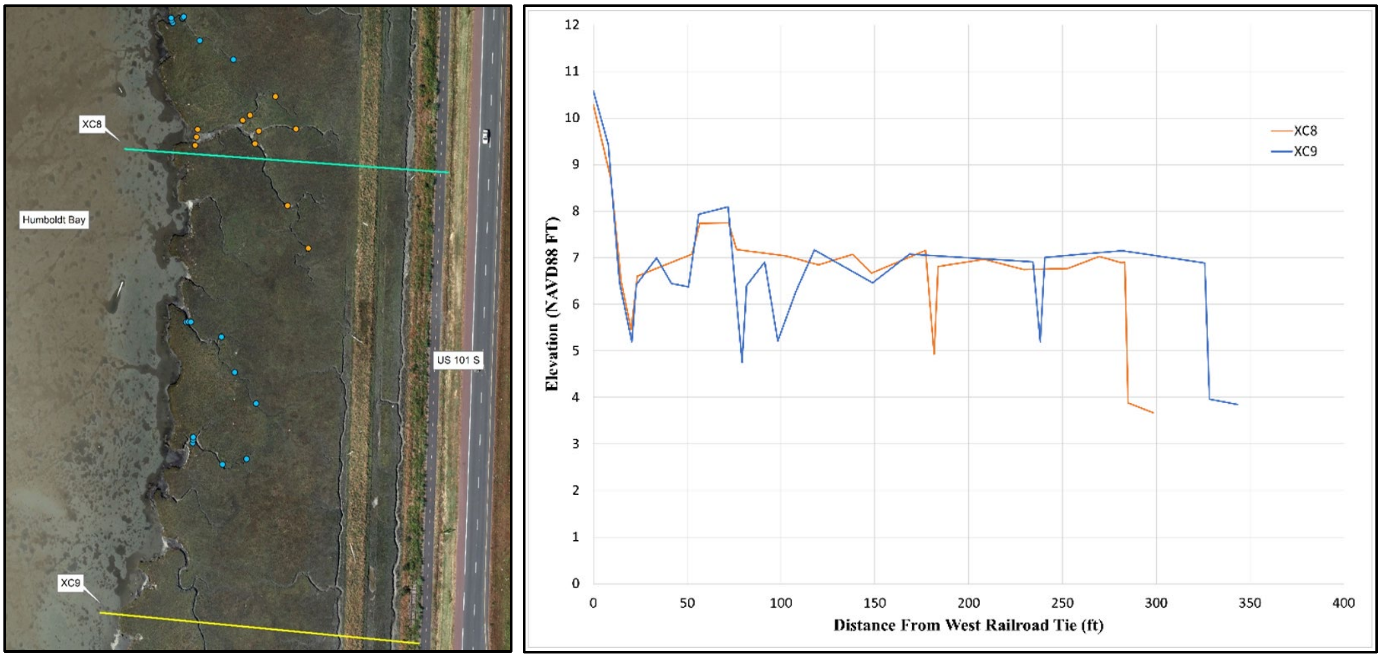


Figure 70 Analog cross-sections 8-9 north of project area at Jacoby Creek Marsh.

7.1.3.2 Tidal Channel Size

Tidal sloughs are formed by exchange of tidal prism with cross-section geometry related to hydraulic shear stress, resulting in larger channel cross-sections for larger tributary tidal areas (Williams and Orr 2002; Williams and others 2002). Empirical relationships developed for San Francisco Bay relate tidal prism which is calculated as the total diurnal tidal volume exchanged between MLLW and MHHW, to cross-sectional area of the tidal channel. For salt marshes with elevations at MHHW, tidal channel sizes can also be sized through use of tidal marsh drainage area. This approach was applied to sizing the tidal channels for this project given the design marsh elevation is established at MHHW, as discussed in following sections.

To correlate the channel size verse marsh drainage area, a network of existing tidal channels within the Jacoby Marsh were surveyed. Channel depth and width were measured at approximately 15 locations within the tidal channels at the locations (blue and orange dots) shown in Figure 72. A combination of aerial imagery and a digital elevation model were used to delineate the contributing salt marsh area upstream of the channel points of measurement. Figure 71 and Figure 72 show the regression equations and r-squared values associated with three different contributing marsh area to channel geometry relationships.

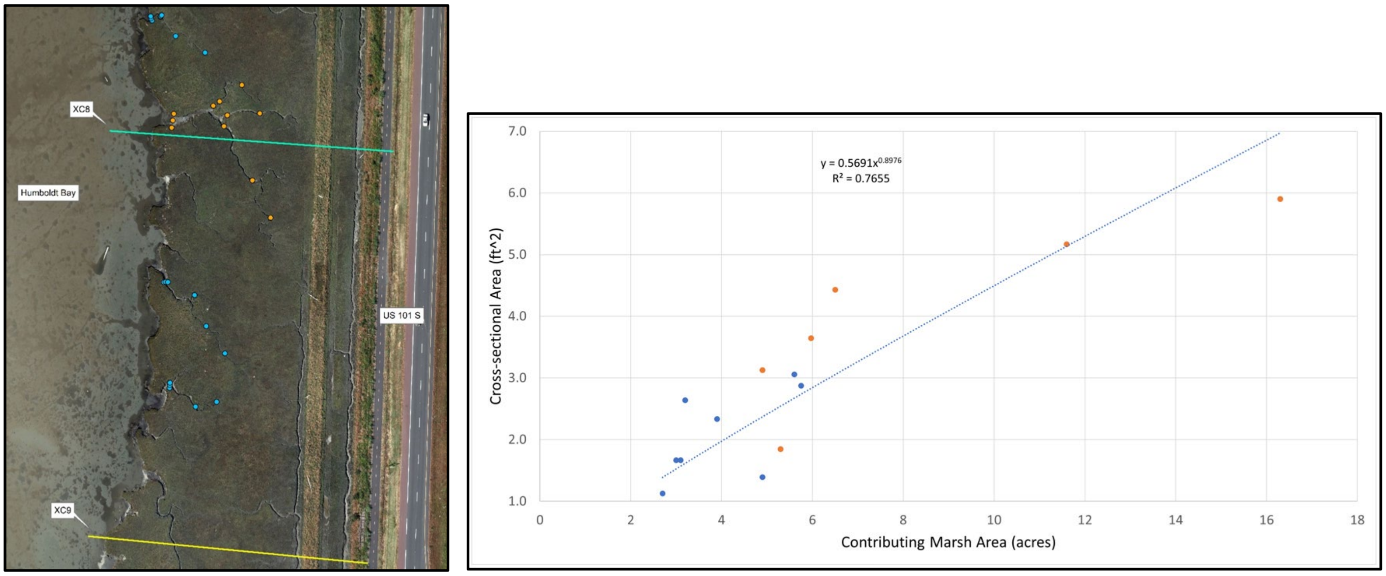


Figure 71 Regression plot showing the relationship between contributing marsh area and tidal channel cross-sectional area within the analog Jacoby Marsh.

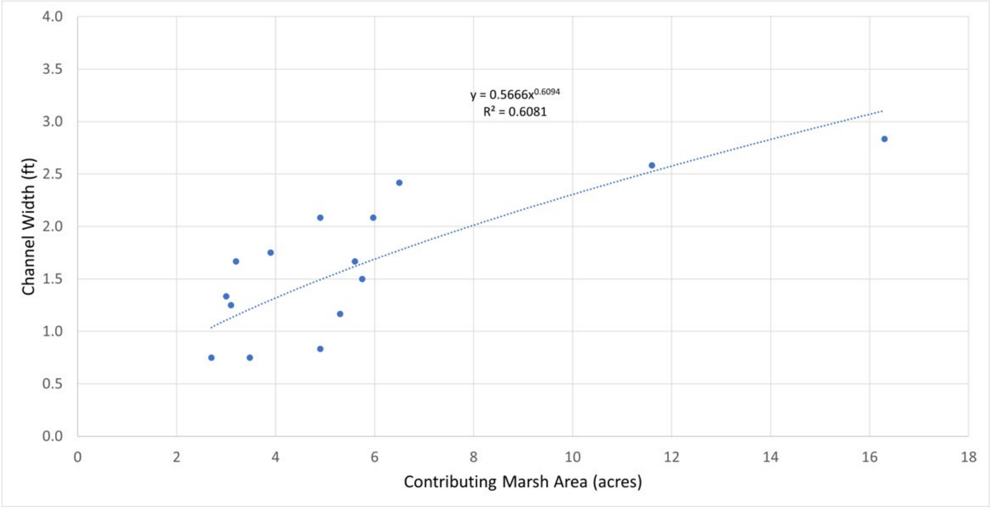


Figure 72 Regression plot showing the relationship between contributing marsh area and channel width within the analog Jacoby Marsh.

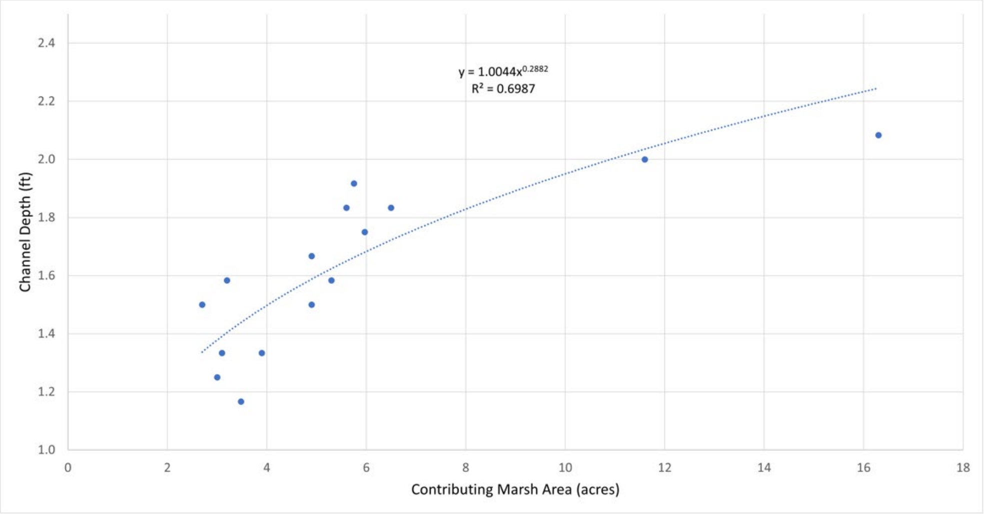


Figure 73 Regression plot showing the relationship between contributing marsh area and channel depth within the analog Jacoby Marsh.

The above information was used to establish the preliminary salt marsh elevation, width and channel size design which is further described in the Preliminary Basis of Design section below. In addition to the use of analog sites to determine potential marsh width and elevation, a wind-wave analyses was conducted to assess effectiveness of wave attenuation with respect to marsh plain width.

7.1.4 Wind-Wave Analyses

To provide an additional design basis for salt marsh width, a wind-wave analyses was conducted to determine the minimum marsh width necessary to attenuate a combination of water levels and wind speeds. An extreme wind speed analysis and Simulation Waves Nearshore (SWAN) model analyses were conducted and are provided in Appendix D and Appendix E, respectively. The water levels assessed ranged from 7.1 feet (MHHW) to 10.7 feet (1% exceedance probability or 100-year recurrence interval), and wind speeds ranged from 38 mph (95% exceedance probability or 1.053-year recurrence interval) to 48 mph (1% exceedance probability or 100-year recurrence interval). Water levels and wind speeds used in the analysis are shown in Table 6 and Table 7.

Table 6 Water levels analyzed

Water Level Definition	Water Level
1% EP (100-yr RI)	10.7 ft
10% EP (10-yr RI)	10.0 ft
50% EP (2-yr RI)	9.4 ft
MMMW	8.4 ft
MHHW	7.1 ft

Table 7 Wind speeds analyzed

Wind Speed Definition (2-min Average Speed)
1% EP (100-yr): 48 mph
10% EP (10-yr): 44 mph
50% EP (2-yr): 40 mph
95% EP (1.053-yr): 38 mph

The SWAN model was implemented as a one-dimensional (1D) model and used to estimate wave generation, dissipation, and set-up under pre- and post-project shoreline geometry. Pre-project conditions assume the Humboldt Bay Trail South Project has been constructed, and post-project conditions include the proposed concept natural shoreline design. Using the SWAN model, each combination of water levels and wind speeds were analyzed. Under pre-project conditions, wind waves travel across the bay unimpeded, allowing the waves to interact and runup the shoreline (Figure 74).

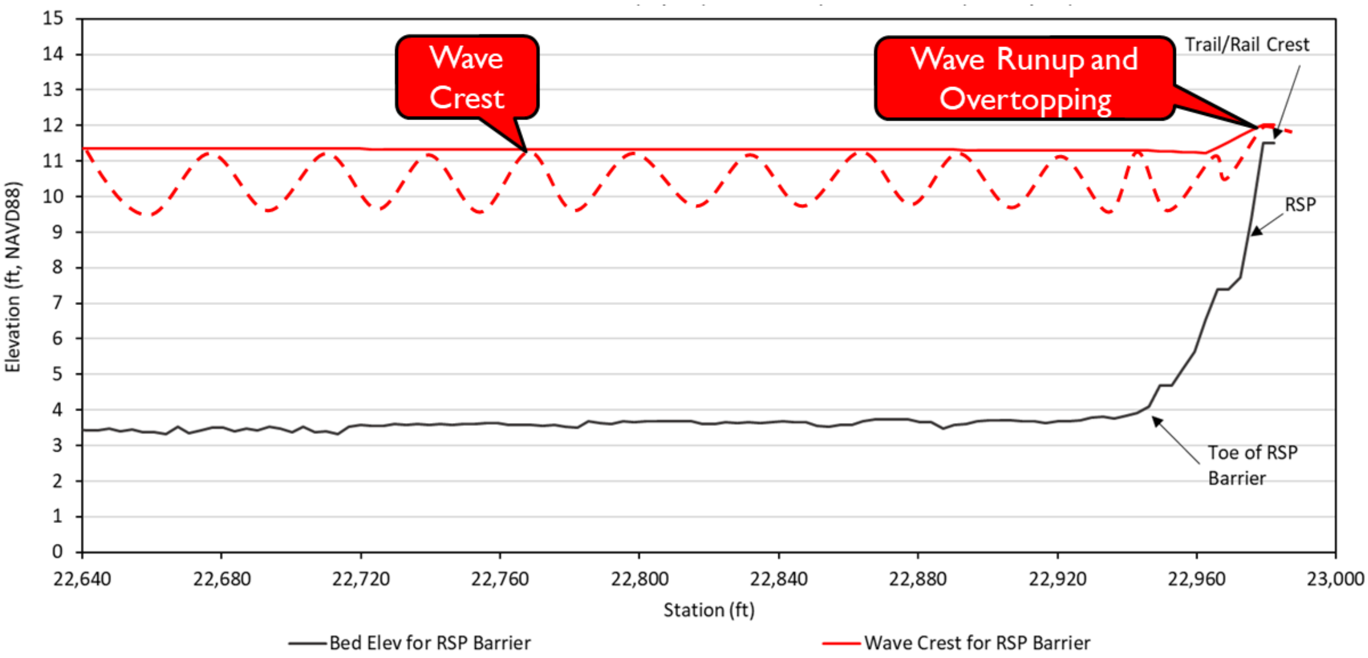


Figure 74 Pre-project wind-wave crest calculated in SWAN for an 8.4 feet water level and 40 mph wind speed overtopping the rail prism (11.5ft).

Under post-project conditions the proposed salt marsh reduces the wave height as the wave interacts with the marsh, preventing wave runup and overtopping of the rail prism for the same water level and wind speed scenario (Figure 75). The model results demonstrate that much of the wave attenuation occurs at the beach barrier and within the initial 100 feet of the proposed salt marsh which is a critical finding of this analyses.

