Sea Level Rise Adaptation Plan for Transportation Infrastructure and Other Critical Resources in the Eureka Slough Hydrographic Area, Humboldt Bay

Final | March 31, 2021

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EXECUTIVE SUMMARY

This plan (study) presents a framework for developing sea level rise adaptation strategies within the highly vulnerable Eureka Slough hydrographic area of Humboldt Bay. The purpose of the study was to work with public agencies, landowners, scientists, and stakeholders to better understand the specific flood risks to the transportation infrastructure and other critical resources within the study area and to identify viable adaptation measures in the near-term planning horizon (now through mid-century) for the most at-risk locations. A primary focus of the study was to develop a scenario-based planning approach for understanding the range of possible impacts and consequences resulting from tidal and fluvial flood hazards under current conditions and with future sea level rise. This approach included detailed hydraulic analysis and an evaluation of the anticipated response of the coastal landscape to various flooding events. The plan is intended to help advance the collective understanding of flood risks and improve the readiness for implementing effective sea level rise adaptation projects. This plan is a technical resource for ongoing planning and adaptation efforts but is not a decision document and does not represent a commitment to implement the project concepts discussed in the plan.

The plan is comprised of three parts:

- Part I – Planning Framework
- Part II – Vulnerability Assessment
- Part III – Adaptation Project Planning

Part I – Planning Framework

Part I introduces key terms and concepts related to sea level rise and presents the vision statement, key assumptions, and guiding principles for the plan. Part I introduces the concept of a dynamic landscape and identifies the hydrologic components of the water cycle that could affect landscape features and the associated flood risks as sea levels continue to rise.

Key Findings

- This study builds on the previous ten years of sea level rise planning work on Humboldt Bay and was developed to support the transition from assessing flood vulnerability to planning and designing adaptation projects.
- This study focused on the Eureka Slough hydrographic area, which occupies approximately 3,300 acres along the northeast border of the City of Eureka and includes a portion of the Eureka-Arcata Highway 101 corridor. The scale of the hydrographic area allows more detailed consideration of geomorphic conditions and physical processes, which improves the understanding of risks and supports the design of effective adaptation measures.

- Communities and landscapes are protected from flooding by multiple lines of defense. Within the study area, important lines of defense include salt marsh, the out-of-service railroad, road embankments, and a network of privately owned and publicly owned levees. Different landowners and managers may have different levels of tolerance or aversion to flood risks. The vision statement for this study expresses a goal for landowners and managers to collaborate on implementing an integrated strategy of short-term and long-term actions to build resilience to flooding hazards and achieve an acceptable level of flood risk. The concept of building resilience against major disruptive and damaging flood events provides a positive future vision that individuals and communities can work towards. Building resilience can also mean aspiring to adapt and grow from disruptive experiences and taking advantage of opportunities to develop creative, or even transformational, solutions to hazards.
- Most of the previous vulnerability studies on Humboldt Bay used conservative assumptions by projecting elevated tidal water levels across the landscape without considering shoreline structures and hydraulic pathways. This approach is useful as a generalized screen-level assessment but does not give insight on actual flooding events and has limited utility for planning and designing specific adaptation projects. Most previous studies have also focused on static water levels (still water levels) without considering the effects of wind waves.
- Sea level rise adaptation warrants an incremental approach utilizing a combination of shorter-term actions to reduce immediate risk and gain time along with longer-term actions to address future conditions. Adaptation measures will be very expensive and funding to implement projects will be a major limiting factor. For some high-risk areas, long-term protection from flooding hazards associated with sea level rise will not be feasible and re-location or "managed retreat" will need to be seriously considered. This study focused on trying to identify feasible adaptation measures in the near-term and did not actively pursue opportunities for managed retreat. The managed retreat concept brings considerable financial uncertainties and warrants further planning and strategic development.
- The longer-term future of the Eureka-Arcata Highway 101 corridor is a major consideration for communities and landscapes along the shoreline due to the protective characteristics of this linear landform. The Caltrans Phased Adaptation Plan for the Eureka-Arcata Highway 101 corridor, due in 2025, is expected to be a foundational planning document for the shoreline and protected interior lands between Eureka and Arcata. For the current plan, it was assumed that a major adaptation project for Highway 101 will not occur until later in the 21st century due to the many complexities and enormous costs. The current plan also assumed that Highway 101 will be adapted in its current alignment along the shoreline due to the even greater costs and impacts of inland retreat.

Part II – Vulnerability Assessment

Part II provides an evaluation of the physical setting within the study area, including topography, existing habitats, property ownership, and existing shoreline structures. Part II identifies and evaluates transportation infrastructure, utility infrastructure, critical resources, land use, and regulatory boundaries. The geomorphic setting and physical processes such as tidal conditions, wind waves, and fluvial events were integrated into a conceptual model that describes the shoreline's geomorphic response to these physical processes. Part II outlines the hydrodynamic analysis that served as the technical basis of this plan.

Key Findings

- Humboldt Bay is a sheltered water body along the "inner coast" which has a different flood risk profile than the open coast (or "outer coast"). Humboldt Bay is subject to ocean tides, storm surge, and locally generated wind waves but is sheltered (except near the mouth) from the large waves associated with ocean swells. The study area is situated within a portion of Humboldt Bay that is particularly vulnerable to the effects of sea level rise and contains a concentration of infrastructure types along with a diversity of land uses.
- The study area contains four geomorphic units: subtidal and intertidal features, constructed linear landforms, diked former tidelands, and uplands. Critical resources within the study area are vulnerable to flooding because they are situated on diked former tidelands protected primarily by linear landforms constructed 75 to 125 years ago when sea levels were approximately 1 to 2 feet lower.
- The physical shoreline and the associated drainage network have changed significantly from pre-development (natural) conditions. Constructed rail prisms, roads, and levees have altered surface and groundwater flow and sediment pathways that, prior to development, shaped the natural landforms through erosion and accretion processes. For example, Fay Slough no longer drains directly to the bay but has been re-directed into Eureka Slough, and diked former tidelands have subsided as a result of being disconnected from sediment sources. Understanding how the landscape and natural processes have changed in the past is important for predicting how they may change in the future and for developing adaptation measures that protect and enhance natural features.
- Salt marsh is a type of coastal wetland that floods and drains on a daily or intermittent basis and is covered with a thick mat of vegetation. Salt marsh occupies a relatively narrow band of elevation in the upper intertidal zone in areas where there is sufficient sediment supply and a relatively low energy environment. Salt marsh has high ecological value by providing habitat for sensitive plant species, invertebrates, larval stages of fish species, and roosting and foraging areas for birds. Salt marsh also provides critical protection to shoreline resources by reducing wave energy and providing protection from flooding and erosion. Salt marsh is a dynamic landform that depends on sediment accretion and plant productivity to maintain the marsh plain elevation in response to subsidence and sea level rise. Salt marsh can keep up with sea level

rise to a point but is at risk of being permanently “drowned” and converted to mudflat due to sea level rise. If salt marsh is converted to mudflat, then the biodiversity, carbon sequestration, water quality, and flood risk reduction benefits are lost.

- An extensive area of salt marsh is situated between Eureka Slough and Brainard but only isolated fragments remain between Brainard and Bracut. Further studies on the resilience of salt marsh within the study area and around Humboldt Bay to sea level rise would be highly valuable. Strategies to maintain existing areas of “high and wide” salt marsh should be developed and the feasibility of creating new salt marsh areas should be pursued.
- The railroad along the shoreline has become critical coastal protection infrastructure. The railroad assets have not received maintenance since the 1990s and have suffered significant erosion and deterioration.
- The interactions between tidal water levels, wind waves, riverine (fluvial) flooding, and groundwater should be considered for a more comprehensive understanding of flood risk. Wind waves can be a significant source of flooding along the eastern shoreline of Humboldt Bay. Within the study area, fluvial flooding from Freshwater Creek and Ryan Creek can be significant in the more inland areas but is not expected to impact Highway 101. Sea level rise will increase the extent of fluvial flooding throughout the study area and extend the drain-off periods from diked former tidelands. Managing inland areas for floodwater storage and conveyance will be increasingly important with increasing sea level.
- This study did not analyze groundwater conditions due to the complexity and lack of data. However, the study describes the conceptual linkage between sea levels and adjacent shallow unconfined aquifers underlying diked former tidelands. Sea level rise could result in aquifer salinization, impeded surface drainage, and conversion of vegetative communities. The timing and spatial extent of these responses depend on site-specific conditions related to underlying lithology, aquifer characteristics, freshwater surface contributions, land uses, and elevation. Ongoing studies such as the Groundwater Sustainability Plan being developed for the Eel River Valley groundwater basin will advance the understanding of sea level rise effects on groundwater on the North Coast. The groundwater basins around Humboldt Bay have received limited analysis.
- Understanding how landforms could respond to changes in tidal still water levels, wind waves, erosive forces, sediment transport, and groundwater levels is important for evaluating flood risks. This study developed a conceptual model for predicting how the geomorphic units within the study area will respond to sea level rise and other physical drivers over time.
- Hazard scenarios were developed for a range of extreme flood events to better understand where flooding is initiated, floodwater volume, the depth and extent of flooding impacts, and how the landscape is likely to respond. As sea levels rise, the probability of extreme flood events will increase. For example, the flood event with a 1% annual chance today (10.6 feet NAVD 88) will have a 50% recurrence probability with one foot of sea level rise and will likely

occur six times a year with two feet of sea level rise. The projected time in the future when these probability levels are reached depends on the assumed rate of sea level rise.

- Under existing conditions, tidal water levels corresponding with the astronomical high tide (highest annual tide) of approximately 9 feet (NAVD) generally result in areas of shallow flooding from impeded drainage and restricted access to underground facilities and low-lying lands. This flooding can be exacerbated with coincident rainfall runoff. Tidal water levels between 10 to 10.5 feet (NAVD) mark the initiation of overtopping of shoreline structures resulting in widespread flooding. Water levels between 10.6 and 11.6 feet (NAVD) mark a significant increase in the extent of overtopping and conditions that have a high potential to create a levee breach.
- The Humboldt Bay Trail South project is a large infrastructure project to create 4.25 miles of paved bikepath (multi-use trail) along the shoreline between Eureka Slough and Brainard Slough. Planning for this project began in 2013 and construction funding has been secured. The project is currently going through the final design, right-of-way acquisition, and permitting phases and construction is targeted for 2022-2023. The hazard scenarios developed for this study were used as a basis for developing the project's minimum design elevations. The project proposes to make urgent repairs to the shoreline armoring of the railroad corridor and raising the railroad prism one to two feet between Brainard and Bracut to increase resiliency to flood hazards and sea level rise. Two hazard scenarios were developed as part of this study to estimate the flood hazard reduction benefits of the Humboldt Bay Trail South project. This project is estimated to reduce the vulnerability of major tidal flooding to inland areas for the next 20 to 30 years.
- Under existing conditions, if Highway 101 closes due to flooding, Highway 255 may also be subject to flooding closures. Myrtle Avenue and Old Arcata Road would provide alternate access around Humboldt Bay up to elevation 11.6 feet. Above elevation 11.6 feet, highway routes around the bay could become completely inaccessible. The risk of full closure of the transportation network would be reduced after the proposed Humboldt Bay Trail South project is constructed. Myrtle Avenue and Old Arcata Road will be an increasingly important alternative travel route around the bay.
- For the Jacobs Avenue levee system, overtopping is the most probable potential mode of failure, followed by underseepage, slope instability, and erosion. The Jacobs Avenue area is also vulnerable to flooding that could originate from overtopping of other hydraulically connected areas near Fay Slough during a severe flood event.
- The main water transmission line for the City of Eureka and Humboldt Community Services District and PG&E's natural gas pipeline cross through areas which are protected by privately owned levees and highly vulnerable to both tidal and fluvial flooding. Tidal flooding is initiated during typical, annual high tides with conditions for potential levee failure at water levels above 9.9 feet. A levee failure would result in daily tidal flooding which would severely hinder access to underground utilities for repairs and maintenance.