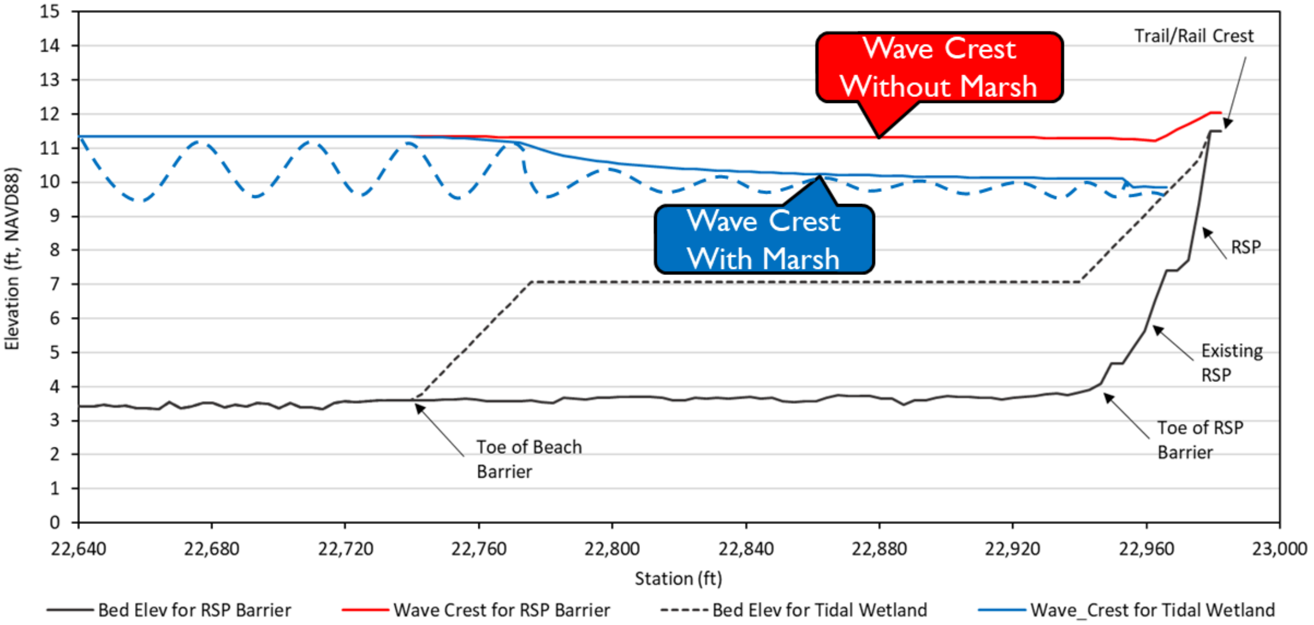


Figure 75 Post-project wind-wave crest calculated in SWAN for an 8.4 feet water level and 40 mph wind speed that does not overtop the rail prism (11.5ft).

7.1.5 Preliminary Basis of Design

7.1.5.1 Salt Marsh Width and Elevation

Based on the Jacoby Marsh analog site, wind-wave analysis and tidal current analyses, a total marsh width of approximately 150 feet was established, of which approximately 115 feet is proposed salt marsh plain at an elevation of approximately 7.1 feet (NAVD88). The remaining approximately 35 feet would include the high marsh ecotone as a transition zone from the salt marsh plain to the rail prism which is described in subsequent sections of this report. The existing fringing marshes in the project area that are lower than the desired 7.1 feet elevation would likely remain and be integrated into the final marsh plain with shallow fill following invasive Spartina removal discussed in subsequent sections of this report.

To assess changes in adjacent water levels and tidal circulation relative to existing conditions, the NSI model described in Section 5.4.2.2 was modified to include the proposed marsh geometry. To accommodate the proposed elements, the existing condition hydraulic model was modified as follows: (1) the grid cells within the Project footprint were raised to an approximate MHHW elevation of 2.2m (7.1 ft); (2) the roughness height (Z_0) in the Project grid cells were set to 0.01 m; and (3) the Project grid cells were changed to account for wetland vegetation drag as described in Section 5.4.2.2. The modified NSI model was simulated for the same general tidal and wind conditions used for existing conditions. Only a subset of the design simulation results is presented here but consistent with the results presented for existing conditions so that direct comparisons can be made.

Figure 76 shows the velocity magnitude and vectors along the project shoreline with the Project elements incorporated into the model domain near slack tide for a 2-yr extreme water level, including no wind and a 10 mps (22 mph) wind coming from the northwest, north, and southwest directions, respectively. These results can directly be compared to Figure 37. The Project tidal wetland grid cells remained dry for this period of the simulation which provides conservative results. Based on a visual (qualitative) comparison the project does not appear to significantly affect the flow field adjacent to the project shoreline, except for the obvious changes within the Project footprint.

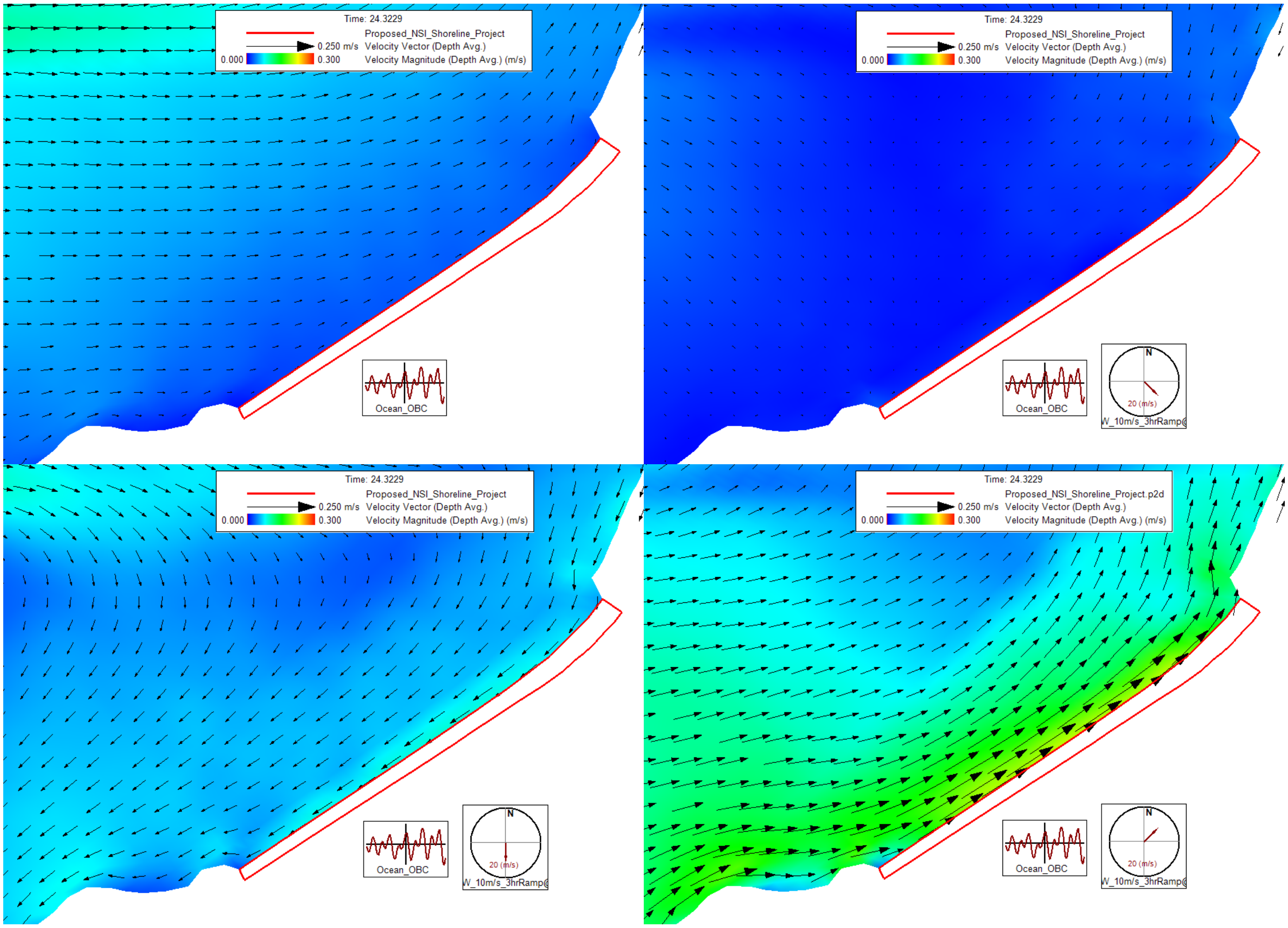


Figure 76 Proposed NSI Project design velocity vectors (magnitude and direction) of tidal currents predicted during an approximate 2-year flood tide along the project shoreline, with no wind (top left), a 10 mps (22-mph) northwest wind (top right), a 10 mps (22-mph) north wind (bottom left), and a 10 mps (22-mph) southwest wind (bottom right).

To provide a more quantitative assessment of the Project design effects on existing conditions, the difference between design and existing conditions for water surface elevation, velocity magnitude, and total shear stress are provided in Figure 77, Figure 78 and Figure 79, respectively for the same flow conditions. It appears that the proposed Project design has minimal effects on the adjacent flow field. Water levels adjacent to the project area differ by less than 0.01 m (1 cm or 0.4 inches). Velocity magnitude changes by less than 0.1 mps (10 cm/s or 0.3 ft/s), with the highest velocity differences directly adjacent to the project shoreline. A north wind produces lower design velocities adjacent to the project shoreline, while a southwest wind increases velocities. Maximum total shear stress differences are approximately 0.1 N/m^2, with design condition total shear stresses lower along the project shoreline than existing conditions for all three wind conditions.

One last assessment of Project design conditions was conducted comparing sediment mobility between existing and design conditions. Appendix I provides side-by-side comparisons between the existing condition sediment mobility plots from Figure 42 to Figure 50 for a 5 mps (~ 11 mph), 10 mps (~22 mph), 15 mps (~34 mph), and 20 mps (~45 mph) wind from the northwest and southeast directions to the equivalent sediment mobility plots for design conditions. Based on a qualitative review of the comparison plots, it does not appear that the Project design affects sediment mobility in Zones 2, 3 or 4 compared to existing conditions. However, as anticipated sediment mobility is lower in Zone 1 for Project design conditions compared to existing conditions due to a portion of this zone being filled to design tidal wetland elevations. This also demonstrates a higher potential for sediment deposition, and lower sediment mobility, in Zone 1 for the proposed Project design elements.

In general, it does not appear that the proposed Project design will significantly affect the water levels, circulation patterns, or sediment mobility adjacent to the project shoreline or in North Bay. The proposed design elements, such as the sand/gravel beach, will provide adequate protection for any potential increase in alongshore currents from the proposed design.

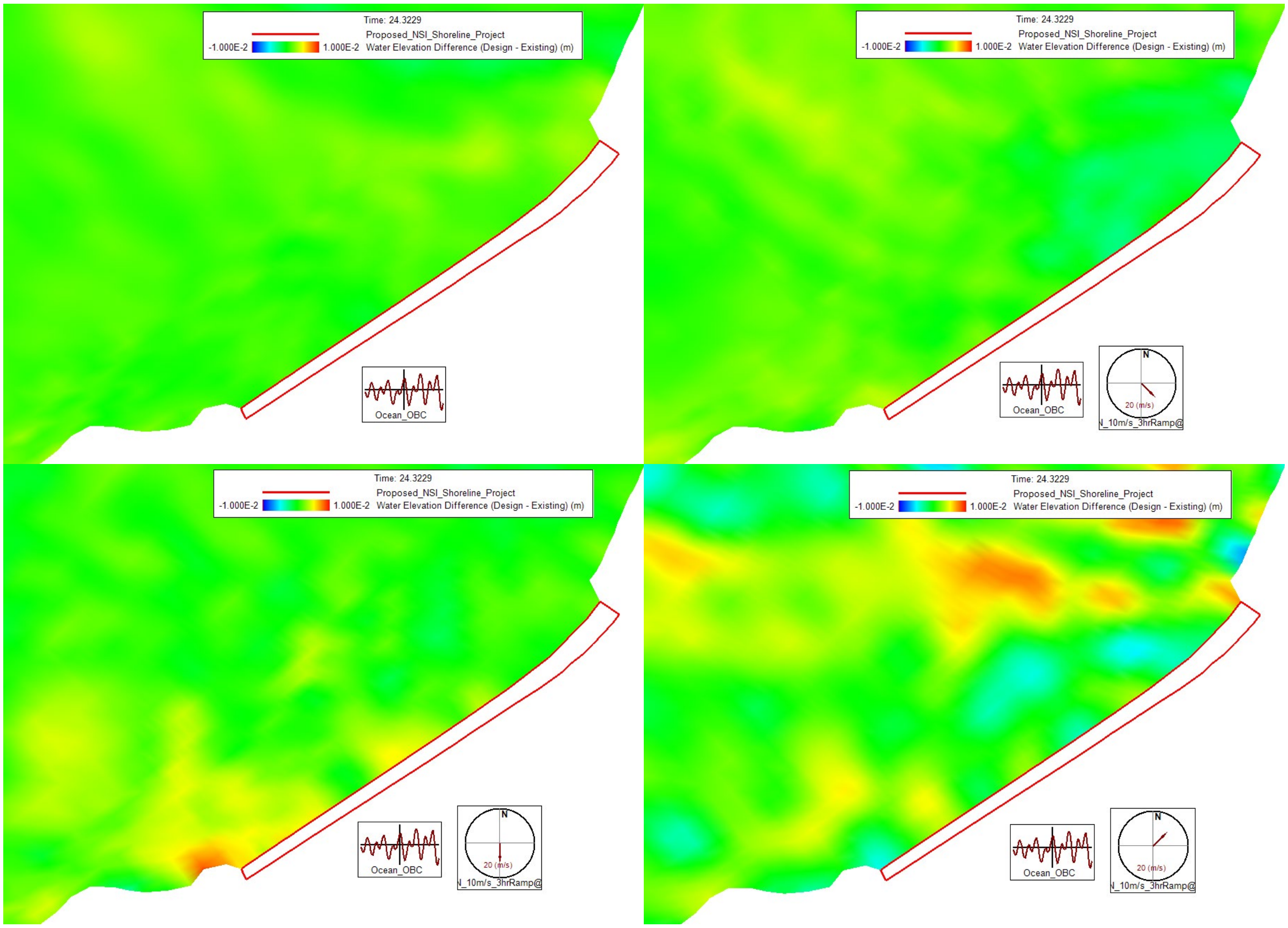


Figure 77 Difference in water surface elevation between the proposed NSI Project design and existing conditions during an approximate 2-year flood tide along the project shoreline, with no wind (top left), a 10 mps (22-mph) northwest wind (top right), a 10 mps (22-mph) north wind (bottom left), and a 10 mps (22-mph) southwest wind (bottom right). The difference is defined as design minus existing conditions, and the range of the water surface elevation differences is plus or minus 0.01 m (1 cm or 0.4 inches). Higher design conditions provide positive differences represented as warmer colors, and lower design conditions provide negative differences shown as cooler colors.

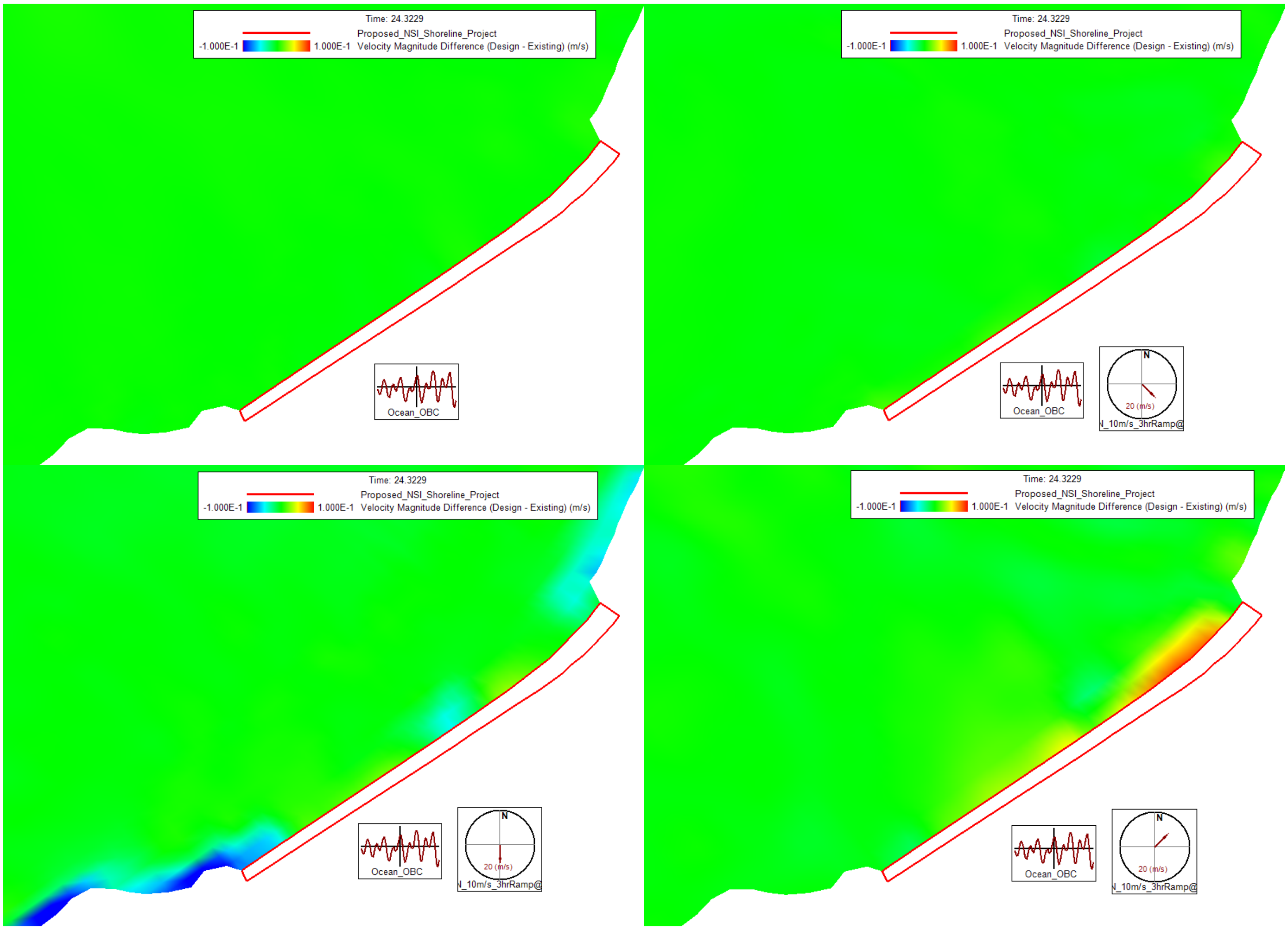


Figure 78 Difference in velocity magnitude between the proposed NSI Project design and existing conditions during an approximate 2-year flood tide along the project shoreline, with no wind (top left), a 10 mps (22-mph) northwest wind (top right), a 10 mps (22-mph) north wind (bottom left), and a 10 mps (22-mph) southwest wind (bottom right). The difference is defined as design minus existing conditions, and the range of the water surface elevation differences is plus or minus 0.1 mps (10 cm/s or 0.3 ft/s). Higher design conditions provide positive differences represented as warmer colors, and lower design conditions provide negative differences shown as cooler colors.

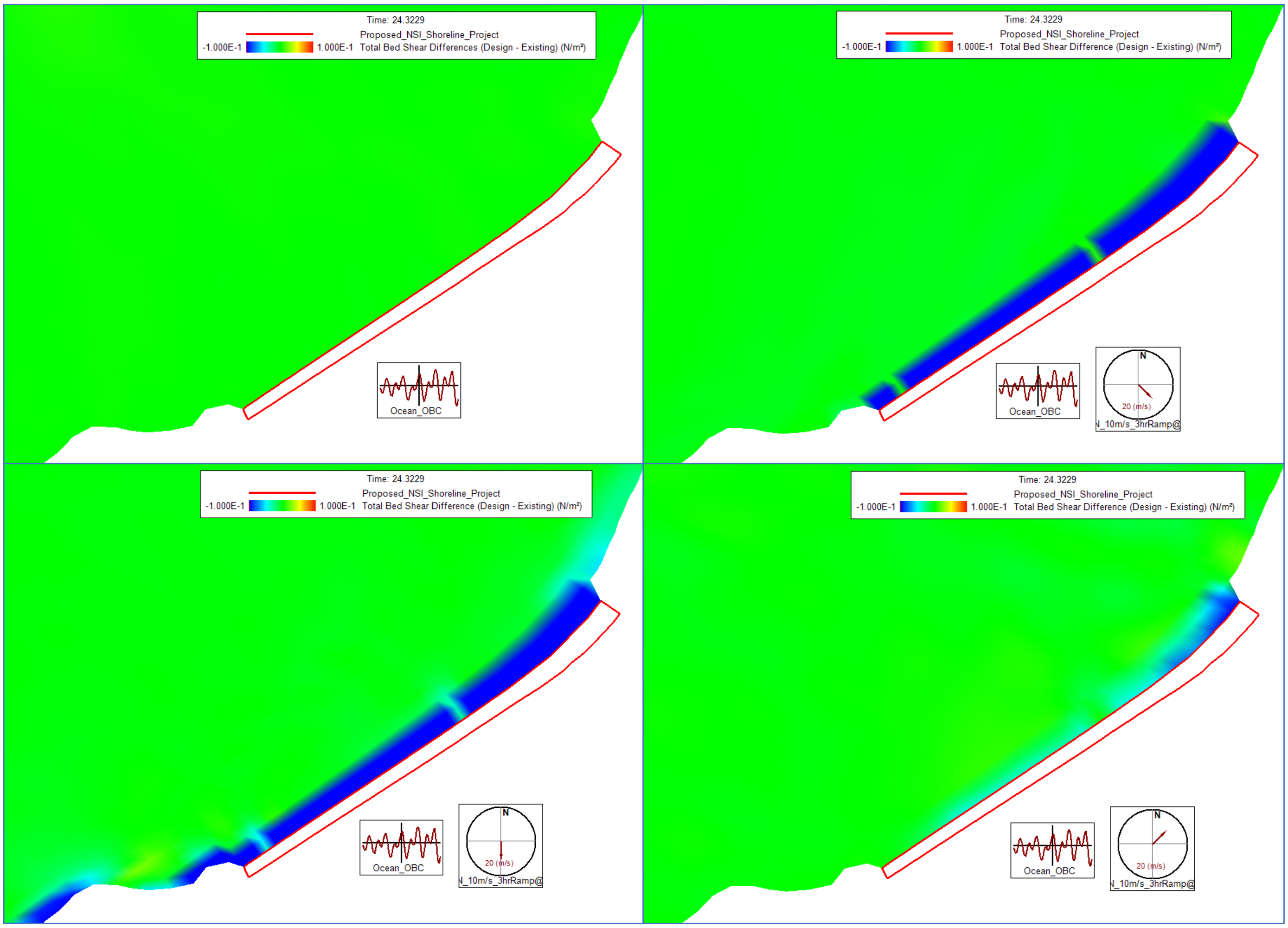


Figure 79 Difference in total bed shear between the proposed NSI Project design and existing conditions during an approximate 2-year flood tide along the project shoreline, with no wind (top left), a 10 mps (22-mph) northwest wind (top right), a 10 mps (22-mph) north wind (bottom left), and a 10 mps (22-mph) southwest wind (bottom right). The difference is defined as design minus existing conditions, and the range of the water surface elevation differences is plus or minus 0.1 N/m^2. Higher design conditions provide positive differences represented as warmer colors, and lower design conditions provide negative differences shown as cooler colors.

7.1.5.2 Tidal Channels

The tidal channel network provides important pathways for water, sediment, nutrients and species between the marsh and Bay. The density and complexity of the channel network is intended to maximize supply of fine sediment and allow for vertical accretion rates on the marsh plain to maintain pace with sea level rise. The tidal channel complexity and density shown on the 50% plans are similar to the Jacoby Marsh. The channel widths and depths were based on the contributing marsh plain drainage area obtained from the Jacoby Marsh analog. The channel sizes shown were slightly oversized to accommodate standard excavation widths using conventional equipment, as the tidal channels would be excavated into the salt marsh plain following fill placement. As the channels equilibrate following construction, some adjustment and/or infilling may occur. Alternative to excavating the channels to the full dimensions, small starter or pilot channels could be excavated to promote long-term channel formation of a dendritic network, reducing the excavation volume. Tidal drainage is likely to be adequate in the long-term with this approach but may be restricted within the first few years following construction. These options can be further assessed as the design advances.

7.1.5.3 Salt Marsh Fill

The salt marsh fill (texture and soil chemistry) should be similar to that of the existing salt marsh sediment (Appendix G). The fill would need to be lightly compacted during placement to accommodate excavation of the tidal channels and resist initial erosion during vegetation establishment. The imported fill would need to comply with the Regional Water Quality Control Board's Incremental Sampling Method (ISM) per Section 7.7.

7.1.5.4 Summary

Table 8 includes a summary of the preliminary design parameters for the salt marsh.

Table 8 Preliminary Design Parameters for Salt Marsh and Tidal Channels

Parameter	Preliminary Design
Total Marsh Width	150 feet total of which approximately 115 feet is salt marsh plain
Salt Marsh Elevation	~ 7 feet (MHHW)
Tidal Channels	Size varies based on the marsh drainage area, see design plans Excavated following placement of salt marsh fill
Salt Marsh Fill	Lightly compacted silts, clays and fine sands (similar to existing salt marsh sediment, see Appendix G) and complies with Regional Water Quality Control Board's Incremental Sampling Method (ISM) per Section 7.7
Salt Marsh Fill Volume	Approximately 85,000 cy
Revegetation	See revegetation section below

7.2 Coarse Sediment Beach Design

7.2.1 Design Objectives

The coarse beach fronting the restored salt marsh plain is intended to provide a buffer against wind-wave energy that would otherwise undercut the salt marsh habitat resulting in scarping, wave reflection and continued erosion.

The coarse beach is not intended to permanently stabilize the shoreline in a fixed position but rather provide a sloping beach face to dissipate wave energy and a local sediment source to facilitate natural evolution of the beach profile in response to future water levels and wave events. The beach will be sufficient to provide initial stabilization of the marsh edge to allow vegetation to establish across the marsh plain.

The coarse beach also provides a natural mechanism for increasing the berm crest elevation in response to storm events and sea level rise. During storm events (e.g. high tide plus wind waves) wave energy will mobilize this sediment in the onshore direction forming overwash berms along the edge of the salt marsh plain, which will provide an opportunity for high salt marsh vegetation to establish along with added wave attenuation.

7.2.2 Overview of Relevant Design Guidelines

The preliminary design of this feature is based on regional and national guidelines for nature-based coastal adaptation strategies, recent pilot projects and research in the San Francisco Bay estuary, and local reference sites. The following guidelines have been compiled from a variety of references and were used to establish the basis of design relevant to this project feature.

International Guidelines on Natural and Nature-based Features for Flood Risk Management (Bridges et al.,2021)

- Plan to let nature do most of the work when managing or implementing a beach system.
- The design should mimic or re-create the natural conditions of the location in question.

- Design of beaches should allow a degree of profile dynamism by focusing on beach slope, volume, and width as primary design parameters, rather than attempting to create a static system.
- The geology and native sedimentology of coastlines, especially the sediment grain sizes, exert considerable influence on the morphology of beaches and should inform design and sourcing for beach nourishments.

SF Estuary - New Life for Eroding Shorelines (SFEI and Baye, 2020)

- Lessons learned from Pier 94 (2006) and Aramburu Island (2011) pilot projects which included beach creation along existing and restored salt marshes.
- Multiple gradation ranges were used in the Aramburu Island project:
  - Gravels from 10 to 25mm (0.5-1 inch) sourced from in bay sand mining,
  - Oyster shell from SF Bay site,
  - ¾ to 6-inch rounded gravels and cobbles, and
  - Medium sand dredged from terminal shoal within bay.
- Volume of beach sediment placed was estimated from the range of modern reference beaches from the Central Bay and South Bay to match the scale of natural beaches in a similar coastal setting.
- Beach sand and shell hash were easily mobilized during storm events offering least resistance for the eroding shorelines at each pilot location. These materials are best suited to sheltered low-wave energy environments, swash-aligned beaches, or groin-partitioned shorelines.
- Gravels were also mobilized during storm events but mostly in the onshore direction, as storm waves created washovers across marsh flats and spread gravel berms into relatively wide and thin veneers over the rubble shore platform.
- Cobbles were mostly immobile and armored the beach platform, although Sandpipers often concentrated in these areas during high tides and foraged amongst cobbles and fine sediment during lower tides.
- Micro-groins or Drift-Sills comprised of large woody debris (LWD) were successful in retaining the coarse beach along shorelines prone to significant alongshore sediment transport.
- Gravel beach berms increased in elevation after storm events up to elevations of 7-8 feet NAVD88, relatively close to the extreme high-water elevation of 8.5 feet NAVD88.
- Sand and shell hash were redistributed into lower berm crest elevations in the 5-5.8 ft NAVD88 range.
- Coarse-medium sand beaches in San Francisco Bay typically range from 3-15 feet wide.
- Material sourcing was a major challenge and lesson learned on the pilot projects. Sourcing proper material types is recommended during the design phase and well in advance of bid advertisement.

7.2.3 Analog Sites

The nature-based design guidelines place a high emphasis on the use of reference (analog) sites as a basis for determining the type, scale, and composition of a nature-based design feature. Several analog sites within and adjacent to the Project provide evidence of the type of coarse beaches that exist along the eastern shoreline of Arcata Bay. Cross-sections 3-5 in the analog marsh survey were established to understand the beach profile slope and sediment composition of the coarse beach shoreline south of Jacoby Marsh. Figure 80 below shows the location of cross sections 4 and 5 and the approximate beach slope is near 20% (5:1, H:V) at this location. Cross-section 3 (XC3), located within the Project reach, was shown earlier in Figure 61 has a slightly flatter beach slope of approximately 15% (~7:1, H:V).

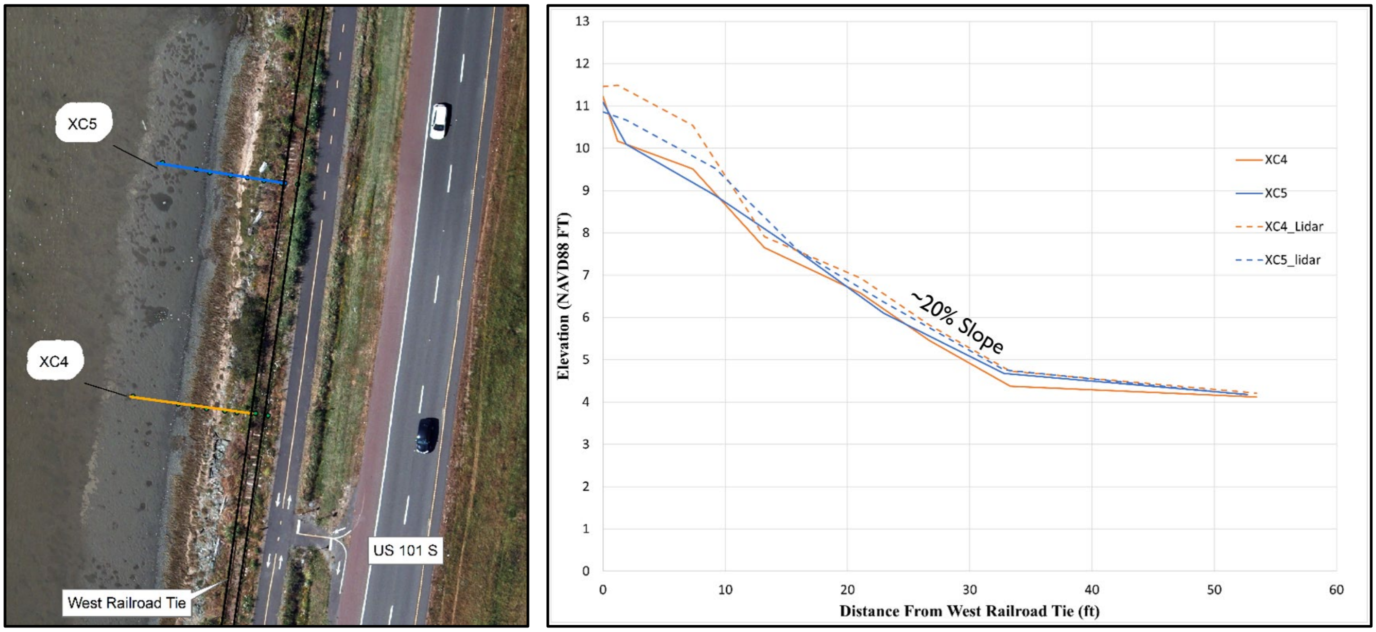


Figure 80 Location of analog cross-sections 4-5 between Brainard Slough and Jacoby Creek Marsh.

Previously shown Figure 67 provides a comparison of the slope and composition of the analog shorelines where a coarse beach persists within or near the project site. These sites each exhibit slightly different characteristics with cobble dominant beaches having steeper slopes than gravel dominant beaches. Given the long trend of erosion along the project reach there is little or no sand remaining, except for a small pocket beach at the south end of the project reach, sheltered by the armored shoreline at Brainard (Figure 81-C).

The different characteristics provide an indication for the sediment transport capacity of the project shoreline. These reference sites illustrate that sand will be easily mobilized within the project reach with the potential for bi-directional transport, although it appears the net transport direction is from north to south. The cobble dominant beach at Bracut (Figure 81-A) has been relatively stable despite the limited supply of coarse-grained sediment to this shoreline, demonstrating a gradation of cobble & gravel that is more resistant to wave-driven sediment transport. The gravel dominant beaches (Figure 81-B/D) have been shaped by waves and tides and demonstrate a gradation of gravel and sand that can be mobilized by waves and currents but is more likely to remain within the project reach over longer durations. A significant source of gravel along these beaches appears to be eroded railroad ballast with typical diameter in the 0.5” to 2” size range.

Figure 81 Coarse Beach Analog/Reference Sites

7.2.4 Preliminary Basis of Design

The preliminary design of the coarse beach consists of a coarse sand and gravel beach fronting the salt marsh. The design intent includes an optional cobble berm along the marsh edge to provide containment for hydraulically (pumped dredged spoils) or terrestrially (land-based equipment) placed fill and equipment access to the marsh edge (if needed). The cobble berm will be fronted by a gravel/sand beach designed to respond to wind-driven storm waves, resulting in a dynamic buffer against erosion and wave runup along the marsh edge. Preliminary design information is provided in Table 9 although the design specifics will depend upon a material sourcing investigation to be performed as part of the detailed design process.