Part III – Adaptation Project Planning

Part III provides the results of a qualitative risk assessment which considers the likelihood and consequences of flooding within the cells of the study area to characterize the relative risks to public health and safety and the economy. The qualitative risk assessment provides decision-support information for prioritizing adaptation needs. Building on the work presented in Part I and Part II, Part III identifies project concepts and technical studies that could help increase sea level rise resiliency in the study area. Project concepts and technical studies are organized into two planning horizons: near-term (today through mid-century) and long-range (mid-century through late-century and beyond). The Humboldt Bay Trail South project, which has been in development since 2013, and three new project concepts were selected for more detailed evaluation of flood reduction benefits and to test a newly developed benefit-cost assessment methodology. The three project concepts selected for evaluation include a natural shoreline infrastructure project (also known as “living shorelines”) between Bracut and Brainard and two projects involving the Jacobs Avenue area. Conceptual designs for the natural shoreline infrastructure and Jacobs Avenue projects were developed.

Part III provides a description of these three project concepts including key features, flood reduction benefits, and opinion of probable costs. Part III includes a summary of stakeholder outreach, a list of studies related to sea level rise currently in progress, and a discussion of strategic considerations for future sea level rise planning and adaptation efforts.

Key Findings

- Thresholds for increasing health and safety risks and economic risks were identified. In general, floodwater depths less than one foot are expected to create nuisance conditions and temporary disruptions. Floodwater depths of one to four feet represent moderate risks with increasing potential for injury, more extended disruption of community services and land use, and temporary business closures. Floodwater depths in excess of four feet represent the most severe conditions with potential death, disruption of regional services, long-term closures, and permanent changes to land use.
- The area along the Highway 101 corridor between Eureka Slough and Bracut (“Cell A”) has the highest potential for high magnitude consequences resulting from sea level rise. Cell A includes higher density development as well as the Jacobs Avenue area, Highway 101, and critical utilities. The Jacobs Avenue area is vulnerable to flooding from levee failure but also from tidal flooding coming across Airport Road from the Fay Slough/Murray Field area. The Jacobs Avenue area contains a number of small businesses and the mobile home park on Jacobs Avenue represents an economically disadvantaged community. This study focused on identifying potential adaptation projects that would have the greatest benefit to Cell A.
- The scale of potential adaptation projects ranges from small to huge. This study did not address adaptation of the Highway 101 corridor since this will be a huge project (or series of projects) and Caltrans has initiated a separate planning process focused on Highway 101.

- The Humboldt Bay Trail South project, scheduled for construction starting in 2022 (pending completion of right-of-way and permitting), is an example of a multi-objective project that can provide flood risk reduction benefits. Other benefits include active transportation, improved safety, coastal access, and reduction of vehicle miles traveled and greenhouse gas emissions. The Humboldt Bay Trail South project would result in substantial, quantifiable flood reduction benefits. Under existing conditions, overtopping of the rail prism starts at a still water elevation of approximately 9.6 feet, resulting in flooding of Highway 101 and the interior of Cell A. At a still water elevation of 11.6 feet, all lanes of Highway 101 are flooded and several feet of flooding affects properties within Cell A. Elevating the rail prism and implementing the trail would prevent this flooding and the associated damages and highway closure for this range of still water elevations. Improvements to the rail prism increases resiliency to wind wave erosion and overtopping failure that would also result in significant flooding of Highway 101 and Cell A.
- Natural shoreline infrastructure, nature-based solutions, green infrastructure, and living shorelines will be a critical component of effective coastal flood management. (The terms and definitions are fluid and often used interchangeably.) “Natural shoreline infrastructure” generally refers to coastal restoration projects that are designed and monitored for physical and biological benefits, including reducing wave energy and erosive forces. A range of habitat types can be considered depending on context. Natural shoreline infrastructure creates the opportunity to protect or expand rare habitat types, re-establish ecotones, and/or beneficially re-use dredged sediment. The approach of using natural shoreline infrastructure has been incorporated into policy and guidance documents, but such projects are still considered innovative (with design questions) and come with tradeoffs and limitations. A high bar exists to achieve issuance of a coastal development permit for work in the coastal zone. For natural shoreline infrastructure projects there is a need for technical studies, pilot tests, and demonstration projects.
- The natural shoreline infrastructure project concept identified in this study would use a horizontal levee (or “ecotone levee”) between Brainard and Bracut to supplement the elevated rail prism in the Humboldt Bay Trail South project and provide additional protection of Highway 101 by reducing flooding in Cell A for combined wind and wave effects up to a water level of 11.6 feet. As a starting point, the conceptual design assumed a large footprint and volume to maximize salt marsh creation and flood reduction benefits. The avoided damage cost and project cost are comparable, indicating a favorable benefit-cost ratio; however, net benefits are expected to diminish in the longer-term with increase sea level rise. The benefits of ecosystem services, as well as safety benefits to trail and highway users are difficult to monetize and were not included in the avoided damage or benefit costs.

  In 2020, Humboldt County received funding from the National Fish and Wildlife Federation and Ocean Protection Council to conduct additional technical studies to evaluate the feasibility and appropriateness of a natural shoreline infrastructure project along the shoreline between Brainard and Bracut. This study will be completed by the end of 2021.

- The Jacobs Avenue Flood Resiliency and Levee Resiliency Projects are concepts focused on enhancing flood protection for the businesses, residents, and infrastructure within the Jacobs Avenue area. The levee resiliency project would reduce the risk of flooding caused by overtopping directly over the Jacobs Avenue levee. The flood resiliency project would reduce the risk of flooding caused by levee breaches along Fay Slough. Both projects would provide substantial benefits in avoided costs by reducing flooding to commercial and residential properties and allow flexibility in adaptation measures for other areas of Cell A. The projects would also provide protection for some of the most vulnerable residents in the study area.
- Under this study a methodology was developed for a benefit-cost analysis that evaluated quantitative and qualitative flood impacts under existing conditions and benefits associated with the implementation of four sequential projects. Flood impacts included damages to structures, land, roadways, shoreline infrastructure (levees and rail prism), public trails, utilities, and the economy. Benefits were largely comprised of avoided property damages and transportation delays due to flooding with project implementation. The intent of the benefit-cost analysis is to provide a tool for guiding prudent investment of limited financial resources. Monetization methods were not developed for several key categories such as road damage and ecosystem services due to complexities of cause-and-effect and valuation. For example, the monetization of habitat conversions, carbon sequestration, habitat enhancement, and water quality improvement were not estimated. The methodology could be improved in the future by developing approaches for these elements which would provide a more complete assessment of impacts and benefits. The benefit-cost methodology assessed monetized benefits using annual probabilities of water levels and in a scenario-based approach that evaluated specific water level events occurring in specific years over a 20- and 50-year planning horizon. Future benefits were discounted to present value using avoided damage costs, the year in which the event is assumed to occur, and an assumed discount rate of three percent per year. This methodology inevitably depends on a number of assumptions as well as professional judgment, and future benefit-cost analyses could be improved by analyzing the sensitivity to changing assumptions.
- Project scoping often starts big and then can be refined, scaled down, optimized, or value-engineered. For most project concepts identified in this study, the next step would be to perform a subsequent feasibility study to define the design objectives, acquire additional site-specific data to inform the design, and consider alternatives. Funding for project development and construction will be a significant challenge.
- This study identified the following strategic considerations for moving forward with sea level rise planning and adaptation:
  1. Aim to maximize multi-benefit projects and nature-based solutions.
  2. Consider how multiple lines of defense including natural features and built structures work together to provide flood protection and explore how they can be improved to optimize protection.

3. Understand the vulnerability of the transportation network as a whole and work to ensure that alternate routes are accessible during flood events to avoid a complete system shutdown.
4. Incorporate sea level rise adaptation measures into capital improvement projects.
5. Make prudent investments of limited financial resources.
6. Look for cooperative funding opportunities where multiple beneficiaries contribute to flood risk reduction measures implemented at a landscape scale.
7. Expand and improve regional coordination on sea level rise planning and adaptation.
8. Find ways for the public to participate in discussions about adaptation approaches and be involved in meaningful and effective actions.
9. Look at other coastal communities for models of success to emulate and learn from (and examples of failures and mistakes to avoid).
10. Work with interested property owners and land managers to explore managed retreat and identify opportunities where such a transition makes sense and could be feasible.

PART I - INTRODUCTION

1. PLANNING FRAMEWORK

1.1 Overview

This plan presents a framework for developing sea level rise adaptation strategies within a highly vulnerable sub-watershed along Humboldt Bay near Eureka Slough. The study area contains a concentration of transportation infrastructure, utilities, businesses, low-income residential areas, and wildlife areas (Exhibit 1-1). The study was motivated by three guiding questions:

1. What are the most significant flooding risks within the study area?
2. What designs for adaptation projects could be feasible and effective?
3. How can collaborative efforts be advanced?

The purpose of the study was to work with public agencies, landowners, scientists, and stakeholders to understand the specific vulnerabilities to the places and resources within the study area and to develop viable project concepts for the most at-risk locations. A primary focus of the study was to develop a scenario-based planning approach for understanding the range of possible flood hazards under current conditions and with future sea level rise. This approach includes an evaluation of how the coastal landscape will likely respond to various flooding events. The study is intended to help advance the collective readiness for designing and implementing effective sea level rise adaptation projects.

1.2 Introduction

Global climate change and sea level rise are ongoing processes that will continue to impact low-lying coastal areas including the developed, agricultural, and resource lands around Humboldt Bay. The Humboldt Bay region is subject to an additional geologic factor that compounds the effects of sea level rise: downward vertical land motion caused by movement of tectonic plates along the Cascadia subduction zone.

The lands around Humboldt Bay have long been vulnerable to flooding. Railroads, roads, and levees built around the bay have served to manage tidal waters, creeks and streams, and local stormwater drainage. Built individually, and maintained individually, these features function as a system to protect inland property and infrastructure from flooding. In particular, the rail prism, situated along the shoreline of the bay, has by default become critical coastal protection infrastructure.

When the first railroads, roads, and levees were built in the early and mid-20th century, it was assumed that sea levels would remain constant. However, data from the North Spit tide gauge from 1977 to 2016 indicates a rate of relative sea level rise equivalent to 19 inches per century. Under current global conditions, the rate of increase is now expected to accelerate.

The potential for flood damage under existing conditions is significant and flood risks will increase as sea levels rise. Failure of a segment of the rail prism or levee system could severely impact low-lying areas and transportation along the Highway 101 corridor. Damage from the 2005 New Year's storm foreshadowed the future if no action is taken. That moderate flood event resulted in overwash of tide waters onto Highway 101, temporary closure of the southbound lane, and damage to the rail prism. To date, the railroad is unrepaired and remains exposed to further erosion, leaving the Eureka-Arcata transportation corridor more vulnerable to future flooding events.

Less immediately visible are the potential adverse impacts to habitat as intertidal salt marshes respond to increasing sea levels. Salt marsh is at risk for being converted to mud flats unless the rate of sediment deposition keeps pace with sea level rise, or there is adequate room for the salt marshes to migrate inland and reestablish at higher elevations.

Tectonics and Relative Sea Level Rise

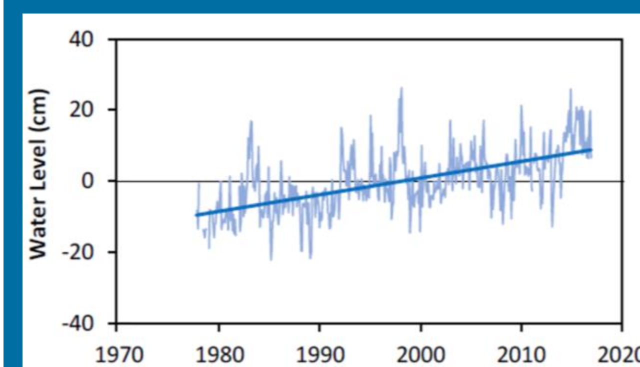
The movement of tectonic plates in the Pacific Ocean off Cape Mendocino causes local sinking, or subsidence, of landforms around Humboldt Bay and the Eel River Delta.