Table 9 Preliminary Coarse Beach Design Parameters

Parameter	Preliminary Design
Avg particle size (d_{50}) for coarse beach material	Sand, 0.1 – 0.3 mm Gravel, 10 - 25 mm (0.5 – 1 inch) Cobble, 2 – 6 inches (for barrier berm)
Crest elevation	Coarse beach, same as marsh plain elevation (~7 ft NAVD88) Cobble berm, 12-18 inches below marsh plain elevation
Beach slope	Estimated equilibrium slope, 10-15:1 (H:V) Constructed slope could be steeper than equilibrium slope, 3:1 to 5:1 (H:V)
Unit Volume (cubic yards/foot of shoreline)	Coarse Beach, 5 – 7 cy/ft Cobble berm, 3 – 5 cy/ft

The design of the coarse beach is intended to provide a self-maintaining erosion buffer for the restored marsh edge. Based on performance of similar coarse-grained beaches in the San Francisco Bay, transport of coarse beach sediment over the marsh edge during storm events can be expected, increasing the elevation of the marsh edge and providing an opportunity for recruitment of high marsh vegetation to further enhance wave attenuation. However, the longevity of this feature depends on the rate of coarse sediment transport to and from the project area which is subject to a variety of parameters and considerable uncertainty around future conditions. Movement of coarse sediment alongshore, as observed under current conditions, will be somewhat hindered by proposed micro-groins discussed below, but these are not intended to be complete barriers to alongshore coarse sediment transport. Re-nourishment of the coarse beach may be desirable at future intervals depending on the outcome of the monitoring program which will reduce the uncertainties associated with sediment transport within and outside the project area.

7.3 Large Woody Debris (LWD) Groins or Drift-Sills

7.3.1 Design Objectives

These features are designed to limit excessive erosion and loss of the coarse sediment downdrift to provide a reliable buffer against erosion of the marsh edge. The LWD groins also referred to “drift-sills” can also help stabilize the shoreline and limit accretion and shoaling of the tidal inlet channels which are important for the salt marsh restoration and long-term resiliency. LWD groins are not intended to be complete barriers to sediment transport. The spacing of LWD groins will be sufficient to permit significant movement of sediment within each of the compartments, control exchange of sediment between compartments, and help to minimize sediment accumulation in the tidal channel inlets.

7.3.2 Overview of Relevant Design Guidelines

The nature-based guidance documents summarized in Section 7.2.2 are most applicable to this project feature. *New Life for Eroding Shorelines* (SFEI and Baye, 2020) provides lessons learned from several restoration projects in the San Francisco Bay estuary. The Aramburu Island project included several “micro-groins” or drift-sills comprised of large woody debris (LWD) which were successful in stabilizing the coarse beach shoreline and maintaining an erosion buffer for the marsh edge.

7.3.3 Project and Analog Sites

Based on the wind and wind-wave assessment, the coarse beach will be exposed to wind-waves and wind-driven currents from both north and south directions. An evaluation of sediment movement along the existing project shoreline and analogs indicate that the net sediment transport direction may be from north to south. However, periodic reversals are expected when strong southerly wind events coincide with high tides. The coarse beach will be designed with a variety of sediment sizes. Sand size particles will be more easily mobilized by waves and currents than gravels and will likely be transported in both alongshore and cross-shore directions.

LWD groins, also referred to as drift-sills, are proposed to compartmentalize the lengthy Project reach and stabilize the shoreline at each of the salt marsh tidal channels. LWD groins were implemented successfully on the Aramburu Island project (Figure 62 previously shown), particularly in segments prone to significant alongshore sediment transport.

7.3.4 Preliminary Basis of Design

The preliminary design of the LWD groins was based upon the successful application of LWD groins to stabilize the Aramburu Island shoreline with adjustments in the dimensions and spacing to account for project specific conditions. Preliminary design information is provided in Table 10 although the design specifics will be subject to refinement as part of the detailed design process.

Table 10 Preliminary Design Parameters for LWD Groins

Parameter	Preliminary Design
Length	30 – 50 feet in length, oriented approximately normal to the shoreline Approximately 3/4 of the groin length will be embedded/buried in the coarse beach/cobble barrier berm
Height	3-5 feet above existing mudflat. Top of log groin at or slightly below marsh elevation at back beach
Materials	Each LWD groin consists of 3-5 logs, 20-40 feet in length Pinning logs (4) used to anchor LWD Douglas Fir, Redwood or cured/seasoned Eucalyptus logs Cobble berm (~1/2 groin length) used to backfill & stabilize base of groin
Spacing	Varies from 600 to 1,000 feet and subject to refinement in detailed design and tidal channel network

7.4 Transition Zone (High Marsh Ecotone) Design

7.4.1 Design Objectives

The primary objective of the transition zone, also referred to as a high marsh ecotone, is to provide a gradual transition from the salt marsh plain (~ 7 foot elevation) to the rail prism top (11.5 foot elevation). The transition zone will accommodate vegetation transgression (migration) overtime with sea level rise. During extreme storm events (e.g. high tide plus wind waves) wave energy will be attenuated on the transition slope.

7.4.2 Overview of Relevant Design Guidelines

The preliminary design of this feature is based on regional guidelines from the San Francisco Bay estuary, and application on local restoration projects. The following guidelines have been compiled from a variety of references and were used to establish the basis of design relevant to this project feature.

Design Guidelines for Tidal Wetland Restoration in San Francisco Bay (PWA et al, 2004).

- Maximum slope of 10H:1V
- Recommended minimum width of 100 feet to provide sufficient refugia for wildlife during extreme tides
- Seeding and planting can prevent colonization of non-native vegetation and diversify species composition
- Soil texture should be suitable to support desired vegetation

Restoring Healthy Transition Zones to Benefit Tidal Marsh Wildlife in San Francisco Bay (Point Blue Conservation Science, 2017).

- Recommended minimum width of 75 feet
- Maintaining minimum of 15% in dense vegetation is beneficial to tidal marsh birds
- Vegetation communities including grasses are important to tidal marsh birds

7.4.3 Project and Analog Sites

Gradual slope transitions from salt marsh to uplands are uncommon around Humboldt Bay as much of the shoreline has been altered and consist of modified, abrupt transitions. However, two analog sites, one within the project area and one nearby (Figure 82) provide evidence of the potential native vegetation composition within the elevation range of the proposed transition zone. These sites each exhibit slightly different characteristics and vegetation species, but demonstrate that native vegetation can establish and persist within the transition zone.

Figure 82 Analog High Marsh Ecotone Transition Zone at Arcata Marsh I Street Parking Lot (left) and northern portion of project area (right).

7.4.4 Preliminary Basis of Design

The preliminary design of the transition zone consists of fill placement to create a transition zone from the salt marsh plain to the rail prism. Preliminary design information is provided in Table 11, although the design specifics will depend upon a material sourcing investigation to be performed as part of the detailed design process. In some locations, the fill will be placed directly over the existing rail prism rock slope protection (RSP). To prevent long-term migration of the fill into the rock voids, care will be required during the placement to adequately backfill rock voids. To provide the maximum tidal wetland bench width within the overall project footprint, the width of the proposed transition zone is less than recommended in the referenced design guidelines.

Table 11 Preliminary Design Parameters for Transition Zone

Parameter	Preliminary Design
Width	35-40 feet
Slope	10-15H:1V, extending from rail prism (11.5ft elevation) to salt marsh plain (~7 ft elevation)
Transition Fill	Same or similar to salt marsh fill however would need to be non-saline to support the desired vegetation
Transition Fill Volume	Approximately 40,000 cy
Revegetation	Place seed, biodegradable rolled erosion control netting, and then container plantings, see revegetation section below.

Given most of the transition slope is supra-tidal, establishment of vegetation will require active revegetation through recommended native seed application, placement of biodegradable rolled erosion control netting, and container plantings which will help inhibit non-native vegetation colonization. The transition zone is inherently a weedy area and is anticipated to require initial maintenance to established native vegetation communities. The design and revegetation of the transition zone is intended to provide a self-maintaining buffer between the salt marsh plain and rail prism top. Based on performance of similar transition zones on local restoration projects, routine non-native vegetation removal will be required initially to support long-term native dominance.

7.5 Revegetation

The project will rely on both passive (natural recruitment) and active (plant installation) revegetation to establish the desired native plant species. The 50% Design Plans show the revegetation approach which is described below. To increase success of native revegetation and reduce spread of non-native and invasive plant species into the restored areas, removal of invasive species within the project area is recommended prior to construction.

7.5.1 Invasives and Non-Native Plant Removal

Invasive and non-native species including dense-flowered cordgrass (*Spartina densiflora*), Himalayan blackberry (*Rubus armeniacus*), fennel (*Foeniculum vulgare*), hemlock (*Conium maculatum*), and pampas grass (*Cortaderia jubata*) have been observed throughout the project area. Approximately 1.1 acres of existing salt marsh within the project area is infested with moderate- to high-density Spartina. Given the relatively small area, removal of Spartina is recommended prior to construction by use of hand-held brush cutters, a technique that has proven to be effective at grinding the rhizomes below ground level (HT Harvey & GHD, 2013, Mateos-Naranho et al. 2012, Eicher and Pickart 2011, Pickart 2012). Following initial removal of Spartina, a second removal will likely be necessary to remove resprouts and seedlings. The other above-mentioned non-native species could also be removed prior to construction by hand equipment or during construction with mechanical equipment. To reduce spreading, removal shall be completed prior to or following the seed-set period when seeds are viable which is typically between late July through October.

7.5.2 Rare Plant Salvage

Three rare salt marsh plants have been observed in the project area as shown the 50% Design Plans and include Humboldt Bay owl’s clover, Point Reyes bird’s beak and Western sand spurrey, which are all annuals. Both Humboldt Bay owl’s clover and Point Reyes bird’s beak are hemiparasitic, in that they photosynthesize as well as parasitize other salt marsh plants by tapping into the xylem of the host plant via haustoria (Grewell 2008, Eicher and Schlosser 2012). Intact marsh habitat with these rare plants will be avoided during construction to the greatest extent possible. If an area with rare plants cannot be avoided, the rare plants along with their host plants will be salvaged using hand tools and small mechanical equipment to harvest and transplant the intact plant materials within the restored areas. A similar approach is planned for the Elk River Estuary Restoration Project in Fall 2022 which could help inform methods applied to this project.

7.5.3 Salt Marsh Plain Revegetation

Passive (natural recruitment) of native salt marsh species is the primary revegetation approach for the salt marsh plain. This approach has been widely applied throughout salt marsh restoration projects in Humboldt Bay and the Eel River Estuary and shown to be effective at appropriate marsh plain elevations. Native species including pickleweed (*Salicornia pacifica*) and salt grass (*Distichlis spicata*) are expected to naturally recruit and revegetate in the marsh plain and will not be actively salvaged or planted. Given the abundant seed source and dispersal in Humboldt Bay, recolonization of Spartina on the marsh plain can be anticipated and will require follow-on removal of resprouts.

7.5.4 Transition Zone (High Marsh Ecotone) Revegetation

Given the infrequent inundation and seed dispersal potential of the higher elevation zone, the transition zone (approximately 6.1 acres) will be actively planted with coastal prairie grassland species using two approaches. Immediately following construction, a native seed mix will be hand-broadcast or hydroseeded on the transition slope and covered with biodegradable coir netting to retain seed-soil contact and prevent seed dispersal and desiccation. The proposed seed mix is shown in Table 12 and consists of native species observed in the transition zones of the analog sites.

Table 12 Proposed Transition Zone Seed Mix

Common name	Scientific name	Lifeform	Pure Live Seed (PLS) Lbs/Acre
Cows clover	*Trifolium wormskioldii*	Perennial herb	1.0
Salt rush	*Juncus lescurii*	Perennial rush	1.5
Marsh gumplant	*Grindelia stricta*	Sub-shrub	2.0
Meadow barley	*Hordeum brachyantherum*	Perennial grass	15.0
Pacific aster	*Sympotrichium chilense*	Perennial herb	0.1
Seacoast angelica	*Angelica lucida*	Perennial herb	2.0
Tufted hairgrass	*Deschampsia caespitosa*	Perennial grass	12.0
		Total	33.6

During the winter and early spring following construction, the transition slope will be planted with native container plants (plugs and/or live cuttings). The proposed species with approximate spacing is shown in Table 13. While the proposed species support a coastal prairie/grassland habitat type, additional native coastal scrub-shrub species such as California Wax Myrtle (Morella californica), Coyote Bush (Baccharis pilularis), Shore Pine (Pinus contorta), California Blackberry (Rubus ursinus) amongst others could be considered. The species and spacing will be selected during the final design. Adequate lead time, commonly one year for a project of this scale, is necessary for planning and procuring native plant seed and cuttings to source and nursery propagate the vegetation plugs for outplanting.

Table 13 Proposed Transition Zone Container Plug Planting Species and Spacing

Common name	Scientific name	Average Spacing (feet)	Percent of Total
Coastal gumplant	*Grindelia stricta* var. *stricta*	3	10
Pacific aster	*Symphyotrichum chilense*	3-4	10
Pacific silverweed	*Potentilla anserina* ssp. *pacifica*	2-3	25
Salt rush	*Juncus lescurii*	3	20
Seacoast angelica	*Angelica lucida*	4	10
Tufted hair grass	*Deschampsia caespitosa* ssp. *beringensis*	3	25

7.6 Interpretative Viewing Areas

Potential interpretive viewing areas have been shown on the project plans and support Project Goal 3: *Create opportunities for innovation and learning*. The viewing areas would be located on the upper portion of the transition zone and could include benches and interpretive signs. Access to the viewing areas from the trail would require crossing the filled rail prism. Considerations for this future use, size and location of the viewing areas would need to be assessed as part of the subsequent design.

7.7 Construction Phasing and Sediment Sourcing

7.7.1 Construction Phasing

The project has been designed to accommodate implementation within either a single construction phase should all material, including fine-grained sediment be available, or through multiple phases/years to accommodate incremental placement that could, for example, align with beneficial reuse of future dredge cycles. The project is envisioned to be constructed from north (Bracut) to south (Brainard) as shown on the 50% design plans. Given the unknown sources and timing of available salt marsh fill, the plans show a southward sequence to implement multiple (nine) phases or “cells” which accommodates incremental construction overtime. The “cells” are delineated at salt marsh divides by barrier berms that would provide containment and stability of the placed marsh fills between phases. The barrier berms are shown as optional, and placement will depend on the contractor’s means and methods of material placement and type. The barrier berms are intended to provide a barrier that maintains a dewatered work area during salt marsh fill placement as well as elevated haul routes to transport imported materials to the final destinations. The barrier berms are intended to remain in place and have been designed to be compatible with the long-term evolution of the salt marsh edge and beach.

A potential variation to the construction approach described above would be to construct the barrier berms and allow natural recruitment of fine-grained sediment to accumulate within each cell naturally forming the tidal wetland. Another option would be to partially fill each cell to an intermediate elevation, that would allow natural tidal channel formation as the wetland gained elevation over time through natural deposition. The time required for the tidal wetland to reach equilibrium elevations for both of these options is not known.

Three approaches for project implementation are possible:

1. The project could be constructed over the entire project area during one mobilization and construction contract. The CEQA document and permits would include the entire project. This approach would likely be the most cost-effective and would allow the project benefits to be realized within the shortest timeframe.
2. The first phase of the project could be constructed as a pilot test (also known as “demonstration project”). This approach may be desirable if funding for the full project is not readily available. This approach would provide an opportunity to monitor the response of the natural system to the proposed improvements and identify opportunities to refine or modify the construction process; these lessons could be incorporated into the implementation of subsequent phases. The CEQA document and permits would include Phase 1 only. The lead agency and project partners could base their decision on whether or not to proceed with subsequent phases based on the results of the pilot test. A visual simulation of the Phase 1 portion of the project is provided in Figure 83.
3. The project could be planned using a hybrid approach in which the CEQA document and permits include the entire project but the project is constructed in phases over time, perhaps over several years, as funding and sediment become available.