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.

The term ***relative*** (or ***local) sea level rise*** accounts for both the rate of sea level rise and land subsidence. Historical data from local tide gages provide estimates of relative sea level rise.

Relative sea level rise rates for Humboldt Bay are approximately 5 mm/year (19 inches per century) which are higher compared to the rest of California. These rates are expected to increase in the future.

The graph below shows the Relative Sea Level Rise Trend of approximately 5 mm/year for North Spit, Humboldt Bay (1977 to 2016) tide gage accounting for land subsidence and sea level rise (NHE 2018).



The vulnerability of the Humboldt Bay area to sea level rise has been studied since 2010 and continues to be a focus and concern for residents and public agencies within Humboldt County. Understanding and planning for sea level rise draws on many disciplines, including hydrology, geomorphology, ecology, engineering, and economics. Methodologies and guidance documents are evolving as new information is gathered, new ideas are developed, and collective knowledge advances. Concurrent sea level rise adaptation planning in other locations, especially in the San Francisco Bay area where sea level rise planning is especially advanced, provides perspective and examples that can inform local planning efforts.

This adaptation planning effort considers these evolving approaches and examples to move forward incrementally toward actionable projects that will help the region prepare for and adapt to the coming changes. Fortunately, previous work has identified vulnerable areas around Humboldt Bay, and the region's technical understanding of flood risk continues to grow. Progress is also being made in regional collaboration, with public agencies expressing strong interest in sea level rise planning, and current projects factoring sea level rise into planning and design documents. The Humboldt Bay community acknowledges and supports urgent action, and its community members, local agencies, and Humboldt State University are providing valuable creativity, expertise and social capital towards adaptation planning.

Broad community support will be an essential condition for success due to the multiple, significant challenges confronting efforts to adapt to sea level rise. Climate change and sea level rise are driven by global-scale activities and processes. Natural systems are dynamic and often unpredictable. While there has been progress at refining local understanding of flooding, many uncertainties remain. The vulnerable lands within the planning area cross ownership and jurisdictional boundaries. Land management has been dispersed, without an enduring centralized organizational structure or planning framework for cohesive coordination. Sea level rise adaptation requires developing implementation strategies at a larger scale than most infrastructure projects. While project concepts exist, development of site-specific adaptation designs are needed. Design objectives and performance criteria have not been established for the new paradigm of sea level rise. Flood protection projects for these lands will be expensive; financial constraints will likely be a major barrier to action. At the same time, projects with the potential to impact coastal resources are subject to significant regulatory constraints by the Coastal Act and other laws and regulations.

With global climate change and rising seas, communities around Humboldt Bay will need to adapt and learn to live with water in new and hopefully innovative ways.

1.3 Key Terms and Concepts for Sea Level Rise Planning

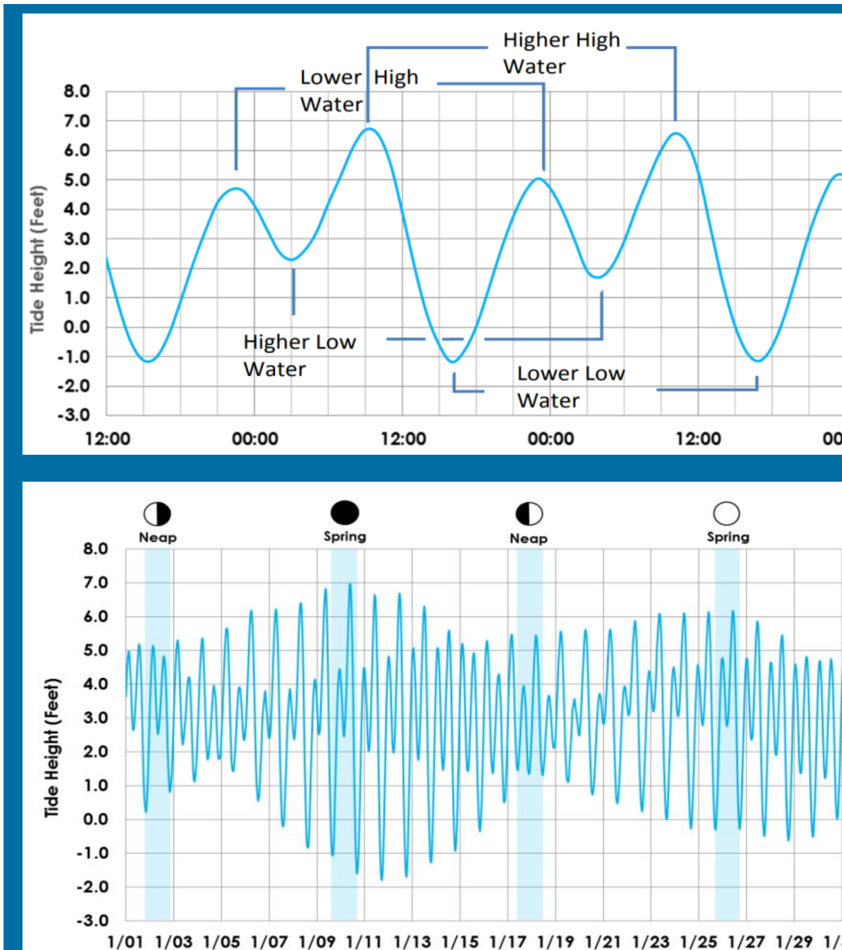
The terms and concepts described here will be referenced repeatedly throughout this plan.

Flooding

Most people recognize flooding as water that has collected or ponded in areas typically maintained as dry and consider it an aberration from the norm. However, flooding is fundamentally a natural process that shapes landscapes, supports specialized habitats and wildlife species, and performs watershed services. Flooding can be initiated by either fluvial or tidal sources or a combination of the two.

Fluvial flooding (or riverine freshwater flooding) results when water exceeds the banks of rivers and streams due to major rain events or snowmelt from the contributing watershed. The rate and magnitude of fluvial flow runoff from a watershed is a function of the rate of precipitation over the watershed and the watershed characteristics (slope, land cover and antecedent soil conditions). In low lying areas where fluvial flow enters estuaries or bays, flooding can be exacerbated by the tide and the coincidence or high fluvial flows with high tides.

Each day Humboldt Bay experiences two high tides and two low tides, with each of the four tides reaching different elevations (referred to as a mixed semi-diurnal tide cycle). During full and new moons, the sun and the moon are aligned with respect to the earth and the combined gravitational effects cause a larger than average tidal range, so differences between the high and low tides are greatest ("spring tides"). During quarter moons, when the gravitational effects of the sun and the moon are opposed, a smaller than average tidal range occurs ("neap tides"). Mean Higher High Water (MHHW) is the average of the higher high-water height of each day's set of tides (NOAA 2016). The highest annual tide predicted is the Highest Astronomical Tide (HAT). The HAT is often referred to as the King Tide, a non-scientific term commonly used to describe exceptionally high tides that have an occurrence of once or twice every year.



Representative mixed semi-diurnal tide cycle during a two-day and one month period including the monthly spring and neap tide patterns associated with the moon phases.
Source: ART 2016, NOAA 2005

Fluvial flooding is beneficial in natural environments where surface water channels are connected to floodplains. Flooding allows the deposition of sediment to maintain ground elevations and replenish soils. Flooding also provides access to unique, off-channel habitat features for aquatic species. However, development within a floodplain often results in the construction of levees and berms intended to prevent flooding, which is considered potentially damaging or a nuisance, but at the expense of these beneficial effects.

Similarly, while tidal flooding supports important processes that benefit coastal wetland ecosystems, many coastal developments often include infrastructure to limit the encroachment of tidal flooding. As sea level rises, tidal flooding along the coast will also increase, increasing erosion on these protective structures and flooding beaches, wetlands, and other low-lying lands with greater frequency.

Concepts Related to Flooding

Erosion
A natural process in which sediment (such as rocks, gravels, soil, sand) separates and moves away from landforms. Erosion is typically caused by the force of wind or water passing against the surface of the landform.

Sedimentation
A natural process by which eroded sediments are deposited. The size of the sediment deposited, and the distance it has traveled, can be used to estimate the energy of the erosive force. Also referred to as deposition or aggradation.

Inundation
A term often used synonymously with flooding. "Inundation" may imply a condition where lands are permanently submerged while "flooding" implies a temporary condition.

Along the coast, storm surges and wind waves can exacerbate both fluvial and tidal flooding. Storm surges are caused by wind and atmospheric pressure pushing water towards the shore and increasing water levels above the astronomical tides. Wind waves are waves generated locally by wind passing over a large body of water like Humboldt Bay. Humboldt Bay is a "sheltered water" area that is largely protected from ocean waves approaching from offshore, but locally generated wind waves can be significant. The height of a wind wave depends on fetch length (the distance winds blow over the water), water depth, wind speed, and duration. Depending upon tidal water elevation, wind speed, and wind wave height, waves may break on the salt marsh or against earthen or rock armored landforms such as levees. In large enough storm surges, waves can break at or over the top of the levees creating splash referred to as wave runup. The wave runup from the breaking wave can overtop the levee and transport water and fine sediment landward. Floodwaters resulting from overtopping can undermine the structural integrity of earthen levees and cause flooding of normally dry land for extended periods of time.

A high tide with storm surge and wind waves can result in exceptionally high-water surface elevations along the shoreline. In addition to overtopping scenarios as described above, tidal flows can travel up fluvial tributaries, extending the tidal influence further upstream. Should this coincide with fluvial flooding in a developed or constrained river corridor or estuary mouth, the resulting flooding can be amplified.

Both fluvial and tidal flooding can be extreme, cause damage to infrastructure and property, and imperil lives. The effects of flooding are often immediate, severe, and easily visible. However, even small and moderate flood events can weaken protective infrastructure over time or otherwise result in cumulative effects.

Hydraulic models of Humboldt Bay developed and refined by Northern Hydrology and Engineering since 2015 are currently the primary tools for evaluating flood risk in the study area.

Flood Risk

Flooding is a potential natural hazard near the interface between human development and water bodies with dynamic water levels. Assessing the risk of flood damage involves considering the likelihood or probability of a certain flood event combined with the magnitude of the consequences from that event. The goal of risk management is to reduce risk to an acceptable level. Residual risk is the level of risk remaining after implementing risk reduction measures. The assessment of risk requires making assumptions based on a person or organization's willingness to accept residual risk (risk tolerance). Some situations warrant being more risk averse, while other situations warrant a higher toleration for risk.

A common starting point for evaluating flood risk is to review flood designations established by the federal government. The Federal Emergency Management Agency (FEMA) regularly evaluates landscapes in terms of their susceptibility to flooding specifically to help local agencies and property owners understand and manage the potential risks associated with development or use. In areas designated Special Flood Hazard Areas (SFHA), the federal government establishes national building standards in floodplain development and requires flood insurance through the National Flood Insurance Program (NFIP). Special Flood Hazard Areas are designated on FEMA flood insurance rate maps (FIRMs). Local agencies may also restrict development in these SFHAs.

The Language of Risk Management

Hazard
Events or physical circumstances such as flooding or erosion that can result in:

- the loss or harm to life,
- damage to property,
- interruptions of economic activity including losses to agriculture, disruptions of transportation,
- environmental damage

Vulnerability
The degree to which a person or asset can withstand or recover from a hazardous event. Considerations include how exposed the person or asset is to hazardous circumstances, and how sensitive they or it is to those circumstances. Vulnerability assessments describe the impacts that would be incurred by an asset or set of assets by temporary flooding or permanent inundation from coastal waters. This may include erosion, physical damage or functional disruption to structures or systems from temporary coastal floods, and/or land and asset loss through permanent inundation.

SFHA designations are established for areas that are likely to be inundated by a flood event that has at least a one percent chance of being equaled or exceeded in any given year (FEMA 2019).

This threshold is often referred to as the base flood or 100-year flood. Moderate flood hazard zones are also often designated on FIRMs, for example the area with at least a 0.2% chance of flooding in any given year (referred to as the 500-year flood). These probabilities are based upon the historical records of the flood source.

FIRMs show the base flood elevations for the SFHA zones affected by both riverine and coastal flooding. The base flood elevation is the elevation of the water surface for the flood event that has a 1% chance of occurrence in a given year. In coastal areas, the base flood elevation is based on the total water level which includes the effects of storm surge and wave runup (FEMA 2019). The base flood elevation that accounts for total water level can substantially exceed the still water elevation. The use of total water levels along the coast reflects a change in FEMA policy which can be observed in Humboldt Bay FIRMs. The 1986 maps were based on still water elevations only, while the maps updated in 2017 provide a more realistic estimate of risk by using total water levels. However, the Flood Insurance Study that generated these maps did not factor sea level rise or projected future storm events. Over time, these areas could experience more frequent and severe flooding than the current FEMA risk analysis captures.

Much of the study area is designated with flood zones A, AE, and VE (Exhibit 1-2). AE flood elevations range from 10-11 feet and VE elevations range from 14 to 18 feet. As noted in the definitions below (Table 1), Zone A base flood elevations are not specified.

Table 1. FEMA Flood Zone Descriptions

FEMA Flood Zone	Description
A	Areas with a 1% annual chance of flooding and a 26% chance of flooding over the life of a 30-year mortgage. Base flood elevations have not been issued within these zones (also known as "Unnumbered A Zones").
AE	Similar to A Zones, except base flood elevations are provided based on detailed floodplain analyses. AE Zones are now used on new format FIRMs instead of A1-A30 Zones.
V	Coastal areas with a 1% or greater chance of flooding and an additional hazard associated with storm waves. These areas have a 26% chance of flooding over the life of a 30-year mortgage. Base flood elevations have not been issued within these zones.
VE, V1-30	Similar to V Zones, except base flood elevations derived from detailed analyses are shown at selected intervals within these zones.

While FEMA flood maps are useful starting points for understanding flood risk around Humboldt Bay, it is important to understand their limitations. FEMA flood maps indicate flood hazard based on only one probability – the 1% flood at its peak. In addition, the hazards are generalized across a large landscape and do not provide details regarding where flooding is initiated or the circulation of floodwaters. FEMA flood maps don't account for flood events with higher probabilities than the 1% flood. The flood models that were used to develop the FEMA flood maps are based on historical flows and water levels and do not account for the effects of climate change such as increased precipitation intensity and sea level rise.

A landscape that is flooding changes by the minute. The duration of flooding will vary and could be localized depending on physical site conditions, storm drainage controls or other factors. Increases in the intensity of precipitation may change flood peaks. Sea level rise will result in increased still water elevations that affect total water elevations, exposing more areas to coastal flooding.

These considerations justify deeper inquiry into flood risk and vulnerability of coastal areas. There is no one single way to assess vulnerability. Vulnerability assessments can have different purposes, approaches, assumptions, and simplifications. Conservative approaches often overestimate risk but can help to screen where problems exist. This protective approach may be appropriate when risk is high; where risk is low, less conservative assumptions may be appropriate. More detailed study with rigorous modeling methods can provide more accurate and realistic estimates of the extent and effects of flooding and refine local understanding of the flood risks.

Levees and Dikes

Levees and dikes are embankments constructed of earth fill used to block surface flows and hence limit or prevent flooding of the protected area (USACE 2000). The terms levee and dike are often used interchangeably. Levees may or may not be formally designed by professional engineers but are often considered more substantial than dikes. Sometimes the distinction is made that levees keep water in, and dikes keep water out. Another common distinction is that levees protect land that is normally dry but that may be flooded when rain or snow melt raises the water level in a body of water whereas dikes protect land that would be naturally underwater most of the time. Additionally, the term levee is commonly used within a riverine setting and the term dike may be more commonly used in a tidal system. Given the diverse landscape setting of the study area where both fluvial and tidal systems span the landscape that was and was not historically flooded, the term levee and dikes could be used interchangeably.

Levees have a trapezoidal shape and are typically situated adjacent to channels or shorelines to prevent flooding. The top may be maintained for access roads or footpaths. Contemporary levees are typically designed with a few feet of additional height (freeboard) above the design maximum water surface elevation as a safety factor. The levee design geometry (height, top width and side slopes) considers multiple factors such as exposure to flood and erosion hazards, risk to landward uses, and material composition of foundation and fills. Levees are typically comprised of low permeability soils and/or an impermeable core to reduce seepage. The soils are placed with mechanical compaction to achieve maximum soil density that reduce pore-pressure under saturated conditions, long-term subsidence and slumping. Under certain conditions, drains are placed in or adjacent to earthen levees to intercept sub-surface seepage under and/or through the levee during prolonged periods of saturation. Based on the levee's exposure to hydraulic forces (i.e., high flow velocity and/or wave attack) surficial erosion prevention measures using armoring techniques (i.e., rock, concrete, etc.) may be necessary.

Levees around Humboldt Bay were generally built by landowners with local native materials and prior to contemporary levee design standards. None of the levees on Humboldt Bay were built by the U.S. Corps of Engineers (USACE), although the USACE did undertake levee projects in other areas of the county. Unlike many of the levees constructed around Humboldt Bay, the railroad prisms were typically filled in the upper 1-2 feet with permeable ballast rock, thereby reducing its effectiveness to prevent seepage during high water events. Although the railroads were not designed to serve as levees, they have become *de facto* levees. Section 4.4.5 will discuss modes of failure for levees in greater detail.

A primary concern about levees is that if they fail, the consequences of flooding can be rapid and severe. One of the challenges of levees is the high cost of repairs. In addition, lands protected by levees are vulnerable to the weakest link in the system, which may be situated on property owned by others. Raising or re-alignment levees are major projects that would require substantial funding and would be subject to extensive design and permitting. Raising a levee would likely require widening the footprint, which depends on having space available and would require mitigation to offset impacts. Regulatory constraints and limitations on levee projects are discussed in Section 1.5 and Section 8.12.

Adaptation

Two high-level approaches for responding to climate change are mitigation and adaptation. Mitigation refers to efforts to reduce the flow of heat-trapping greenhouse gases into the atmosphere, either by reducing emission sources or enhancing the sinks that accumulate and store these gases. Adaptation refers to efforts to adjust to life in a changing climate by reducing the vulnerability to the harmful effects of climate change, along with making the most of any potential beneficial opportunities. This study focuses on adaptation measures to reduce flooding risk associated with sea level rise.

Adaptation approaches generally fall into three categories:

- **Protect.** Vulnerable assets may be protected from hazards through the placement of protective structures or natural features that will resist the impact(s) of the hazardous event. Levees are an example of a "protect" approach.

- **Accommodate.** Vulnerable assets may be modified to accommodate the action of the hazardous event. In floodplains, the raising of homes on piers or pilings to allow floodwaters to pass beneath is an example of the "accommodate" approach.
- **Re-locate or Managed Retreat.** Vulnerable assets may be relocated from the path of the hazardous event and reconstructed on safer ground. The planned re-routing of Highway 101 in Del Norte County at Last Chance Grade is a local example of a relocation approach to a landslide hazard. Relocating a levee further away from a flooding source (called a "setback levee") is another example.

Adaptation measures are actions that can be taken to help make vulnerable areas and assets more resilient to flood hazards. The San Francisco Estuary Institute identifies four categories of adaptation measures (SFEI, 2019):

- **Nature-based measures.** Physical landscape features that are created and evolve over time through the actions of environmental processes or features that mimic characteristics of natural features but are created by engineering and construction (in concert with natural processes) to provide coastal protection and other ecosystem services.
- **Conventional physical (gray) infrastructure.** Physical features (such as levees and seawalls) constructed by humans to provide coastal protection with relatively hard materials such as concrete, rock, and steel, and without incorporation of biological components.
- **Policy and regulatory measures**. Laws, policies, and regulations such as permits, zoning, and general plans to influence future land use and the built environment to manage risk. Examples include FEMA's National Flood Insurance Program, the California Coastal Commission's Coastal Act, and local building codes and zoning.
- **Financial measures.** Non-physical ways of creating financial incentives and disincentives to enable implementation of other structural and policy measures. Examples include conservation easements and transfer of development rights.

Nature-based measures are increasingly promoted for the multiple benefits they can confer to a project. Examples of this type of project include constructed oyster reefs, constructed salt marsh "horizontal levees" and reforested or revegetated buffer habitats such as living shorelines. All of these examples dampen the energy of incoming waves to reduce damage of assets along the coast. Not all of these examples are necessarily applicable along Humboldt Bay. Gray infrastructure is recognizable in the levees, breakwaters, sea walls, and other armored features that protect shorelines, usually by "hardening" them. Hybrid approaches that integrate nature-based measures and conventional physical infrastructure are possible.

Phasing of adaptation strategies over time should be expected. Implementation of a shoreline protection strategy may come in phased segments. With limited resources, the areas of greatest vulnerability will be prioritized to minimize potential harm to the public and assets, with additional segments implemented with the availability of funding. Phasing may also have an intentionally temporal scale, with implementation of short- and long-term strategies: start with short term infrastructure protection and follow with policy and financial strategies for eventual accommodation or relocation.

One approach for flood risk reduction is to plan for a system of combined measures, or multiple "lines of defense." A shoreline protection strategy may incorporate the nature-based measure of a horizontal levee with the gray infrastructure of rock riprap or a raised levee as a secondary level of protection. This may also be accompanied with redevelopment restrictions, or other policy or financial measures on the property behind, bringing together short-term and long-term time frames.

Exploring viable combinations of measures with phasing that responds to predicted rates of sea level rise is an important step in the adaptation planning process. This undertaking may result in the recognition that some property or infrastructure may not be able to be protected at some point in the future.

Resilience

Extreme events represent disturbances that can have severe adverse consequences, potentially leading to fundamentally altered conditions and in the worst-case scenario irreparable damage or total collapse. The concept of resilience reflects the overall preparedness for enduring an extreme event. The concept of resilience can be applied to human beings, communities, natural systems, and the built environment (Rodin, 2014). Broadly speaking, resilience is the capacity to (1) absorb disturbance and (2) recover from shocks and stresses while maintaining basic function and structure. In addition, human beings and communities can aspire to (3) adapt and grow from disruptive experiences and (4) take advantage of opportunities to develop creative (even transformational) solutions to the hazards they face. These dimensions of resilience provide a positive vision that humans and communities can work toward. In this context, resilience should be viewed as a continuous practice rather than an end-state. Individuals and communities can emerge stronger from disturbance events and use them as growing and learning experiences. Many plans and studies look specifically at the concept of resilience applied to coastal resources (e.g., NRC, 2012; ASBPA 2014; Masselink and Lazarus, 2019).

Critical Resources

Critical Resources are broadly defined as resources that provide a service that is relied upon within and adjacent to a project area (USACE 2014). These could include structures (residential and commercial); sensitive environments or habitats; infrastructure (roads, water/sewer lines, power, navigation channels), facilities (police, fire, hospitals, nursing homes and schools); and evacuation routes. Section 6 of this study evaluates the vulnerability of critical resources to sea level rise impacts within the study area.

Landforms and Human-made Features

Landforms are physical features on the Earth's surface with characteristic shapes produced by natural processes. Coastal shorelines are situated at the interface between marine and terrestrial environments, resulting in a dynamic mosaic of landforms. Geomorphology is the study of the properties, origins, evolution, and trajectory of landforms. The term "landscape" refers to an area comprised of a collection of natural landforms and human-made features. Human-made features include roads, railroads, and levees.

Natural Shoreline 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))

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 a, 2018):

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

Time Scales

Riverine and coastal flood processes act on landforms over time and a range of events. Low intensity, frequent activity generally maintains geomorphic forms, such as the shape of a stream or slough channel, or the slope of a coastal salt marsh complex. Higher intensity, but less frequent, extreme events (storms) tend to disrupt these forms. As low intensity, high frequency activity resumes, the shapes gradually re-form, incorporating the effects of the disturbance into it. The temporal scales of these events can be daily, monthly, annual, decadal, or longer. In the case of coastal processes, tidal movement shifts constantly, by hours and minutes.