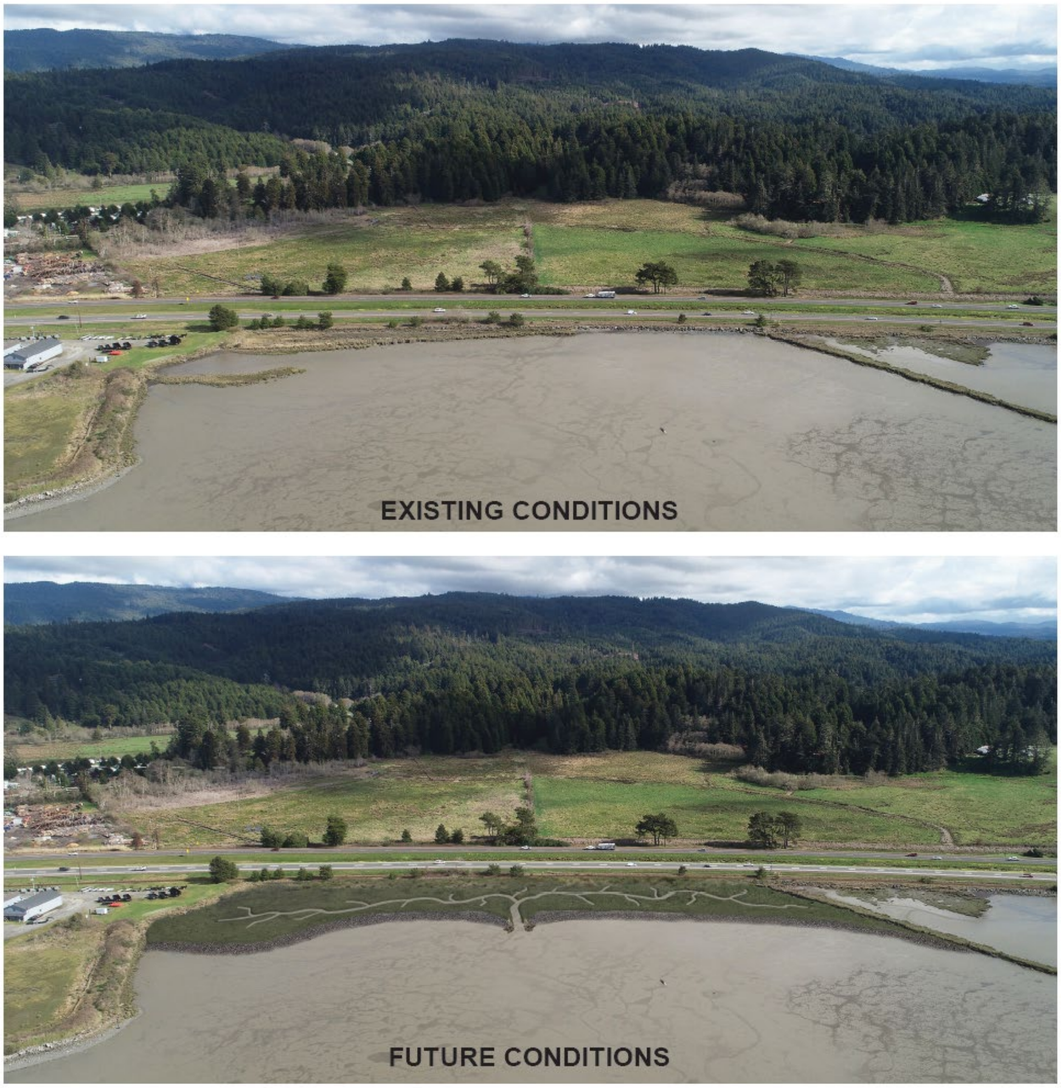


Figure 83 Visual simulation of Phase 1

7.7.2 Construction Access and Staging

The project area would be accessed from one of two established driveways off Highway 101, including Bracut Industrial Park and Brainard. Temporary stockpile and staging areas could be established at both locations. These areas are privately owned and would require authorization of use and appropriate agreements. The size and use of the staging areas would depend on the construction phasing and potential need for stockpile and material storage. Material could be transported from the staging area to the final placed locations using the existing rail prism and barrier berms. As part of the Humboldt Bay Trail South Project, the rail prism will be elevated with aggregate base to elevation 11.5 feet (NAVD88).

7.7.3 Sediment Sourcing and Testing

The sources of sand/gravel and cobble are readily available and can be procured from nearby sources. However, the source of fine-grained sediment to construct the salt marsh is currently undefined. Sources could include dredge spoils currently stockpiled at the Harbor District's dredge disposal site near Highway 255 bridge, dredge spoils from future dredge cycles, reuse from future local restoration projects, and other currently unidentified sources. As part of the planning process to identify suitable sediment sources, the project should anticipate adherence to fill placement requirements as part of the Water Quality Certification (401) issued by the North Coast Regional Water Quality Control Board. Prior to fill placement, the onsite sediment and imported materials will require testing for comparison. The following sampling methods and tests are anticipated and were required prior to imported fill placement at the White Slough Restoration Project (WDID No. 1B15030WNHU).

<u>Preliminary Sampling, Testing, and Analysis of Onsite Sediment and Imported Fill</u>

1. Sample material using the Incremental Sampling Method (ISM).
2. Analyze for total concentration levels of Cam 17 metals, PAHs, PCBs, Pesticides, Dioxins/Furans, TPH and values for pH, TOC, and sediment texture.
3. Conduct modified Deionized Water Waste Extraction Test (Di-WET) test on soluble and mobile constituents that are elevated above the receiving site and analyze for soluble concentrations.

If all levels of fill constituents are below those of the receiving site, the fill material will meet suitability requirements. If imported fill constituent levels exceed receiving site levels for specific chemicals, exposure toxicology would need to be further assessed as outline below to ensure imported fill material is suitable for these beneficial uses and is compatible with species associated with the re-established aquatic habitats.

<u>Supplemental Toxicological Testing and Analysis</u>

1. Compare elevated import fill results with NOAA Screening Quick Reference Tables (SQuiRT) for preliminary screening for potential risks levels.
2. If imported fill constituent levels exceed receiving site values, conduct sediment exposure toxicology assessment with 10-day acute bioassay using appropriate sensitive organism representative of three life history stages (filter-feeding, burrowing, and deposit feeding) of appropriate benthic aquatic species, using imported fill sediment. (US Army Corps Inland Testing Manual protocol).

7.8 Opinion of Probable Construction Cost

Opinions of probable construction cost (OPCs) were developed for both the entire project and the Phase 1 portion only based on the 50% design plans and quantities. These OPCs are very preliminary but can be used for planning and budgeting purposes. The OPCs are available in Appendix J. Each OPC consists of a combination of estimated labor, equipment, and materials necessary to implement the current design. An estimating contingency was included in the OPC to account for material and construction cost volatility and uncertainties given the early planning phases of this project. OPC unit costs are based on recent bid results of similar projects and the basis of professional experience. Construction costs associated with tidal marsh restoration projects are difficult to estimate given the unique nature of work and lack of applicable industry standard construction estimating resources, such as RSMeans data. Site conditions such as a tidal exchange and the presence of threatened and endangered species increase construction costs. The risks associated with working in these environments are much higher relative to typical construction projects. Project construction costs are subject to variations in contractor bidding, labor rates, material costs and availability, permitting conditions, site accessibility, general economic pressures, and other unforeseen costs associated with a project in the current planning level. Given these potential variations, GHD or the Project Team makes no warranty, express or implied, that actual project costs will not vary from the provided OPC.

The total construction cost is extremely sensitive to the unit cost to procure, transport and place sediment to create the salt marsh. Two unit costs were used to provide a lower and upper range of total construction cost. The lower unit cost assumes the sediment delivery cost is covered by the source project/entity and the upper unit cost reflects procurement and transport costs. The upper range would reflect land-based (i.e. trucks) transporting within a 10-mile radius or aquatic-based transport (i.e. pumped dredge spoils) from within the bay. The costs also assume a single construction season. Multiple construction seasons to accommodate phased construction would require additional mobilization/demobilization and construction administration costs. Costs associated with the remaining planning, engineering, environmental compliance, and construction management were included as percentages of the total construction cost. Additionally, a range of post-construction monitoring and management costs for 3-years following construction were also included and assumed limited management actions to maintain the project. As the design and regulatory approval processes advances, these costs should be re-assessed to account for inflation.

8. Monitoring and Management Framework

Given the pilot nature of this project, the variety of habitats and hydrologic conditions, the high initial disturbance to the ecosystem, interactions with tidal conditions, and typical level of uncertainty associated with the evolution of ecosystem restoration projects, the project would benefit from a monitoring and management program. The project is designed to be self-sustaining; however, there are inherent uncertainties associated with natural, dynamic processes. As a result, some interventions may be needed for the project to remain on trajectory to meeting goals and objectives.

A monitoring and management program would be a systematic and iterative process that provides for feedback between monitoring and management actions. The feedback mechanism would be engaged when monitoring data are analyzed, and the results are utilized to adjust project operations in a manner that optimizes the achievement of project goals.

A monitoring and management program would assume a level of uncertainty with respect to the range of potential changes associated with restoration activities. This would essentially be an iterative process by which scientifically driven, hypothesis-based decisions are brought forward in a management plan context, and information gained through plan implementation is then used to refine and improve the original decisions, in a positive feedback loop.

A monitoring and management program would employ a structured approach, yet it is also a flexible tool that can adjust to a dynamic environment and an evolving project. The program would thereby keep a project ‘on track’ toward meeting its goals and objectives, despite the variability inherent in dynamic, natural systems over spatial and temporal scales. The program would assist managers in responding to unanticipated changes in the various components of a project such as hydrology, sedimentation, target habitat development, or changes in the species’ response along a restoration trajectory.

A monitoring and management program would be driven by the project goals and objectives together with the regulatory permit requirements. The process would include identification of initial monitoring activities proposed to evaluate project progress towards meeting the goals and objectives, establishment of triggers or thresholds that would initiate a management response and predicted ranges of potential adaptive management actions. If monitoring determines that a trigger has been “activated,” three possible response pathways would result:

1. Determine that more data is required and continue (or modify) monitoring;
2. Identify and implement a remedial action; or
3. Modify project goals and objectives (this option would *only* be considered as a last resort and upon careful consideration by and consensus of project participants).

Monitoring is a key component of long-term project success and replication the pilot project elsewhere through Humboldt Bay and beyond. The development of baseline data would allow triggers, even if rudimentary, to be developed which are integrated into the overall environmental monitoring program. If triggers are exceeded, potential impacts can be reviewed and the flexible mitigation plan can be adapted to limit the observed impacts.

Under a monitoring and management program, there may be multiple management action options when a particular trigger or threshold is activated, depending on a variety of factors such as how far the project is from achieving a specific goal, whether the situation is an imminent threat to local infrastructure, ecosystem services/functions, or site stability, etc. The monitoring and management process would apply to the project as a whole, but management actions can be identified and implemented on individual reaches or sub-reaches, as needed. The process is flexible as it allows for a wide range of management actions but just as importantly it imposes a structured approach as management actions must derive from monitoring results. The process also accommodates different physical and temporal scales for management actions.

At a minimum, the program would need to address mandatory compliance monitoring. The program would need to be crafted flexibly as not to unintentionally hinder advancement of implementation planning and construction.

Recommended components of a monitoring and management plan for the project would include:

- Monitoring and management goals, objectives, and thresholds for action;
- Roles and responsibilities, describing who is responsible for funding, implementing, and reporting adaptive management monitoring and results;
- A detailed monitoring plan for each discipline (e.g., geomorphic response, revegetation success, fish use, etc.), including field and analytical methods as well as thresholds and/or triggers for adaptive management;
- A site plan depicting the location(s) of proposed annual maintenance and/or management activities, including applicable APNs and property owner names for all proposed work sites and associated construction areas;
- A description of the type(s) of proposed annual management activities;
- Cross sections, maps, and associated calculations as necessary that accurately depict the proposed annual maintenance/adaptive management work area(s);
- Any necessary biological and botanical surveys needed for approval of annual maintenance/management activities;
- Site specific revegetation objectives, specific to the timeframe of the adaptive management plan (e.g., 5 to 10 years); and
- A schedule for proposed annual maintenance/adaptive management activities.

The overall project objective is to use natural shoreline infrastructure to promote habitat restoration and reduce coastal flood risk for the Eureka-Arcata Highway 101 transportation corridor. The monitoring program described in this section provides a unique opportunity for innovation and learning (Project Goal #3) that will benefit local and regional partners looking for solutions to similar coastal challenges. The key questions the monitoring and management program will attempt to answer include:

- How has the salt marsh and supporting natural systems (coarse beach, LWD groins and transition slope) adjusted to waves and water levels over the monitoring period?
- Does the restored salt marsh and supporting natural systems provide habitat of similar value as nearby reference sites?
- Does the natural shoreline infrastructure provide effective coastal flood protection for the transportation corridor?
- Will the natural shoreline infrastructure be resilient and able to respond to sea level rise and future storms without the need for significant intervention?
- What are some lessons learned that can be applied to similar projects?

Development and implementation of a monitoring and management plan would likely be requested by the regulatory agencies. The final monitoring and management plan would be consistent with CEQA, NEPA, permitting, final design requirements and level of long-term commitment or obligation by the project lead. Following are potential monitoring and management measures that could be anticipated.

8.1 Physical Monitoring

The physical monitoring program will include surveys, field observations and data collection to document and measure the changes observed within the natural shoreline infrastructure project area and at marsh control sites. Jacoby Marsh and Eureka Slough could be monitored to compare Project performance against established marshes subject to similar meteorological and oceanographic conditions. The overall post-construction monitoring period is assumed to be 5 years. The following sections summarize the monitoring parameters, sampling methods, and analysis approach.

8.1.1 Topographic Surveys and Aerial Imagery

The restored salt marsh and supporting natural systems will be monitored on an annual basis using data collected from unmanned aerial vehicle (UAV) surveys. The UAV should be capable of collecting both high resolution ortho-imagery, LiDAR data or elevation measurements sufficient to produce a digital elevation model (DEM) of the project area. A baseline survey would be conducted soon after project construction to establish the reference data for comparison purposes to subsequent monitoring surveys. Additionally, Surface Elevation Tables (SETs) could be placed on the marsh plain to monitor fine sediment accretion rates that may not be detectable with conventional topographic surveys. The collected data will be used to measure the following parameters and analyses:

- Marsh accretion rates: used to evaluate sediment supply / adaptability of marsh to SLR
- Tidal channel morphology: used to inform the design & sizing of future projects
- Shoreline change: used to analyze coarse beach dynamics / adaptability to storm events & SLR
- Sediment transport potential: used to analyze the potential need for coarse sediment nourishments
- Erosion of backshore/ecotone slope: used to analyze level of protection for transportation corridor

8.1.2 Field Observations

Field observations will be performed in conjunction with the survey monitoring to provide ground photographs to supplement the aerial imagery and survey data. Additional field observations will be performed to document significant coastal storm events which occur when high tides coincide with significant wind waves. These events will be documented with photographs and data collection (described below) to characterize each event. We anticipate the need to monitor 3-5 events in the first year after construction, with frequency in subsequent years adjusted based on the observed changes.

8.1.3 Data Collection

The physical monitoring efforts described above will be supplemented with collection of water level, wind speed and wave data. This data will be analyzed to document the metocean conditions during each monitoring period for correlation to the observed physical and biological monitoring results. Water level data will be downloaded from the North Spit gage (NOAA Station 9418767) and corrected for site specific location based on established hydrodynamic relationships. Wind speed data will be downloaded from publicly available sources such as the monitoring station at Eureka Airport or NOAA Station 9418768 (North Jetty Landing, California). The water level and wind data will be analyzed to estimate the wind wave characteristics and total water levels (TWLs) experienced over the monitoring period.

An optional feature of this data collection effort would be the installation of pressure sensors or other instruments near the project site to provide site-specific measurements of waves and water levels. Depending upon the instrument used, currents may also be measured. Although not essential, the measurement of site-specific wave, water level and current data would provide thorough documentation of the hydrodynamic forces driving physical changes within the project area.

8.1.4 Success Criteria and Management Decisions

The physical monitoring will be evaluated based on the project’s ability to naturally respond to waves, water levels and currents while still providing valuable marsh habitat and protection for the transportation corridor. Based on the outcome of the physical monitoring program, project proponents can better estimate the long-term viability of the marsh in adapting to SLR and what adaptation measures (if any) would be required to improve the performance and sustainability over longer time periods. Comparison of the Project performance to established marshes in Humboldt Bay will also inform potential strategies to improve Project performance, or vice versa. There may be elements of the Project that could be applied to established marshes to improve their longevity or ecosystem value. The final management plan would include potential triggers that if observed through monitoring would provide a pathway to implement management actions as needed such that project would maintain trajectory for meeting long-term goals and objectives. For example, a management actions could include adjusting or adding additional LWD groins to slow alongshore course sediment transport, adjust marsh elevations or tidal channels, nourish the coarse beach, etc.

8.2 Vegetation Monitoring

Vegetation monitoring will likely be conducted annually post-construction and will include the results from annual *Spartina* resprout surveys and increases in native plant cover. Monitoring will be conducted for an anticipated five years to visually estimate *Spartina* resprout cover and native plant cover using Rapid Assessment methods and/or transects.

Monitoring efforts will begin with a report documenting the success of *Spartina* removal after the second year of treatment. *Spartina* cover will be compared to pre-removal conditions using a combination of photo-monitoring, transects, and/or rapid assessments. Rapid assessments of native plant cover may be utilized if trampling in the restoration area is detrimental to plant establishment and topsoil retention.