Coastal flooding is related to extreme high tide events. Tides are influenced by the position of the sun and the moon; the movement of tidal waters across the spheroid shape of the earth and its coastlines; weather patterns and climatic factors. A significant recurrent multi-year climate cycle is the El Niño Southern Oscillation (ENSO), which involves an oscillating warming and cooling pattern of the Pacific Ocean. ENSO effects the intensity of coastal storms and overall precipitation in northern California, triggering both droughts and extreme precipitation events.

The rate and of sea level rise will depend primarily upon global greenhouse gas emissions. Although the long-term trend is upward, ocean circulation patterns associated with ENSO and Pacific Decadal Oscillation (PDO) will cause variability along the California coast at seasonal and multi-year scales. As a result of sea level rise, long term water level conditions are not stationary.

Thresholds and Tipping Points

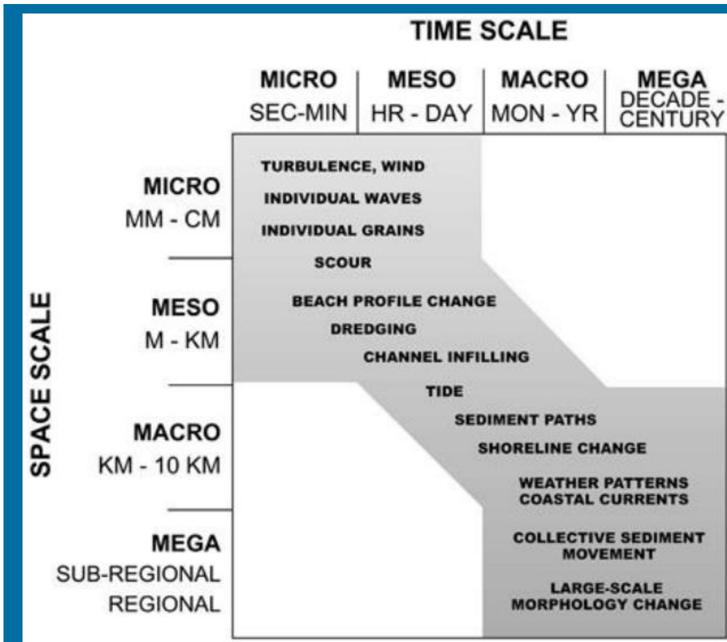
As sea levels rise, a road may occasionally be flooded, during a King Tide, for example. It is a nuisance but doesn't cause significant damage. However, at some point the frequency of tidal inundation will become significant, interrupting operations that has a cascading effect on users. This point when the impact becomes significant is the **threshold**. If action is not taken, the road's operational capacity, and physical structure, may decline, to the point where it is structurally compromised or fails. This critical point when instability or decline rapidly occurs is called the **tipping point**.

There are also time scales for built assets. A mortgage can last 30 years, which influences lending, purchase and insurance decisions; the economic period of analysis for an infrastructure project is often 50 years. The design life of a bridge may be 75 years. Built projects often outlast their design lives.

Both the project design life and the actual "useful life" of a project may be in conflict with, and be cut short, if sea level rise projections aren't factored into project's planning horizon. This is complicated by the fact that, while projections are fairly clear over a 10 to 20-year horizon, projections diverge (and may be subject to significant revision as new information becomes available) over the 50 to 100-year horizon. Considering that the planning timeframe for a large infrastructure project itself is 10 to 30 years, it is prudent to be conservative when estimating the long-term effects of climate change on a proposed project. However, being overly conservative could make beneficial projects financially infeasible or necessitate the diversion of funds at the expense of other important projects.

Spatial Scales

Spatial scales are the geographic frames of reference from which a project is studied. They vary from very large (e.g. global) to regional (e.g. Humboldt Bay) to landscape (i.e. large areas with common ecosystem or hydrologic processes, or other characteristics) to fine (i.e. a specific site or project footprint). Different scales may be more pertinent to different data sources or models, types of evaluation, and levels of detail in planning and design. The finer the scale, the more capability there is for focusing on key variables and site-specific conditions that control processes; the larger the scale, the more general and greater the need for simplifying assumptions. It is important to select the best spatial scale for technical analysis of natural processes and flood hazards. Landscape scale refers broadly to a spatial scale large enough to adequately encompass ecological processes, landforms, and habitats that can be managed cohesively by a common set of planning objectives.



Temporal and Spatial Scales of Morphological Response to Coastal Processes, Gallop et al. (2015).

This project's study area is a landscape-scale hydrographic area that is a subset of coastal plains around Humboldt's North Bay. The North Bay is one spatial sub-unit of Humboldt Bay, which also includes South Bay and Entrance Bay. The study will explore design concepts for specific sites (project footprints) within smaller hydrographic units, spatial units protected by unique levees and therefore separated by slough channels and the Bay shoreline. Spatial scale can also influence social organization and stakeholder engagement, which is tailored to respond stakeholder's proximity and level of impact by the issues under study.

Uncertainty

In the context of sea level rise adaptation planning, there are many potential sources of uncertainty, including:

- Global emissions and atmospheric/ocean response
- Rate of relative sea level rise
- Occurrence of extreme events is unpredictable

- Potential clusters of extreme events before repairs are made
- Future human interventions
- Physical and ecological systems are dynamic and interact in complex ways
- Limited knowledge and data
- Potential major disturbance from seismic event or tsunami

Some of these uncertainties can be reduced with improved information or understanding, while other uncertainties are irreducible. While there may be an instinct to delay action and attempt to resolve uncertainties, this creates a risk of paralysis and failure to act in a timely manner. The consequences of not acting may be more severe than the consequences of acting with residual uncertainty. Strategies for dealing with uncertainty include: (1) explicitly account for uncertainty in plans and designs, (2) adopting a learning approach that makes adjustments over time, and (3) focusing on ways to build resilience and make "robust decisions." A "robust decision" is designed to be less sensitive to uncertainty about the future by performing well across a wide range of future conditions, although it may not be optimal for any particular future scenario (Kalra et al, 2014; Dittrich et al, 2016).

1.4 Project Outline

Study Area

Humboldt Bay is a tidal lagoon system located in northern California approximately 100 miles south of the state's border with Oregon. It is the second largest enclosed bay in the state of California and supports over 300 marine and wetland wildlife species through its diverse coastal habitats that include deep-water channels, tidal channel and sloughs, mudflats, salt marsh, brackish marshes, freshwater marshes, coastal prairies and agricultural pasture. The bay supports the largest West Coast oyster production operations.

The study area focuses on an approximately 3,300-acre subset of the Bay, characterized by the influence of the Eureka Slough, a navigable water body that drains into the Arcata (or North) Bay segment of Humboldt Bay (Figure 1). The Eureka Slough hydrologic sub-unit includes tidal sloughs and channels, mudflats and wetlands, diked agricultural lands, culverts and drainage ditches. A network of linear landscape features protects low-lying land (diked former tidelands). These are common features throughout Humboldt Bay, making this study area ideal for establishing a methodology for adaptation elsewhere in the bay.

The study area receives freshwater flows from Freshwater Creek and other smaller streams draining agricultural, forested, and urban areas. In addition to agriculture and ranches, utilities, transportation and a mix of industrial, commercial, and residential land uses also traverse the study area, including critical resources and places, such as:

Figure 1. Project Study Area

- Transportation infrastructure and corridors (Highway 101, Humboldt Bay Trail, railroad)
- Jacobs Avenue residential and commercial area
- Myrtle Avenue, city streets
- Murray Field Airport
- Mid-City Motor World and Brainard (former mill site)
- Agricultural lands and Fay Slough Wildlife Area
- Mudflats, salt marsh, riparian areas
- Residential areas along Eureka Slough (Bay Street)
- Eureka's Bridge District
- PG&E natural gas and electrical distribution systems
- City of Eureka and Humboldt Community Services District water distribution and sewer collection systems

Multiple boundaries of a natural, legal, or structural character traverse the study area. These include governmental jurisdictions, ownerships, built and natural features, tidal and fluvial waters, open bay and inland, and motorized and non-motorized infrastructure.

The study area lies fully within the Coastal Zone, an area subject to the Coastal Act as administered by the California Coastal Commission. The City of Eureka and Humboldt County are the two jurisdictions with land use authority (Exhibit 1-3). The study area within the City of Eureka jurisdiction spans approximately from Halvorsen Park to Second Slough, between Myrtle Avenue and Eureka Slough, Jacobs Avenue and Indianola Cutoff, including the recently annexed former California Redwood Company (CRC) Mill. The study area within Humboldt County jurisdiction includes Myrtletown, agricultural lands on the northwest side Myrtle Avenue, and rural residential developments near Indianola cutoff.

Landscape Features of Study Area

Subtidal and intertidal lands
The open water, mudflat, and salt marsh landscapes are prominent features of the landscape and study area.

Linear landscape features
Constructed elements with a linear form, such as railroad prism, levees/dikes, and highways cross the study area, directing movement and defining many views. While many of these linear features were created to enable transportation, they often also function as a bulwark against incoming tide waters.

Protected low-lying land and the interior drainage network
Agricultural pasture (formerly tidelands) and tidal slough channels separated by levees.

Uplands
The upper terraces and valleys, many of which are developed to some degree with residences, or other urban development.

Funding Sources

The primary funding for this study was an Adaptation Planning Grant awarded to the County of Humboldt by the California Department of Transportation (Caltrans). The County of Humboldt, Humboldt County Association of Governments, and City of Eureka are co-sponsors of the project and contributed match funding. The relatively high concentration of low-elevation multimodal transportation infrastructure, utilities, businesses, low income residential and wildlife areas, combined with exposed and aging flood control infrastructure result in a high vulnerability ranking and therefore prioritization of this area for adaptation planning.

Project Objectives

1. Build relationships and an organizing framework for advancing collaborative efforts among public and private landowners at a regional scale
2. Improve the collective understanding of risks to transportation infrastructure from flooding and inundation hazards associated with sea level rise in Humboldt Bay
3. Identify vulnerable populations and the interests of affected landowners and stakeholders, including non-transportation infrastructure (water, natural gas, electricity) and agriculture
4. Identify feasible conceptual designs that protect infrastructure and are compatible with adjacent land and develop an implementation strategy
5. Develop tools for evaluating the costs and benefits of investing in adaptation projects
6. Establish a methodology for developing adaptation plans that can be applied in other discrete watershed basins around the perimeter of Humboldt Bay

Primary Tasks

This study undertakes two major tasks, advancing vulnerability assessment and initiating planning for adaptation projects (Figure 2). Embedded within the vulnerability assessment, the project team uses existing condition information and data to build descriptive and computational models of the geomorphic conditions, site hydraulics, and study area assets. These models will be used to generate hazard scenarios specific to sea level rise, flooding, and storm surges or wave attack. The output from these scenarios will produce an inventory of vulnerable infrastructure assets and lands.

The adaptation project planning task focuses on a qualitative risk assessment for transportation assets and other critical resources with consideration of the likelihood of extreme flood events and the potential consequences. This analysis will help identify the most at-risk assets and resources. Conceptual design alternative approaches to adapting these assets and resources to climate change will be developed, followed by a benefit-cost analysis. With an understanding of the financial, functional, and quality of life ramifications of each alternative, the project team will conclude the study by presenting adaptation strategies for these resources.

Project concepts presented herein are for discussion purposes only. Inclusion of project concepts in this plan does not imply a commitment that the projects will be implemented. This plan does not contain legally binding policies or have any effect on land use designations.

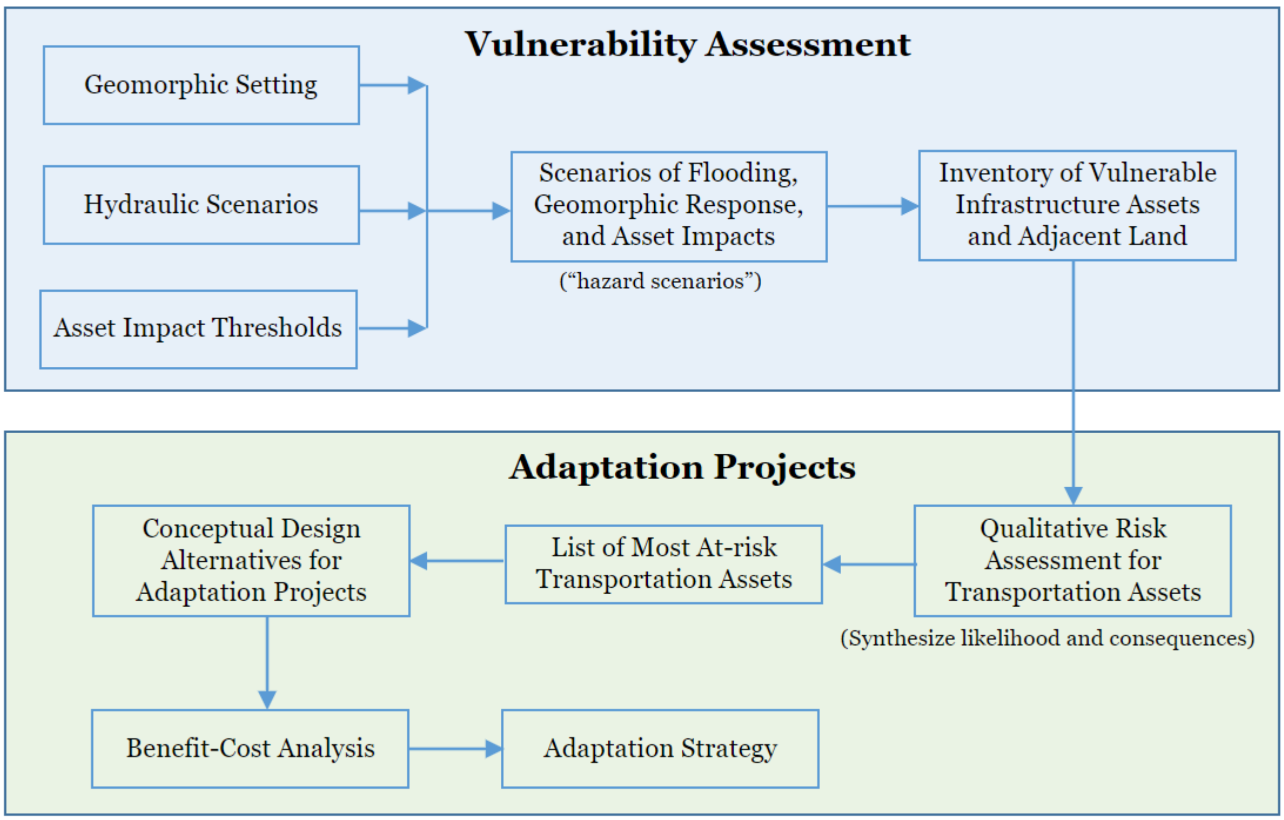


Figure 2. Sea Level Rise Adaptation Planning Flow Diagram

Intended Use of Report

This study is intended to enable advancement from screening-level vulnerability assessment to more detailed, place-based risk analysis and project planning. The study introduces a planning approach for sea level rise at the hydrographic area scale. The study will provide decision-support tools to property owners, land managers, planners, and engineers to apply to specific projects in the future.

The project will be a building block for future advancements. Sea level rise planning is a rapidly advancing field. Reports contribute to incremental progress but become obsolete as new information arises, typically within in 3-5 years. The intended audience for this report encompasses the general public including citizens, students, landowners, and specialists.

1.5 Vision Statement and Key Assumptions

Vision statements articulate our core values and express our collective goals and desired future conditions. This study adopted the following vision statement:

Vision Statement

1. Landowners and managers collaborate on implementing an integrated strategy of short-term and long-term actions to build resilience to flooding hazards and achieve an acceptable level of flood risk. Major disruptive flood events are avoided. For properties where maintaining current land use is unsustainable due to the flooding hazards associated with sea level rise, there is strategic relocation and an orderly transition to a new future use.
2. The critical resources of the Eureka Slough hydrographic area are protected from flooding hazards by multiple lines of defense including natural features (mud flats and salt marsh) and built structures (such as levees and embankments).
3. Public officials, landowners, and residents are aware of flood hazards associated with Humboldt Bay and freshwater tributaries and incorporate the goal of reducing flood risk into all pertinent planning and management decisions.
4. Diverse habitat types and healthy ecosystem functions are maintained.
5. Disadvantaged communities are not disproportionately impacted by flooding hazards or the costs of adaptation.
6. Adaptation projects are supported by federal and state funding.

Key Assumptions

1. The Highway 101 transportation corridor between Eureka and Arcata will likely need to be reconstructed as a causeway or viaduct (either a raised embankment or a roadway built on piers) 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).

e. Caltrans is making substantial investments through the Eureka-Arcata Highway 101 Corridor Improvement Project currently in construction and the future replacement of the Eureka Slough bridges (see Section 2.3.1).

2. Sea level rise adaptation will require an incremental approach utilizing a combination of short-term actions to reduce immediate risk and gain time along with long-term actions to address future conditions. There is not a single project or action that will accomplish complete adaptation.

3. Projects to enlarge or expand a levee to increase protection from flooding hazards will be limited under the Coastal Act to the protection of structures that existed prior to 1977. In addition, the Coastal Commission is unlikely to approve new development, redevelopment, or major renovations that would rely on existing or enlarged or expanded levees for hazard protection.

4. Adaptation projects will need to minimize impacts to coastal resources (including public access, recreation, marine resources, prime agricultural land, 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).

5. Many adaptation projects will depend on the availability of state or federal funding and the willingness to participate of affected landowners.

6. Adaptation will be an ongoing process for the Humboldt Bay region. Progress will be made through collaboration, advances in scientific understanding, innovation, experimentation, monitoring, and continuous learning.

7. For some properties, protection from flooding hazards associated with sea level rise will not be feasible at some point in the future and the concept of managed retreat will need to be considered.

1.6 Guiding Principles

Guiding principles reflect commonly shared beliefs and values. Guiding principles provide a solid foundation that remains firm while strategies and scientific understandings may change and evolve.

1. **Risk management approach:** Actions can be taken to reduce risk. The overarching goal is reducing risk to an acceptable level. Flood risk should be considered holistically at the scale of the hydrographic area. A cardinal rule is to avoid transferring risk from one property to another property except through mutual agreement. In some cases, risk reduction in certain areas could be accomplished through flood accommodation in other areas.

2. **Multiple lines of defense:** Properties along the shoreline of Humboldt Bay are protected from flooding by multiple lines of defense. Planning for flooding and sea level rise needs to consider how the lines of defense work together and how they can be improved to optimize protection.
3. **Engage stakeholders:** Flooding hazards represent threats to people's livelihoods, public safety, the regional transportation network, economic prosperity, and public trust resources; everyone has a stake. There is a need for creative ideas for potential actions and feedback on what is feasible. Adaptation measures may need to span multiple ownerships. Success will depend on partnerships.
4. **Understand natural processes at the landscape scale:** The hydrographic area provides an optimal spatial framework to guide adaptation strategies for sea level rise planning around Humboldt Bay. The geomorphic and hydrologic processes that control the flow of water and sediment must be understood in order to plan and design effective adaptation measures.
5. **Apply best available science:** Planning efforts should make use of the best available science. The best available science will evolve incrementally over time. The appropriate level of understanding and tolerance for uncertainty will vary based on the potential consequences of a decision and the time frame available for making the decision. Science-based evaluation should identify data and methods and include clear statements of assumptions and limitations. The most credible scientific information undergoes an independent peer review process. Criteria for best available science include relevance, objectivity, and transparency.
6. **Aim to maximize multi-benefit projects and nature-based solutions:** The starting point for water resource planning in California is the paradigm of integrated regional water management and multi-benefit projects. Nature-based solutions, and hybrid measures that integrate nature with engineered structural approaches, may provide the optimal total benefits for coastal resilience and risk reduction. Nature-based solutions work with natural processes and landforms to provide protection for both ecosystems and the built environment.
7. **Prudent short-term actions with adaptive capacity are needed to improve resilience:** Short-term adaptation measures are needed to reduce immediate flood risks. Adaptation projects should be developed with consideration for a range of possible future conditions. Low-probability future scenarios should be considered but are unlikely to be the basis for design. Short-term measures should be designed for compatibility with likely long-term measures (i.e., with a "no regrets" approach that does not preclude important long-term options). Prolonged planning and analysis create the risk of being stuck with the status quo and unprepared for hazardous flood events.
8. **Coordinated Adaptation Planning:** Local, state, and federal planning efforts should share information, coordinate efforts, and collaborate where feasible to leverage existing work efforts and improve consistency.

1.7 Sea Level Rise Projections

Recent science reviews by the State of California indicate that sea levels are expected to rise at an accelerating pace resulting in a rise of 3 to 7 feet, and as high as 11 feet, by year 2100 (CNRA – OPC 2018; OPC 2017). Future sea level projections for Humboldt Bay are provided in several State studies, as summarized below. Vertical land motion affects apparent sea level changes (sometimes called “relative Sea level rise” to acknowledge the inclusion of regional and local vertical land motions).

Sea level rise projections developed by Northern Hydrology and Engineering (NHE) in 2015 as part of the Humboldt Bay Sea Level Rise Adaptation Planning Project were based on the OPC (2013) Guidance and its scientific basis, *Sea level Rise for the Coasts of California, Oregon, and Washington* prepared by the National Research Council (NRC) in 2012. The NRC (2012) study presented regional curves that could be adjusted based on site-specific or local information on vertical land motion. Because the OPC (2013) guidance presented simplified guidance for areas north and south of Cape Mendocino, and local tectonics of Humboldt Bay were counter to the assumptions presented in NRC (2012) and OPC (2013), sea level rise projections were updated by NHE (2015) to include local variations in vertical ground motion as summarized by Patton et al. (2014).

Because the OPC (2018) Guidance summarized local sea level rise projections at several well-established tide gauges along the coast of California, regional vertical land motion is incorporated into the OPC (2018) projections. Laird (2018) includes a letter authored by Jeff Anderson, Aldaron Laird, and Jay Patton in 2017, which was submitted to the California Coastal Commission (CCC) and OPC as part of the comment and review period of the State’s draft sea level rise policy update, that comments on the need to explicitly address the unique vertical land motion of the Humboldt Bay Area relative to the Cascadia zone north of Cape Mendocino. The OPC (2018) update includes tables of sea level rise projections based on several tide gages along the coast, including the North Spit of Humboldt Bay, and therefore includes the local vertical land motion at the North Spit. Our interpretation of the guidance is that application of the range of sea level rise projections as a function of risk accounts for most variations and uncertainty in vertical land motion in Humboldt Bay relative to the North Spit.

Figure 3 presents sea level rise projections for the Humboldt Bay North Spit as presented by OPC (2018) and NHE (2015). The solid lines represent the projections of OPC (2018) and the dashed lines are the projections of NHE (2015). 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. The State 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 represents a low likelihood of occurrence within the associated timeframe and provides a precautionary projection that should be used for less adaptive, 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) associated with the high, mid-level, and low emissions scenarios, respectively. Note that the updated OPC (2018) guidance presents significantly higher amounts of sea level rise than shown by the NHE (2015) projections. However, since 2015, NHE has updated projections as described in the City of Arcata Sea Level Rise Risk Assessment (April 2018) and these curves are referred hereinafter as NHE (2019) and also shown on Figure 3. Overall, the NHE (2019) projections track closely to the projections for North Spit provided by OPC (2018).