8.2.1 Transects with Quadrats

Transects will be located randomly within the created wetland and transition slope areas. The location of the first quadrat will be randomized relative to the beginning of the baseline, with quadrats at set distances thereafter. Percent absolute vegetative cover, non-wetland native cover, hydrophytic cover, and non-native or invasive cover will be estimated within each quadrat. Plant species present within each quadrat will be identified and noted.

If the use of transects is determined to be detrimental to seedling establishment, rapid assessment estimations of plant cover may be used instead. In the summer of years one (pre-construction), and two through five, target invasive plant cover will be calculated from the data collected, as described above. For each year of data collection, the percent cover of invasive species will be compared.

8.2.2 Photo Monitoring Stations

Permanent photo-documentation points will be established along the restoration area. Photographs will be taken annually during the monitoring period and cardinal directions recorded for repeatability. Photos will be taken with a digital camera with a moderate wide-angle lens. The make and model of camera and type and focal length of lens will be noted in monitoring documentation. Photographs will be taken from about five feet in height, ideally from a tripod with the height noted, consistent from year to year.

8.2.3 Success Criteria and Management Actions

The goal of *Spartina* and other invasive removals and revegetation is to maintain minimal (ideally 10%) invasive cover by the end of year five post-construction. The success criteria for native revegetation will be determined by surveying analog marshes and transition slopes and comparing the cover and diversity of native vegetation. Final cover and success criteria would be established in consultation with the regulatory agencies. The goal of revegetation is to achieve a density of native salt marsh species similar to natural recruitment within five years post-construction. If the performance criteria have not be met within the first three years, management will be adapted to address shortfalls. Potential management strategies include additional *Spartina* removal or additional plantings of native species.

8.3 Avian Species Monitoring

Avian surveys are not typically required as a permitting condition, especially when existing avian habitat is not impacted as a result of project construction and/or operation. Within the project shoreline, avian species utilize both existing mudflat and salt marsh habitat, although salt marsh habitat is less submerged and more available (see Sections 4.6.2 and 4.6.5 regarding avian use of salt marsh and mudflats, respectively). Pre- and post-project avian monitoring could be included in the monitoring and management program.

Avian species are expected to benefit from the project as a result of salt marsh creation and enhancement and overall improvements to the marine food web as a result. Avian monitoring would focus on evaluating two key hypotheses:

- By expanding the salt marsh, the project will result in increased avian habitat quantity and quality; and
- Avian use and species diversity will increase along the project shoreline.

Baseline, pre-construction avian habitat would be documented via remote sensing and existing studies to capture the area of avian habitat by type (mudflat, salt marsh, or upland) at a reference tidal condition (e.g., mean high water). Post-construction avian habitat monitoring would be completed three to five years following the close of construction to allow for salt marsh establishment and revegetation. Post-construction habitat would also be documented via remote sensing combined with related project studies to document the area of avian habitat by type. The post-construction assessment would be supplemented with field-based documentation of habitat conditions, which could be paired with post-construction salt marsh and vegetation monitoring. Supplemental field-based documentation would support an assessment of habitat quality (e.g., low to high) and habitat use (e.g., foraging, breeding, roosting).

Baseline avian surveys would be completed prior to construction to document existing avian use by species. Several species would be recommended across one year to capture seasonal migration variability. Avian surveys would be repeated three to five years following construction, following salt marsh establishment and revegetation.

Comparative results from pre- and post-project avian assessments would be used to evaluate key hypotheses and incorporated into monitoring reporting for the overall project. Where feasible, collaboration with scientists at CDFW, USFWS, Cal Poly Humboldt, and other agencies/organizations could help further develop the avian species monitoring approach, identify suitable funding, and complete monitoring and reporting activities.

8.4 Annual Reporting

Annual monitoring reports would include a summary of the physical and biological monitoring performed. Physical monitoring data and observations will be summarized to describe the overall trends of changes measured and observed across the beach, marsh and backshore areas. Vegetation monitoring will describe the results of the *Spartina* resprout survey, percent native salt marsh cover, maintenance conducted on the resprouts, a discussion on whether or not the success criteria are being met and potential remedial actions if success criteria are not being met, and photos from each permanent photo point with a caption describing the photo.

Following completion of the final year of monitoring, a Final Monitoring Report will evaluate whether the restoration has met the goals and success criteria along with lessons learned based on the monitoring data. If success criteria have not been met then adaptation measures and continued monitoring efforts will be identified.

9. Ecosystem Services and Project Benefits

Generally, the increase in salt marsh is expected to provide significant ecosystem services and be accompanied by many benefits. Ecosystem services and benefits resulting from the project are described below and would include 1) increased habitat diversification benefiting wildlife and the marine food web, 2) improved carbon sequestration, 3) enhanced water quality through nutrient removal and 4) wave attenuation reducing flood risk and damage (Zedler and Kercher 2005). Ecosystem services associated with estuarine and coastal ecosystems have not been valued reliably but are among the most heavily used and threatened natural systems (Barbier et al. 2011).

9.1 Habitat Diversification

The project proposes to convert various habitat types within the project area, mainly converting mudflat to salt marsh. A habitat conversion analysis was conducted to evaluate potential changes based on proposed project conditions (Figure 84). Table 14 shows the comparisons between historic (1870), existing, and proposed conditions.

Table 14 Habitat Change in Project Area.

Habitat Description	Habitat Area (acres)			
	Historic (1870)	Existing [1]	Proposed	Change
Coarse Gravel Beach	0.00	0.89	4.64	+3.75
Rock Slope Protection (RSP)	0.00	1.30	0.12	-1.18
Mudflat	8.27	22.67	0	-22.67
Salt Marsh	19.89	2.23	17.11	+14.88
Spartina Dominated Salt Marsh	0.00	1.07	0	-1.07
Tidal Channels	0.00	0.00	1.00	+1.00
High Marsh Transition	0.00	0.00	5.29	+5.29
Total	28.16	28.16	28.16	
[1] Assumes Humboldt Bay Trail South (HBTS) Project is constructed				

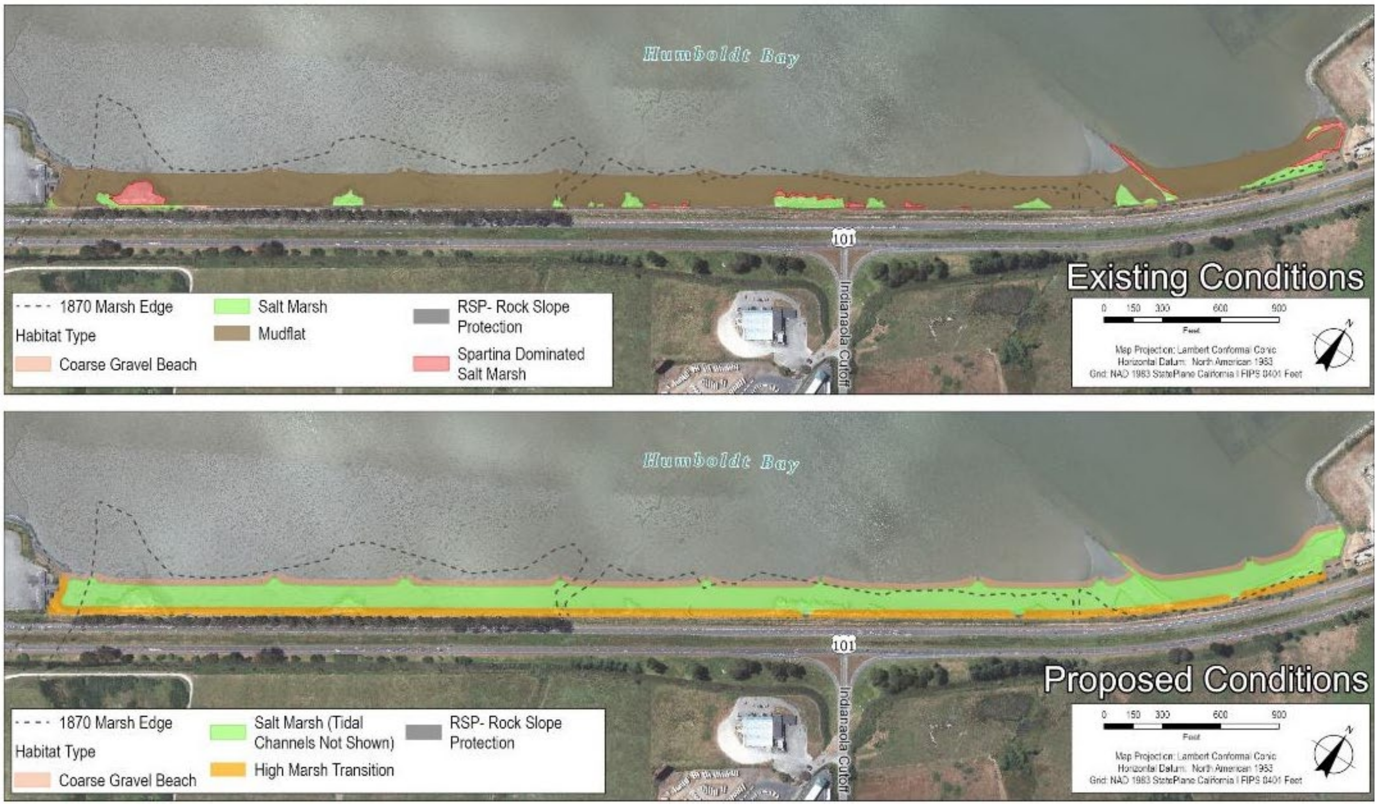


Figure 84 Existing and Proposed Habitat Types

Historically, mudflats and intertidal channels made up 60-70% of Humboldt Bay and salt marsh and inter-tidal wetlands covered 30-40% of the bay's total area (Barnhart 1992, Laird 2007). Since that time, Humboldt Bay decreased in size from approximately 25,800 acres (Laird 2007) to approximately 16,000 acres (Proctor et. al. 1980, Barnhart 1992) due to development, agriculture, and the construction of transportation corridors around the bay. Salt marsh habitat significantly decreased and various studies between the late 1990s and early 2000s found it covers only 4-6% of Humboldt Bay's total area (Barnhart 1992, Pickart 2001, Laird 2007, Schlosser and Eicher 2012). Mudflats make up approximately 65-70% of Humboldt Bay habitat (Barnhart 1992, Schlosser and Eicher 2012).

Due to human disturbance and manipulation of Humboldt Bay and the surrounding watersheds, there are currently significantly more mudflats than salt marshes, compared to historic conditions. Although both habitat types decreased since the 1850s, the proportion of mudflat habitat has remained much more consistent than salt marsh habitat. The project proposes to convert approximately 22 acres of mudflat to salt marsh, which in the context of bay-wide habitat, would reduce approximately 0.2-0.4% of total mudflat habitat and contribute to increasing the overall percentage of salt marsh toward the pre-development habitat ratio. While mudflats play an important role for migratory shorebirds, the proposed conversion to salt marsh would provide beneficial opportunities for increased biodiversity, resting, roosting, and foraging habitat, which are currently limited in most of the project area. The conversion to salt marsh would also increase foraging habitat and refugia for fish during higher tides. Project implementation resulting in additional salt marsh would benefit native vegetation through the creation of more suitable habitat and removal of *Spartina densiflora*. Figure 85 shows a visual simulation of the restored salt marsh habitat.

Figure 85 Visual simulation of the restored salt marsh habitat with the constructed Humboldt Bay Trail South

9.2 Carbon Sequestration

By increasing salt marsh scale and quality, the project will result in increased carbon sequestration (storage) relative to existing conditions. Creating and enhancing salt marsh at elevations that can persist despite rising sea levels is necessary to retain and expand the carbon storage potential of Humboldt Bay salt marsh. In California, the largest area of tidal wetlands can be found in San Francisco Bay; however, Humboldt Bay holds the second largest area and is a primary contributor to carbon sequestration from tidal wetlands in the state.

Sequestration of carbon in salt marsh is a long-term process. Tidal wetlands are carbon dense ecosystems sequestering large amounts of carbon from the atmosphere over thousands of years (Chmura et al. 2003; Bridgham et al. 2006). Tidal wetlands store high concentrations of carbon due to their high primary productivity, continuous sediment burial, and relatively slow decomposition rates (Connor et al. 2001; Hussein et al. 2004). Vegetation growing in salt marsh captures carbon through photosynthesis that is then stored in the plants and sediments. Coastal salt marsh are carbon sinks frequently referred to as “blue carbon” (Nellemann et al. 2009).

Salt marshes temporarily store carbon in above ground vegetation such as leaves and stems, below ground roots and soil, and non-living (e.g. litter) biomass for years or decades (Mcleod et al. 2011). Unlike terrestrial systems, carbon stored in salt marshes is trapped for much longer periods of time due to high soil saturation from daily tides that results in anaerobic conditions (low to no oxygen). The low anaerobic condition of the salt marsh soil limits decomposition of the soil carbon. Salt marshes naturally accrete sediment from daily tide, tributary inputs, and storm events. Higher rates of carbon storage have been documented in tidal wetlands with lower salinity (e.g., Craft 2007). When low decomposition is coupled with sediment recruitment, carbon storage increases over time (Chmura et al. 2003).

The project area has experienced an overall net loss of salt marsh since initial disturbance in 1896. With implementation of the project, expansion of the salt marsh will result in an overall increase in carbon sequestration.

9.3 Water Quality

By expanding and enhancing salt marsh along the project shoreline, water quality would also improve. Wetlands have long been documented to improve water quality because they retain nutrients and thus reduce the impacts of eutrophication on receiving waters (e.g., Singh et al. 2019, Van der Valk and Jolly 1992, Mitsch and Day 2006). Wetlands reduce nitrogen levels via denitrification, burial, and plant uptake (Day et al. 2003) and reduce phosphorus runoff from agricultural lands, along with other nutrients at local and regional scales (Singh et al. 2019). Wetlands also reduce biochemical oxygen demand via physical and microbiological processes (Gearhart and Higley 1993).

Water quality in Humboldt Bay varies seasonally and geographically due to tributary inflows and other factors. Water quality is generally good due to high rates of tidal exchange (HBHRCD 2007). Existing water quality concerns are related to surface runoff from lands surrounding Humboldt Bay. Specific pollutants of concerns result from agricultural runoff and individuals waste treatment systems in unincorporated areas of the watershed (HBHRCD 2007), both of which are present near the project shoreline and elevate nutrient inputs to Humboldt Bay. Salt marsh creation and enhancement along the project shoreline would beneficially reduce nutrient contributions to Humboldt Bay receiving waters from the surrounding watershed. The salt marsh would also capture fine sediments and other particulates from tributary inputs and runoff via depositional processes, slower velocities, and longer residence times, which would occur at seasonally variable rates and extents.

Humboldt Bay is listed on the Clean Water Act Section 303 (d) list of impaired water bodies for polychlorinated biphenyls (PCBs); dioxin is also a constituent of concern, related to legacy industrial uses surrounding Humboldt Bay (HBHRCD 2007). Both PCBs and dioxin are persistent contaminants that accumulate in sediments and can be redistributed as sediments are disturbed through anthropogenic and natural processes. Research related to the remediation of PCBs via phytoremediation and rhizoremediation (plants and roots) is ongoing but indicates the naturally occurring rhizosphere can reduce PCBs (Urbaniak 2013). While a longer-term process, vegetation communities associated with the created and enhanced salt marsh could help to remediate legacy PCBs remaining in Humboldt Bay present at or near the project shoreline.

Improvements in water quality resulting from the project would benefit natural aquatic communities and commercial aquaculture in the North Bay. Water quality benefits would be proportional to the scale and quality of created and enhanced wetlands.

9.4 Flood Risk Reduction and SLR Resiliency

As previously described (Section 1.3), the project area is exposed to wind-generated waves from Humboldt Bay and is vulnerable to increasing risks of shoreline erosion and wave overtopping. Erosion damage to the rail prism (which serves as a de facto levee) would result in reduced flood protection of inland areas and increased vulnerability to future wind wave events until the shoreline is repaired. Overtopping of the shoreline would result in flooding of adjacent property and infrastructure (including the Humboldt Bay Trail and Highway 101), compromised use of overtopped facilities, and potential erosion damage. A primary objective of the project (Section 1.5) is to reduce the risks of shoreline erosion and coastal flooding and improve the resilience of the shoreline. The proposed NSI project (salt marsh creation with barrier berm and shingle beach) was analyzed to assess the flood risk reduction benefits for wave overtopping and inland flooding under a variety of water level and wind speed scenarios. The calculated wave heights, wave periods, and water levels from the SWAN analysis (Section 7.1.4) were used to calculate the average wave overtopping discharge to assess the flood reduction benefit of the project.