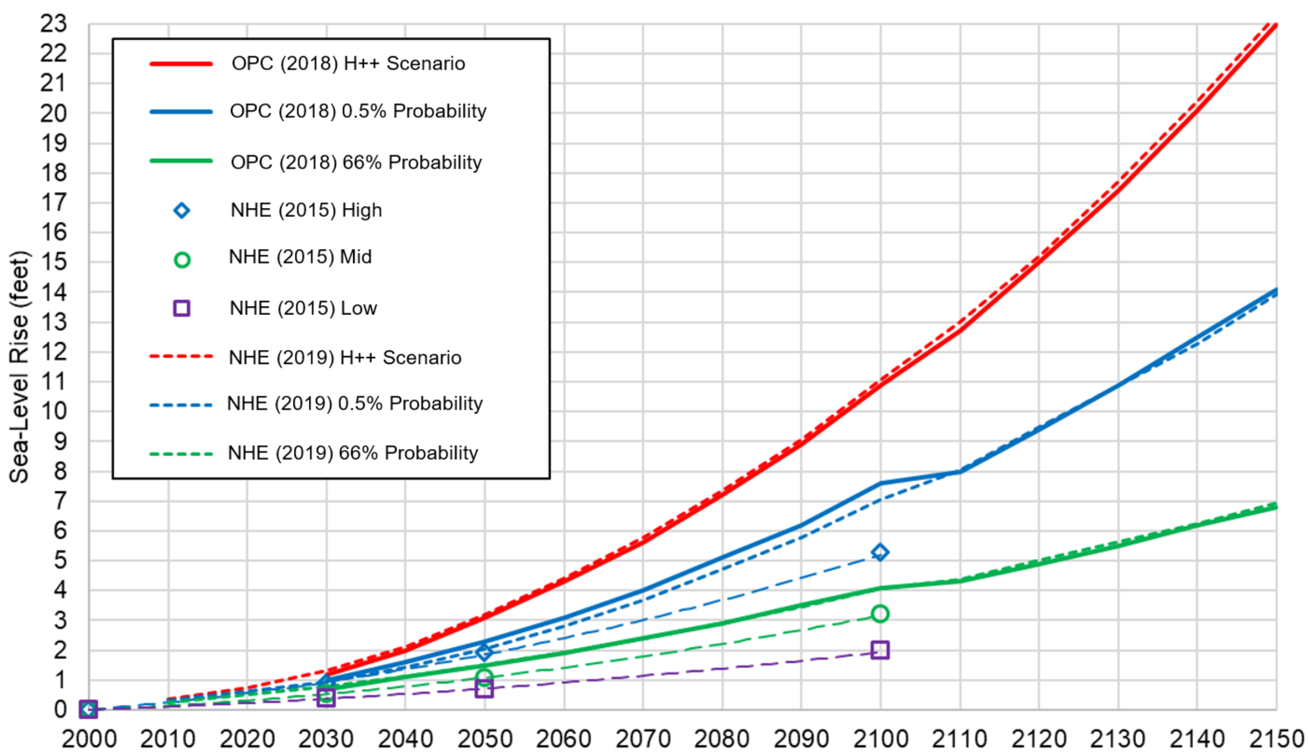


Figure 3: Sea level Rise Projections for North Spit, Humboldt Bay: OPC (2018) State Guidance (solid lines) and Regional Projections by NHE (2015) and NHE (2019)

Table 2 is a tabular version of Figure 3 and shows the projected rates of sea level rise for a range of time periods, low and high rates of emissions that contribute to global warming, and the risk of exceedance. The National Oceanographic and Atmospheric Administration (NOAA[1]) reports the relative sea level trend to be 4.87 mm/year +/- 0.91 mm/year based on monthly mean sea level data from 1977 to 2018, which is equivalent to a change of 1.60 feet in 100 years. This existing rate is equivalent to the low end of the "likely rate" range of projected future rates (Table 2), whereas higher projected rates are 4 to 8 times higher than the existing rate.

Note that the Humboldt Bay sea level rise rate of nearly 5 mm/year is higher than many other California locations, such as San Francisco which has an existing rate of about 3 mm/yr.[2] Sea level rise rates are estimated to vary across Humboldt Bay from 2.5 to 5.8 mm/yr (Patton and others 2014). For Humboldt Bay, land subsidence affects the relative sea level rise rate and amount (Patton and others 2014), as addressed below.

Table 2: Predicted Rates of Sea level Rise at Humboldt Bay (Source OPC 2018).

		Probabilistic Projections (mm/yr) (based on Kopp et al. 2014)				*H++ scenario (Sweet et al. 2017) *Single scenario*
		MEDIAN	**LIKELY RANGE**	**1-IN-20 CHANCE**	**1-IN-200 CHANCE**	
		50% probability sea-level rise meets or exceeds…	*66% probability sea-level rise is between…*	*5% probability sea-level rise meets or exceeds…*	*0.5% probability sea-level rise meets or exceeds…*	
High emissions	2030 – 2050	8.7	6.4 - 11	14	19	28
Low emissions	2060 - 2080	7.4	5.1 - 10	14	24	
High emissions	2060 - 2080	11	8.2 - 16	20	31	44
Low emissions	2080 – 2100	7.4	4.5 - 11	16	29	
High emissions	2080 – 2100	13	8.1 - 18	24	39	56

**Most of the available climate model experiments do not extend beyond 2100. The resulting reduction in model availability causes a small dip in projections between 2100 and 2110, as well as a shift in uncertainty estimates (see Kopp et al. 2014). Use of 2110 projections should be done with caution and with acknowledgement of increased uncertainty around these projections.*

1.8 Dynamic Landscape Evolution and Flood Risk Change

A primary focus of this study is to better understand how flooding interacts with the landscape and how sea level rise could cause changes in flood risk. Previous vulnerability studies have assumed a static landscape where landforms and landscape features do not change due to flooding and sea level rise. The static landscape assumption is acceptable for screen-level evaluations but limits the accuracy of the assessment and does not provide insight into the types of adaptation measures that may be effective. The current study assumes a dynamic landscape and tries to understand and predict how landforms and landscape features will respond to changing conditions.

[1] NOAA Tide Station 9418767 North Spit Humboldt Bay https://tidesandcurrents.noaa.gov/sltrends/sltrends.html

[2] NOAA Tide Station 9414290 San Francisco

The diagram presented in Figure 4 depicts how hydrologic components of the water cycle could affect the landscape features of the study area, resulting in changes in flood risk due to sea level rise trends. The diagram presents a representation of the fundamental elements of the system and their basic interactions between these hydrologic sources and geophysical processes and the resulting potential physical impacts. Section 4 expounds on this conceptual model and provides a more detailed discussion. Uncertainties associated with these interactions and the potential impacts are listed in the diagram.

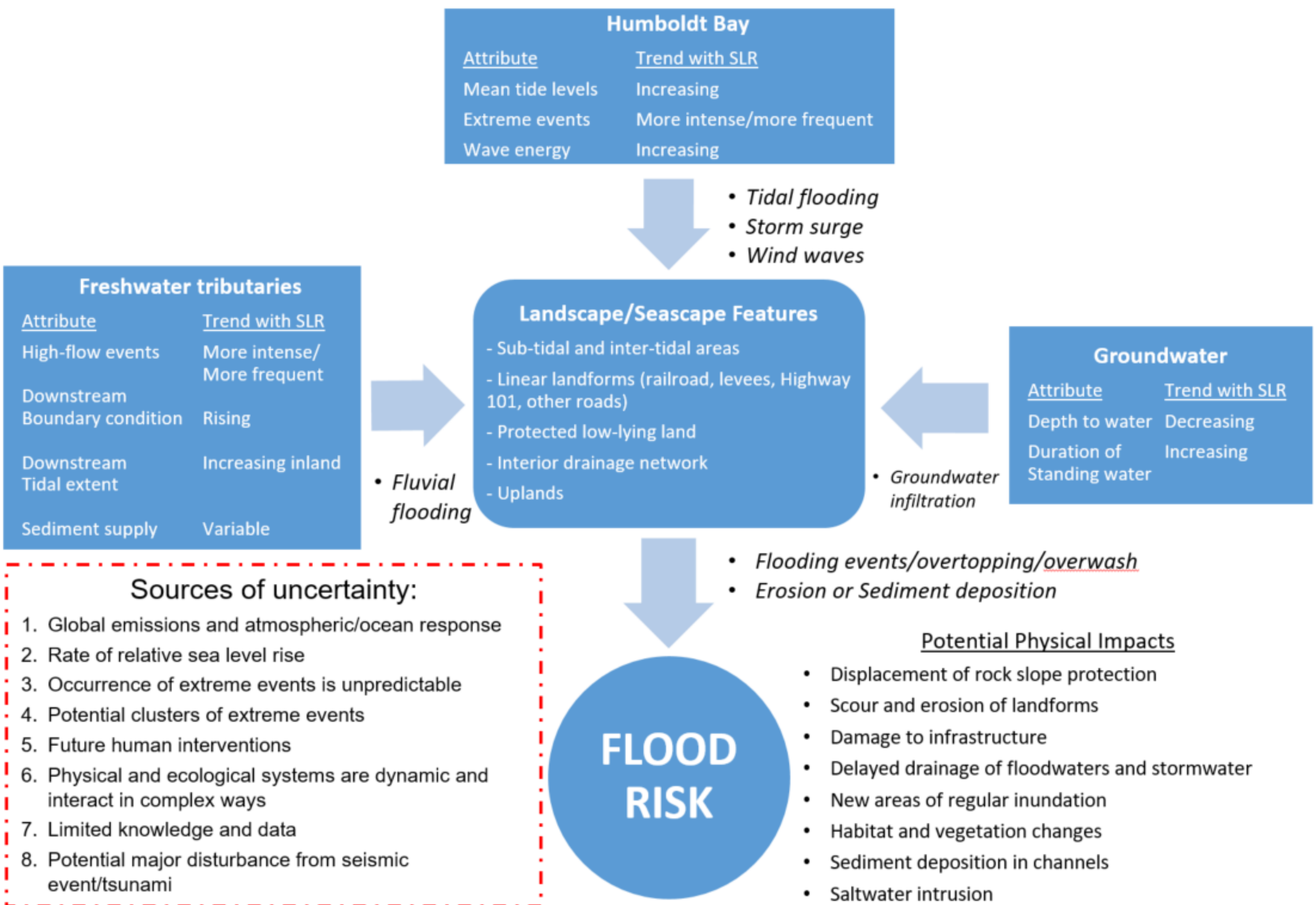


Figure 4. Conceptual Model of Dynamic Landscape Evolution and Flood Risk Change around Humboldt Bay due to Sea Level Rise

1.9 Scenario-based Planning

This study utilizes a scenario-based planning approach to evaluate risk and uncertainty. The approach considers a range of plausible future conditions rather than a single specific outcome. The approach is not a prediction, but rather a study of possibilities and consequences. It supports the goal robust decision making against a range of potential future conditions. The overall process of scenario-based planning can be summarized as follows (adapted from USFWS, 2014):

1. Scoping and Planning Preparation. In this phase, the issues are identified, and purpose and outcomes of scenario plan defined. The goal is to understand the issues, agree on a model of the system, understand and integrate data, and define the overall scope or roadmap of the project.
2. Building and Refining Scenarios. In this phase, the key drivers and variables are defined, scenarios are detailed, reviewed and quantified. Narratives, comparative tables of scenarios, graphics, and model outputs are all generated.
3. Applying Scenarios. The consequences of the scenarios are explored, potential strategies or actions are developed and prioritized, preferred short-term actions identified, and strategies for monitoring and research are developed. As a result of this work, knowledge gaps are identified, and an action plan with timelines and monitoring indicators can be developed.

In essence, scenario planning is a “what if” decision support tool that makes uncertainties apparent; can be updated over time as more information becomes available; and can incorporate insight from multiple perspectives, including both quantitative and qualitative information. It can be applied for simple or complex explorations and applied at a variety of scales. Common applications of scenario-based planning efforts include global emissions scenarios, regional sea level rise scenarios, and regional temperature and precipitation scenarios. Section 6 applies scenario-based planning in this study.