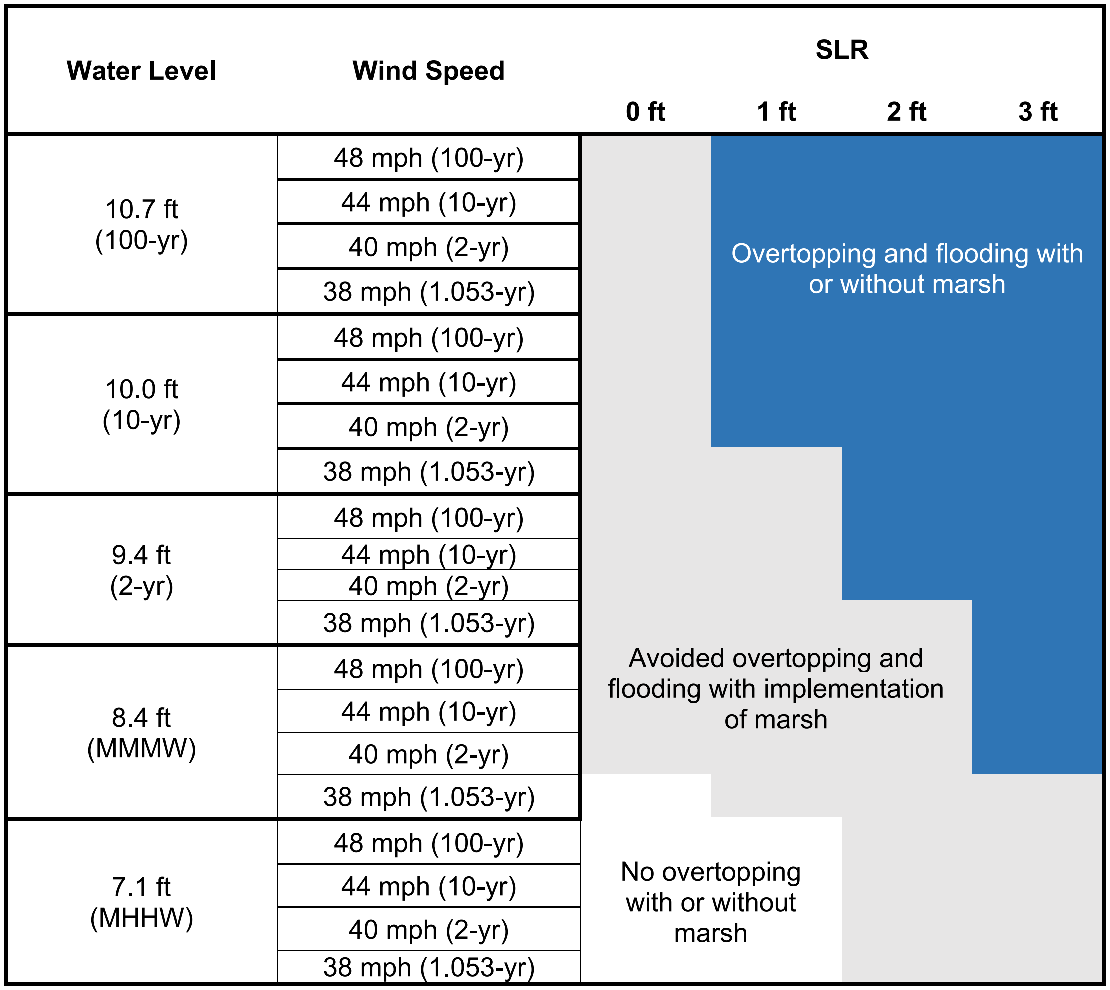
Average wave overtopping discharge was calculated using the design and assessment approach for breaking and non-breaking waves presented in EurOtop (2018). Overtopping of the rail prism would begin with minor flooding of the trail and floodwaters would initially be stored and conveyed in the drainage channel between the trail and highway. The calculated average wave overtopping discharge can be multiplied by the length of the overtopped rail prism and assumed duration of two hours to estimate the volume of flooding and compare the result to the available conveyance and storage capacity. The drainage channel between the trail and highway has an approximate flow capacity of 20 cfs (Humboldt County 2021). When that flow capacity is exceeded, the storage capacity of the drainage channel is approximately 9.5 acre-feet before the roadway shoulder would begin to flood (Humboldt County 2021). Flooding of the travel lanes would begin when the flood volume exceeds 15 acre-feet. The entire southbound roadway would be flooded with 18.5 acre-feet of flood volume.

Avoided flooding and damages associated with the proposed project are summarized in Table 15. The proposed NSI project would provide flood protection up to the current 100-year water level (10.7 feet) with a combined 100-year wind speed (48 mph). With sea level rise, the frequency of higher water levels will increase. A summary of the avoided flooding, up to 3 feet of sea level rise is shown in Table 16.

Table 15 Summary of avoided flooding and damages with implementation of the proposed Project natural shoreline.

Water Level (RI)	**Wind Speed**	**Pre-Project**		**Post-Project**
		Flooding	**Damage**	**Flooding/Damage**
10.7 ft (100-yr)	48 mph (100-yr)	Flooding of Highway 101 South Bound Lanes	Damage to Pavement	No Overtopping, Flooding, or Damage with Marsh
	44 mph (10-yr)			
	40 mph (2-yr)		Damage to Rail Prism	
	38 mph (1.053-yr)			
10.0 ft (10-yr)	48 mph (100-yr)			
	44 mph (10-yr)			
	40 mph (2-yr)		Trail Usability Compromised	
	38 mph (1.053-yr)			
9.4 ft (2-yr)	48 mph (100-yr)			
	44 mph (10-yr)		No Damage	
	40 mph (2-yr)			
	38 mph (1.053-yr)			
8.4 ft (MMMW)	48 mph (100-yr)	Flooding of Trail and Highway Shoulder		
	44 mph (10-yr)	Flooding of Trail		
	40 mph (2-yr)			
	38 mph (1.053-yr)	No Overtopping, Flooding, or Damage pre- or post-project		
7.1 ft (MHHW)	48 mph (100-yr)			
	44 mph (10-yr)			
	40 mph (2-yr)			
	38 mph (1.053-yr)			
EP = Exceedance Probability, RI = Return Interval				

Table 16 Avoided overtopping and flooding with implementation of the proposed Project natural shoreline.



Water Level	Wind Speed	SLR 0 ft	 1 ft	 2 ft	 3 ft
10.7 ft (100-yr)	48 mph (100-yr)	▨	🟦	🟦	🟦
	44 mph (10-yr)	▨	🟦	🟦	🟦
	40 mph (2-yr)	▨	🟦	🟦	🟦
	38 mph (1.053-yr)	▨	🟦	🟦	🟦
10.0 ft (10-yr)	48 mph (100-yr)	▨	🟦	🟦	🟦
	44 mph (10-yr)	▨	🟦	🟦	🟦
	40 mph (2-yr)	▨	🟦	🟦	🟦
	38 mph (1.053-yr)	▨	▨	🟦	🟦
9.4 ft (2-yr)	48 mph (100-yr)	▨	▨	🟦	🟦
	44 mph (10-yr)	▨	▨	🟦	🟦
	40 mph (2-yr)	▨	▨	🟦	🟦
	38 mph (1.053-yr)	▨	▨	▨	🟦
8.4 ft (MMMW)	48 mph (100-yr)	▨	▨	▨	🟦
	44 mph (10-yr)	▨	▨	▨	🟦
	40 mph (2-yr)	▨	▨	▨	🟦
	38 mph (1.053-yr)		▨	▨	▨
7.1 ft (MHHW)	48 mph (100-yr)			▨	▨
	44 mph (10-yr)			▨	▨
	40 mph (2-yr)			▨	▨
	38 mph (1.053-yr)			▨	▨

🟦 Overtopping and flooding with or without marsh

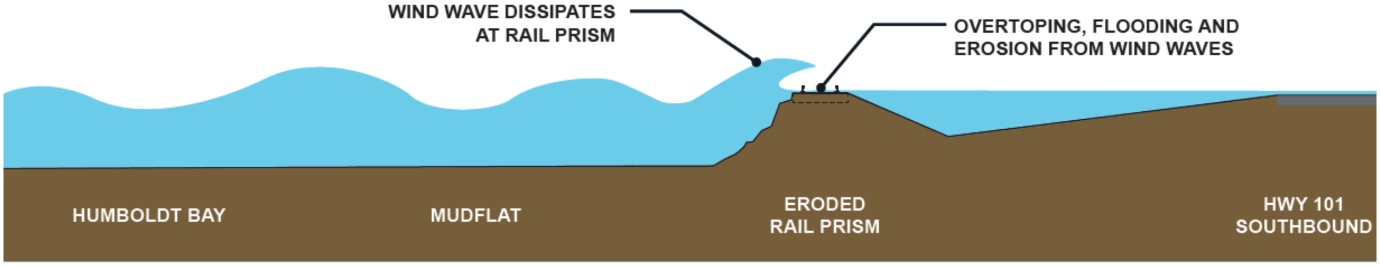
▨ Avoided overtopping and flooding with implementation of marsh

No overtopping with or without marsh

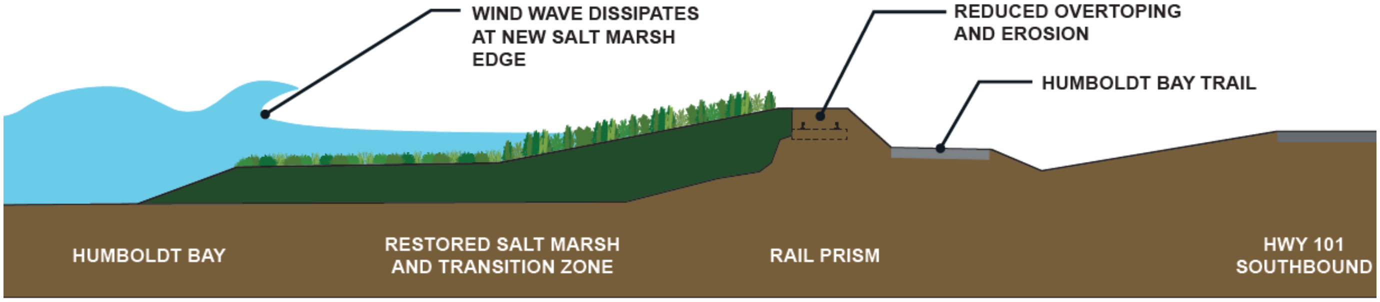
The results in Table 15 indicate that for existing conditions (i.e., no sea level rise) the proposed project provides significant wind-wave attenuation and flood risk reduction. Without the proposed project, overtopping would occur at the 2-yr and greater water levels with wind speeds above 38 mph. The proposed natural shoreline would prevent structure crest overtopping for all water levels and wind speeds analyzed, up to the 100-yr stillwater level.

For 1 foot of sea-level rise (Table 16), the proposed natural shoreline project would provide wave attenuation and flood risk reduction for the more frequent high water level conditions and extreme wind events, but overtopping would still occur for the less frequent high water level conditions (e.g. 10-yr and 100-yr) combined with extreme wind events. Without the proposed project, overtopping would occur at the monthly water level (MMMW) when those conditions coincide with extreme wind events. For 2 feet of sea-level rise, the natural shoreline project would provide overtopping protection for the monthly sea levels (MMMW) and any extreme wind condition, but overtopping would occur for extreme water level conditions above the 2-yr recurrence interval combined with extreme wind speed cases. Without the proposed project, overtopping would occur at daily high water levels (MHHW) and extreme wind events. By 3 feet of sea-level rise, the existing shoreline would be overtopped at daily levels and any extreme wind event, while the proposed natural shoreline project would provide protection at the daily water levels for all extreme wind events.

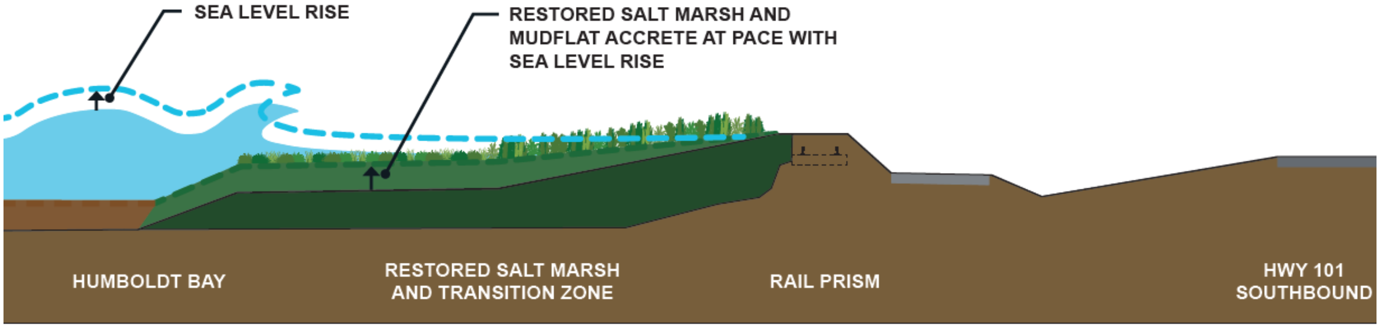
The project provides a significant reduction in flood risk to critical resources landward that would provide immediate and long-term benefits. The sediment trapping properties of the proposed salt marsh are intended to maintain pace with SLR thereby providing continued benefit into the future (Figure 86). The proposed project should provide significant flood risk protection and sea-level rise resiliency to at least year 2050, and moderate risk protection to approximately 2 feet of sea-level around year 2070.



PRE-PROJECT



PROJECT



PROJECT ADAPTATION TO SEA LEVEL RISE

Figure 86 Conceptual representation of wind wave dissipation on the rail prism pre-project (top), at the marsh edge following project implementation (middle) and with sea level rise (bottom).

10. Environmental Compliance & Regularity Considerations

10.1 Policies, Laws, and Regulations

Advancing this project from the current feasibility study level to implementation will require engaging with state and federal agencies to coordinate with existing policies and obtain permits to demonstrate adherence to state and federal regulations. The following state and federal environmental regulations will need to be considered as the project advances and as recommended that these pathways be confirmed with the respective agencies as part of the next project planning phase.

10.1.1 Wetlands “No Net Loss” Policy

An important feature of much environmental permitting is the implementation of a “no net loss” policy related to the filling and mitigation of wetlands. Initiated as a federal goal in 1977, this policy is also undergirds many state environmental regulations. Multiple agencies, including the U.S. Army Corps of Engineers (USACE) and Regional Water Quality Control Board (RWQCB), will have criteria and review process for ensuring that any wetlands impacted by an adaptation project will be adequately replaced, or mitigated. With the exception of a portion of the rock slope projection and portion of the gravel shore along the rail prism, most of the project area is comprised of existing salt marsh and mudflat which are considered wetlands. Creation of the new salt marsh would result in fill placement over the existing wetland (mudflat), however would remain as a wetland and therefore an overall loss of wetlands is not anticipated for this project, avoiding the need for on- or off-site wetland mitigation. The proposed transition zone could result in a wetland loss and therefore analyses would be needed during the next phase to assess potential impacts. Previously completed local inter-tidal restoration projects have demonstrated that fill placed at or below elevation 9 feet (NAVD88) within the inter-tidal zone is not consider conversion to an upland. A similar approach would be proposed for this project to minimize/avoid wetland fill and determine need for on- or off-site mitigation. Onsite mitigation ratios are often lower than off-site, and therefore if needed the project would endeavor to identify on-site uplands that could be converted to wetlands to result in an overall no net loss of wetlands. Should on-site balance not be achievable, off-site mitigation can be anticipated.

10.1.2 Federal Water Pollution Control Act, A.K.A. Clean Water Act (CWA)

Implementation projects frequently trigger review for compliance with Sections 404 and 401 of the Clean Water Act. Section 404 governs the dredging and filling of Waters of the United States and is regulated through the USACE. Section 401 pertains to water quality standards and is regulated through the United States Environmental Protection Agency (USEPA, or EPA), which delegates authority to the State Water Resources Control Board (SWRCB), which in turn delegates authority to its regional offices, or Regional Water Quality Control Boards (RWQCBs). Section 401 and 404 permits should be expected for projects on Humboldt Bay. The project could be considered under the Nationwide Permit 54 (Living Shoreline) or a Nationwide Permit 27 (Aquatic Habitat Restoration, Establishment and Enhancement), however due to the project size and type, the USACE may find that an Individual Permit would be necessary.

10.1.3 Endangered Species Act (ESA)

Under this law, the “taking” of protected species and protection of their habitats is regulated through a review and mitigation process under the supervision of the United States Fish and Wildlife Service (USFWS) and/or National Oceanic Atmospheric Agency (NOAA) Fisheries Service. Federal agencies are required to consult with these resource agencies for any projects or policies that they may authorize, fund, or otherwise implement. ESA may be triggered by projects proposed on Humboldt Bay.

Projects on Humboldt Bay may require ESA Section 7 coverage for Coho, Chinook, Steelhead, Tidewater Goby, and other listed marine fish. The USACE would consult with and be required to obtain NOAA and/or USFWS ESA concurrence. The project would be eligible for NOAA’s updated Programmatic Biological Opinion for Restoration Projects for take of Coho, Chinook, and Steelhead. The USACE would consult with and be required to obtain a separate concurrence or Biological Opinion for Tidewater Goby, with the USFWS.

10.1.4 Migratory Bird Treaty Act of 1918

This international treaty protects migratory birds from takings without prior authorization from the USFWS. If the species is also endangered, ESA review would be required. Should projects on Humboldt Bay impact habitat, including roosting grounds, of migratory birds, consultations with USFWS would be expected and standard buffers and avoidance measures may be required.

10.1.5 National Environmental Policy Act (NEPA)

NEPA is a federal law that requires a process for reviewing and weighing environmental quality equally with other considerations when permitting a project or policy that is either funded or otherwise influenced by a federal agency. It establishes a formal planning framework, review process, and means for public input. Some level of NEPA should be anticipated for projects on Humboldt Bay.

NEPA would be required if the project receives federal funding. The USACE would complete NEPA as part of their Clean Water Act Section 404 review. The NEPA funding lead agency may tier off the USACE NEPA documentation or develop a separate NEPA documentation for funding.

10.1.6 California Environmental Quality Act (CEQA)

The California Environmental Quality Act (CEQA) ensures that projects have been adequately assessed for environmental impacts, that alternatives have been explored and thoroughly considered prior to the project being adopted or permitted. The CEQA process is led by a lead agency but involves review of many state, and potentially federal, agencies. The lead agency has not been determined for this project. Lead agencies could be local or state agencies with jurisdictional authority, land use control, and/or funding contributions. Possible lead agencies could include:

- Humboldt County (property owner, land use control)
- Humboldt Bay Harbor Recreation and Conservation District (shoreline jurisdiction) and beneficial reuse of dredge spoils
- Caltrans (project benefits Caltrans existing ROW)
- CDFW (property owner)
- City of Eureka (property owner, land use control)
- State funders (State Coastal Conservancy, Ocean Protection Council, Wildlife Conservation Board, etc.)

Permitting strategies could differ depending on the lead agency. An IS/MND is anticipated however the Cutting the Green Tape Initiative could allow use of the recently released CDFW Statutory Exemption for Restoration Projects (SERP) or the State Water Board’s General Order for Restoration Project Exemption expected for release in August 2022. The project is anticipated to be eligible for both CEQA exemption programs given the restoration orientation. If the project accepts reuse dredge sediments, then use of the Program EIR for Humboldt Bay Sediment Management (SCH#2018012052) could also be considered.

10.1.7 California Coastal Act

The State of California also authorizes the California Coastal Commission, in partnership with coastal cities and counties, to implement the Coastal Act, established in 1976. The Coastal Act sets forth standards for public access and protection of coastal resources. As a part of its responsibility to administer the Coastal Act, the Coastal Commission also issues guidance and resources for local governments on climate change adaptation, as discussed elsewhere. It issues Coastal Development Permits (CDP) for development projects in areas of its retained CDP jurisdiction and delegates CDP issuance responsibilities to local jurisdictions with Local Coastal Programs (LCP) that have been certified by the Commission, in this case Humboldt County and the City of Eureka. The Project is located in the State’s jurisdiction; therefore, a CDP would be required from the Coastal Commission. The Coastal Commission also performs Federal Consistency Determinations to ensure that federal projects within the Coastal Zone or which may have spillover effects on the Coastal Zone adhere to federal Coastal Zone Management Act policies, where such determination is required. The following policies would likely need to be thoroughly considered for this project:

Section 30235: Shoreline Altering Projects

Sea level rise related shoreline protection projects, such as living shoreline projects, that impact coastal wetlands or ESHA could be allowable under the Coastal Act if they are (1) required to serve coastal-dependent uses or protect existing structures in danger from erosion, and (2) when designed to eliminate or mitigate adverse impacts on local shoreline sand supply (per Section 30235). If a project meets those requirements, per Section 30235, the Coastal Act could allow for the construction of revetments, breakwaters, groins, harbor channels, seawalls, and other project elements that alter natural shoreline processes. The project proposes to restore salt marsh habitat and provide protection to at least some infrastructure that was constructed prior to establishment of the Coastal Act in 1976 and therefore assumed to be consistent with this section of the Coastal Act.

Section 30230 and 30231: Uses of the Marine Environment

Coastal Act policies 30230 and 30231 call for the maintenance and enhancement of marine resources, biological productivity, and water quality, as well as the restoration of those resources where feasible. As discussed in other sections, the Project design would improve habitats for many marine species and improve water quality through the creation of salt marsh. The Project would also implement strategies such as Best Management Practices (BMPs) and Stormwater Pollution Protection Plans (SWPPP) or Water Pollution Control Plan (WPCP) during construction to provide adequate water quality protection, manage runoff, and minimize potential impacts to the marine environment.

Section 30233: Wetland Fill

Allowable diking, dredging, and filling of open coastal waters, wetlands, estuaries, and lakes under Section 30233 (diking, filling or dredging continued movement of sediment and nutrients) of the Coastal Act is permitted only for seven specific types of projects, and in those cases only if there is no feasible less environmentally damaging activity and if feasible mitigation measures are provided to minimize adverse environmental effects. These project types include:

1. New or expanded port, energy, and coastal-dependent industrial facilities
2. Maintaining existing or previously dredged navigation channels, turning basins, and similar boating areas
3. New or expanded boating facilities (disallowed in wetlands)
4. Incidental public services, such as burying cables and pipes
5. Mineral extraction
6. Restoration purposes
7. Nature study, aquaculture, and similar resource dependent activities

The project may qualify as a restoration and/or incidental public services project, as the project proposes to restore areas to salt marsh and protect vital infrastructure. Design considerations would include minimizing impacts to wetlands and waters and avoiding wetland fill that would convert wetlands to uplands to the greatest extent possible. The project would also consider appropriate mitigation for unavoidable impacts. Mitigation ratios for coastal wetlands are no less than 1:1 but higher ratios of wetland mitigation activity-to-wetlands impacted can be required. Project specific ratios are ultimately determined at the discretion of the Commission.

In evaluating potential allowability for wetland dike, dredge, and fill under Section 30233, the Commission requires an analysis to demonstrate the proposed project is the least environmentally damaging feasible activity in the context of wetland impacts. This may include evaluating whether the assets requiring protection can feasibly be relocated as an alternative to filling wetlands to protect vulnerable assets in place. This exercise of evaluating alternatives ensures consideration is given to the feasibility of, and the short- and long-term costs and benefits of, relocating existing assets away from increasingly vulnerable areas rather than protecting them in place; however, relocating existing assets also requires consideration of other potential challenges such as cost, landownership, and access control.

Section 30253: Minimizing Development in Hazardous Areas

Section 30253 requires the minimization of development, and therefore risks to life and property, in areas of high geologic, flood, and fire hazards. The policy also requires that new development “assure stability and structural integrity,” and therefore not require “construction of protective devices that would substantially alter natural landforms along bluffs and cliffs.” This restoration project would not include new development that would put life or property at risk and is designed to protect critical resources from shoreline erosion and coastal flooding hazards.

Section 30270: Sea Level Rise Considerations

Section 30270 requires the Commission to consider the effects of sea level rise in project evaluation in order to avoid and mitigate potential effects, to the extent feasible. As described in this report, sea level rise in the project area could threaten coastal habitat, critical infrastructure, existing development, coastal trail access, and agricultural land. The project design provides opportunities for sediment accretion that sustains salt marsh persistence and provides wave energy dissipation, thus protecting inland infrastructure and reducing the potential for wave induced erosion in other areas of the bay. As described in this report and based on the hydraulic modeling, the change in wind-wave induced and tidal currents adjacent to the project are anticipated to be negligible.

10.1.8 California Fish and Wildlife Section 1600 Permit

California Fish and Game Code section 1602 applies to activity that diverts, obstructs, changes the channel, bed, or banks of any river, stream, or lake, or otherwise uses or disposes of material from any river, stream or lake. Permits are required for any such activity; mitigation may also be required. Proposed changes to the bay, agricultural wetlands, and levees would likely require a 1600 Permit.

10.1.9 California Endangered Species Act (CESA)

Similar to the Federal ESA, the state regulates the take of state listed species. Where a federal ESA permit has findings that adequately cover state regulations, the state Department of Fish and Wildlife may provide a Consistency Determination, with no additional CESA permits required. Safe Harbor Agreements (SHA) allow for incidental take of a listed species when the larger project provides net benefits to a species. Projects on Humboldt Bay would require CESA compliance (such as an Incidental Take Permits or Memorandum of Understanding) for Longfin Smelt and Coho.

10.1.10 California Porter-Cologne Act

The Porter-Cologne Act is also the California Water Code Division 7, which established the SWRCB and RWQCBs. It applies federal National Pollutant Discharge Elimination System (NPDES) permits and mandates water quality control plans for Waters of the State. For Waters of the US, Section 401 Water Quality Certification through the North Coast RWQCB will also provide coverage of Porter-Cologne. Compatibility of fill placement will need to follow ISM standards as previously described.

10.1.11 California State Lands Commission Lease or Permit / Harbor District Shoreline Development Permit

The State Lands Commission (SLC) has authority over public trust lands including tidelands, submerged lands, and the beds of navigable rivers, streams, lakes, bays, and estuaries including waterfront lands and coastal waters. The Commission protects and enhances these lands and natural resources by issuing leases for use or development, providing public access, resolving boundaries between public and private lands. Through its actions, the Commission secures and safeguards the public’s access rights to natural navigable waterways and the coastline and preserves irreplaceable natural habitats for wildlife, vegetation, and biological communities. In 1970, the Commission granted the Humboldt Bay Harbor Recreation and Conservation District (Harbor District) all ungranted tide and submerged lands in Humboldt Bay, requiring development or other land disturbance projects in Humboldt Bay to obtain a lease or permit through Harbor District. Written determination from the SLC of the status of state or public trust lands would be obtained prior to project implementation which would inform if a lease or permit is required through the SLC or Harbor District.

10.1.12 Humboldt County Permits

For projects that include more than 50 cubic yards of grading, a Humboldt County Building and Grading Permit would be required. The project area is zoned NR: Natural Resources with combining zones D: Design Review, W: Coastal Wetlands, therefore it would not require a use permit but may require design review.

10.1.13 City of Eureka Permits

A portion of the project area is located within City of Eureka's city limits. The project area land use and zoning designation is GI: General Industrial. The City may require a use permit or other authorization and would be contacted in the next project phase to determine approval requirements.

10.2 General Regulatory Considerations

10.2.1 Mitigation and Habitat Conversion

Mitigation requirements for impacts to wetlands and other sensitive habitats, especially within the Coastal Zone, can result in substantive project delays and increased project cost, reducing the number of projects that can be funded concurrently due to limited funding. Inflexible requirements to mitigate existing resources can be barriers to implementing projects to protect future resources. During final design and subsequent studies, the project would strive to demonstrate a no net loss of wetlands and therefore avoiding mitigation. If wetlands are filled and converted to uplands, agencies may impose a mitigation ratio that results in more wetland acreage created than originally filled. Mitigation can create an incentive for projects with a smaller project footprint, that leverage restored wetlands as part of a flood hazard reduction strategy, or that incorporate restoration into project design. No mitigation bank is currently established for Humboldt Bay; therefore, the project mitigation would require other on- or off-site compensatory mitigation. Locating a potential mitigation site can further constrain project feasibility.

Most habitat conversion proposed in the project would be from mudflat to salt marsh. Regulatory agencies carefully review proposals with a conversion of one type of wetland to another type of wetland. Conversion of a habitat type with higher environmental and ecological benefit to a lower benefit could require a higher mitigation ratio. However, typically in Humboldt Bay, conversion of mudflat to saltmarsh is not discouraged, as salt marsh is viewed as having a higher and more biodiverse value than mudflat and as previously described.

10.2.2 Innovative, Nature-Based Projects in Dynamic Environments

Environmental regulations and traditional permitting requirements may be a significant challenge for permitting sea level rise adaptation projects using nature-based approaches. Many environmental regulations have an implicit preference for the status quo and inadvertently create a disincentive for pursuing innovative projects or projects that require short-term impacts in order to achieve longer-term benefits with uncertain timing. Permitting agencies often want applicants to commit to delivering specified outcomes. However, nature-based approaches that rely on restoring or modifying dynamic natural processes are inherently uncertain. For example, sediment accretion in restored or created salt marshes is a complex interplay of sediment supply and sediment transport processes that occur at a watershed and bay scale along with biological and hydraulic processes at the project scale. A project applicant is unable to control these processes and guarantee specific outcomes. Questions regarding the appropriate level of mitigation, monitoring, and adaptive management will need to be resolved. Some degree of regulatory reform may be needed to alleviate unintended disincentives to pursuing nature-based approaches.

11. Implementation Strategy and Next Steps

As described in this report, the proposed project would provide significant ecosystem services while remaining compatible with different adaptation approaches of the Highway 101 corridor. Several potential next steps to advance the project are possible, depending in part on which agency or agencies would serve as project proponents, available funding, and the overall implementation strategy. The first fundamental decision is to determine whether to advance the project over the entire study area or to advance the Phase 1 portion as a pilot test (demonstration project) (see Section 7.7.1). The following "next steps" would generally be the same with either approach, although the cost and timeframe would be different. In general, potential next steps include:

1. Perform additional technical studies (e.g., geotechnical testing, regulatory analysis, hydraulic modeling) to refine the project design, develop a more precise cost estimate, and optimize the project benefits. Geotechnical studies include defining the standards for suitable imported fill material to support vegetation establishment; analyzing the potential for consolidation (settlement) of the fill material and the implications for project planning; and establishing technical standards for the shingle beach. Regulatory analysis includes determining applicable water quality standards for the imported sediment and calculating the final amounts of habitat conversion. Additional hydraulic modeling to assess potential off-site impacts associated with each constructed phase would also be necessary. A decision whether to include the barrier berms will need to be made.
2. Identify source options for the large quantity of material needed (approximately 20,000 cubic yards for Phase 1 or 130,000 cubic yards for the entire project). Perform more detailed construction planning regarding construction means and methods, including material handling and placement, to develop a complete project description narrative. The approach for re-vegetation (active planting and/or natural recruitment) will need to be determined.
3. Perform additional outreach and solicit comments from additional stakeholders and the general public. The project is located in a high-profile location (visible from Highway 101) and would generate a significant amount of public interest. Some of the project elements (i.e., placing fill material on mudflats) may be controversial. Engaging with stakeholders and the general public would help determine if the community as a whole is ready to support the project.
4. Secure required right-of-way and land use approvals.
5. Perform civil design work including progressive development of project plans, specifications, and estimates.
6. Develop an environmental study for compliance with the California Environmental Quality Act (CEQA) and identify any applicable mitigation requirements.
7. Consult with permitting agencies to identify applicable regulatory constraints and requirements. Develop and submit environmental permit applications.
8. Develop a post-construction monitoring and adaptive management plan.
9. Implement construction.

The following Table 17 summarizes the remaining tasks and considerations for three implementation options. Option 1 assumes the project will be advanced in its entirely, Option 2 assumes Phase 1 implementation only and Option 3 assumes a hybrid that advances the project as sediment sources become available.

Table 17 Remaining tasks and considerations for three implementation options

Tasks and Considerations	OPTION 1 Entire Project	OPTION 2 Demonstration /Pilot Project (Phase 1 only)	OPTION 3 Hybrid (phased)
Project Lead	TBD	TBD	TBD
Funding Source(s)	TBD	TBD	TBD
Remaining Technical Studies	Entire Project	Phase 1 only	Entire Project
Regulatory Compliance	Entire Project	Phase 1 only	Entire Project

Tasks and Considerations	OPTION 1 Entire Project	OPTION 2 Demonstration /Pilot Project (Phase 1 only)	OPTION 3 Hybrid (phased)
Fine Sediment Volume & Sourcing	~130,000 CY	~20,000 CY	~130,000 CY
Final Design	Entire Project	Phase 1 only	Phased as Sediment Sources Become Available
Right-of-Way (ROW)	Multiple Private Parcels	Bracut Lumber, CDFW & County	
Bid & Construction	Entire Project	Phase 1 only	
Monitoring	Entire Project	Phase 1 only	
Construction Cost	$12.8 - 17.2M	$3.8 - 4.5M	Comparable to Option 1

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Appendix A

Exhibits

Appendix B

Habitat Mapping

Appendix C

Wildlife Species List

Appendix D

Extreme Wind-Wave Analyses

Appendix E

Wave Run-up Analyses

Appendix F

Mudflat Sediment & SedFLUME

Appendix G

Marsh Sediment Sampling

Appendix H

50% Design Plans

Appendix I

Sediment Mobility Analyses

Appendix J

Opinion of Probable Cost

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→ The Power of Commitment