1.10 Prior Studies

Humboldt Bay has been the subject of much inquiry related to sea level rise. Studies throughout Humboldt Bay and within the study area that are directly related to the objectives of this study and will be expanded upon are summarized below.

Humboldt Bay Shoreline Inventory, Mapping and Sea Level Rise Vulnerability Assessment (Laird et al, 2013)

This report documents the construction type and condition of shoreline protection structures, including observations of vulnerable segments. The report also presents initial modeling of sea level rise impact area conservatively assuming failure of shoreline protection structures.

FEMA Coastal Flood Study for Humboldt Bay (FEMA, 2014)

FEMA performed a detailed coastal engineering analysis and mapping for the Pacific coast of California, including Humboldt Bay. Tidal still water levels, wind waves, and wave runup were analyzed to generate predictions for total water levels along the shoreline for current conditions (not reflecting sea level rise projections). Total water levels within the project area range from 11 to 14 feet NAVD 88. Prior to this work, the base flood elevation for Humboldt Bay on FEMA flood maps was a uniform 9.37 feet NAVD88. The analysis of wind waves in this study was relatively simplified but provided the first bay-wide estimate of total water levels. This study supersedes the FEMA 1986 FIS and FIRM which reports a single base flood elevation for Humboldt Bay of 9.34 feet, based on still water elevation only.

Caltrans District 1 Climate Change Vulnerability Assessment (Caltrans, 2014)

This report utilizes the Federal Highway Administration (FHWA) methodology for assessing potential climate impacts to the transportation infrastructure, including leveraging downscaled climate data, available sea level rise flooding and erosion mapping, and evaluating the vulnerability of transportation assets. This study presented an inventory of assets in Humboldt, Del Norte, Mendocino, and Lake Counties, and identified four pilot locations that were used to explore potential adaptation approaches. One of the pilot locations was the Highway 101 corridor between Eureka and Arcata, adjacent to the Humboldt Bay Trail South project site. The report described potential adaptation measures for the highway, including protection, accommodation, and retreat strategies.

Humboldt Bay Sea Level Rise, Hydrodynamic Modeling, and Inundation Mapping (NHE, 2015)

This technical report documented the development of a sophisticated hydrodynamic model to evaluate the spatial distribution of flood elevations throughout Humboldt Bay, which can vary several feet due to tidal amplification and other processes. The NHE Humboldt Bay model provides estimates for still water levels throughout the bay (not including wind waves). The report provided estimates for the extent of inundation for various increments of sea level rise and supported the vulnerability assessment performed by Laird (2015) and conservatively assumes the absence of levees to show the potential flood hazard areas. The NHE Humboldt Bay model continues to be the primary tool for predicative modeling of still water elevations for extreme high water events and sea level rise scenarios around Humboldt Bay.

Humboldt Bay Sea Level Rise Adaptation Planning Project, Phase 2 Report (Laird et al, 2015)

This report synthesized information on vulnerability around Humboldt Bay using NHE 2015 and presented concepts for a regional collaborative adaptation planning process. The Eureka-Arcata Highway 101 corridor was analyzed in one of the two detailed case studies focusing on critical regional assets at risk.

Jacobs Avenue Levee Bathymetric, Hydrologic, and Hydraulic Study (NHE, 2016)

This technical memorandum evaluated wind and wave effects on flood elevations for a reach of the north bank levee of the Eureka Slough. Leveraged prior modeling efforts to identify likely flood elevations.

City of Eureka Sea Level Rise Adaptation Planning Report Addendum No. 1 (Bayview Consulting, 2016)

Planning memorandum providing background and context for potential strategies and approaches to addressing sea level rise and regulatory compliance within the City of Eureka's Local Coastal Program.

Caltrans District 1 US Route 101 Transportation Concept Report (Caltrans, 2017)

This report was a long-range planning document for Highway 101 on the North Coast that identified existing and future conditions as well as future needs. The report identified the ultimate facility concept for the Eureka-Arcata Highway 101 corridor as a "climate resilient corridor" to address the impacts of sea level rise.

Humboldt Bay Area Plan Sea Level Rise Vulnerability Assessment (Laird, 2018a)

This report synthesized information on sea level rise vulnerability around Humboldt Bay to inform Humboldt County's update of the Humboldt Bay Area Plan (in progress). The Humboldt Bay Area Plan contains policies and standards for land use and new development and will provide a framework for initiating proactive sea level rise adaptation measures. This report notes that the Eureka-Arcata corridor traverses diked former tidelands, making it susceptible to tidal inundation if the railroad grade is breached and susceptible to flooding from extreme storm events. The Eureka-Arcata corridor is rated as "highly vulnerable."

Humboldt Bay Area Plan Diked Shoreline Sea Level Rise Adaptation Feasibility Study (Laird, 2018b)

This study was prepared to support the Humboldt Bay Area Plan update by analyzing the vulnerability of the diked shoreline around Humboldt Bay and exploring adaptation measures applicable to diked shoreline structures. The hydrologic sub-unit encompassing the project area received the highest vulnerability rating out of the 23 total hydrologic sub-units around Humboldt Bay.

Humboldt Bay Trail South Sea level Rise Vulnerability and Adaptation Report (ESA 2018).

The Humboldt Bay Trail South project is currently in the right-of-way, permitting, and final design phase. A study by ESA evaluated the vulnerability of the proposed trail to sea level rise and identified a range of adaptation measures to mitigate rising still water flooding, wave runup, and overtopping. The trail project performance was evaluated using the low risk aversion projection of the OPC (2018) Guidance through approximately year 2070. This is based on the assumption that the consequences of coastal impacts to the trail are low. Several technical analyses were conducted for the project, including an analysis of the tidal still water levels and wave runup along the shore of the project. The still water analysis included assessing the change in frequency of inundation events per year greater than a selected threshold elevation. Trail criteria were identified and evaluated for different trail elevations along the project extents. Finally, a series of potential adaptation measures were described for the project that was based on the recommended process described by the California Coastal Commission (CCC) 2018 Guidance.

Caltrans Eureka-Arcata Highway 101 Corridor Project Sea level Rise Analyses (ICF, 2019 and Caltrans, 2018)

The Highway 101 Corridor Project is a project led by Caltrans to upgrade the vulnerable stretch of highway, including the Indianola interchange, Jacoby Creek bridge, and four tide gates. The following are two available documents: ICF (2019) and Caltrans (2018).

The study by ICF on sea level rise identified approximate times that the Highway 101 corridor is exposed to selected flooding threshold elevations using the Ocean Protection Council (OPC) 2018 sea level rise projections. The analysis is largely based on the work of Aldaron Laird (2018) but updates with the more recent guidance by OPC (2018).

The memo prepared by Caltrans planning staff provides a basis for decisions in the Highway 101 corridor project (Caltrans 2018). The memo selects the Northern Hydrology and Engineering (NHE) 2015 study as “the best projections for the immediate local area.” From those projections, their use of the sea level rise of 3.2 feet by 2100 implies that they are using the mid-level “projection,” rather than the projected sea level rise resulting from higher emissions. The high emissions curve of NHE (2015) projected sea level rise of approximately 6 feet by 2100.

The Caltrans (2018) memo presents a discussion on long-term planning and summarizes available adaptation alternatives, as well as a proposal for future community-based planning and technical studies. A mix of alternatives, including a causeway that connects the Bay and landside areas hydraulically, raising infrastructure, and constructing levees or berms to protect infrastructure, were discussed as potential strategies. The memo concludes managed retreat option of rerouting the highway as too high of impact, although it is not clear that an impacts analysis or economics analysis was conducted. The Caltrans (2018) memo suggests that additional studies will be completed to evaluate vulnerability and develop alternatives.

Caltrans Adaptation Priorities Report – District 1 (Caltrans, 2021)

This report prioritizes assets within Caltrans’ four-county region of District 1 for further work on climate change adaptation. Caltrans has adopted the Framework for Enhancing Agency Resiliency to Natural and Anthropogenic Hazards and Threats as part of its long-term plan for incorporating adaptation into its activities. The report defines exposure metrics and consequence metrics and applies weighting factors to generate prioritization scores for at-grade roadways, bridges, and culverts. Next steps include performing detailed adaptation assessments for the high-priority assets and integrating the prioritization measures into the asset management system used in the district.

1.11 Studies in Progress

USGS Coastal Storm Modeling System (CoSMoS)

In coordination with the California State Coastal Conservancy, the USGS is extending its sea level rise hazard mapping tools to the north coast of California, including within Humboldt Bay. The mapping is based on the Coastal Storm Modeling System (CoSMoS), a dynamic modeling approach that is being used by the USGS to assess coastal flooding for existing and future conditions with sea level rise and for a range of storm scenarios over large geographic areas (Barnard et al. 2014). The modeling approach uses a predominantly deterministic framework to make detailed predictions of storm-induced coastal flooding and erosion along the open coast. The resulting mapping is presented in an on-line interactive web mapper that allows users to visualize results representative of a composite of multiple model runs for different sea level rise and storm scenarios (see Our Coast Our Future Web Tool[3]).

USGS is applying CoSMoS to the north coast and results are expected to be available by the end of 2021. As was done for San Francisco Bay, hazard projections within Humboldt Bay will include coastal flooding and typical coincident fluvial flooding from major drainages.

1.12 Guidance Documents for Sea Level Rise Planning

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

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 emissions scenarios but recommends using the range in sea level rise projections by risk level for a particular time horizon.

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[3] Our Coast Our Future: http://data.pointblue.org/apps/ocof/cms/

The relevance of the State's sea level rise guidance to this Study is that it provides a basis for selecting sea level rise scenarios to assess vulnerability of the assets within the study area and to evaluate the performance of potential adaptation strategies under future conditions.

California Coastal Commission Guidance of 2018

Technical methods and guidance for using the OPC (2018) projections as part of an adaptation planning process are included in the *Sea level Rise Policy Guidance* developed by the California Coastal Commission (CCC), which was recently updated 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). 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.

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.

Caltrans Guidance on Incorporating Sea level Rise

Caltrans developed a guidance document in 2011 to determine whether and how to incorporate sea level rise concerns into the programming and design of Caltrans projects (Caltrans 2011). This guidance presents a two-step approach to determine the need for incorporating sea level rise adaptation measures into a project:

1. Determine whether there is a potential for the project to be impacted by an increase in sea level rise
2. Balance the potential sea level rise impacts with the level of risk and the potential consequences to the transportation system to determine whether the potential impacts warrant programming resources to include adaptation measures into the project

The first step uses an initial screening process to check that the project would be potentially impacted by sea level rise. The screening criteria include project design life, transportation-related issues like redundancy, and environmental constraints. If the screening process indicates that the project may be impacted by sea level rise, then a more detailed documentation of sea level rise and adaptation.

The second step requires the documentation of the project's timeframe, risk-tolerance, and adaptive capacity. For example, projects with a longer design life would be expected to be potentially impacted by greater amounts of sea level rise later in the century. Likewise, the risk-tolerance is a major factor for decision making, and projects with large consequences may warrant design changes or identification and programming of resources for future adaptation. Although the Caltrans (2011) Guidance references older and lower amounts of sea level rise, the process appears to meet the planning-level needs for incorporating sea level rise into projects. Our interpretation is that Caltrans would have to comply with updated and recent state guidance (i.e., OPC 2018 and CCC 2018).

Guidance by Federal Highways Administration

The Federal Highways Administration (FHWA) has supported the development of many tools and guidance for assessing climate-related impacts and adaptation approaches to civil works projects. Two of these documents are summarized below.

Adaptation Decision-Making Assessment Process

A brief document presents the Adaptation Decision-Making Assessment Process (ADAP) as a tool for planners and designers to account for climate change in the design of civil works projects (FHWA 2016). This risk-based tool uses several parameters to help decision makers evaluate tradeoffs: life cycle cost, resilience, regulatory and political settings, etc. The framework presented by ADAP helps guide the planning process, including determining the scope of analysis that may be required to evaluate the potential impacts of climate change and the benefits of adaptation. For example, the process walks a planner/designer through several steps to assess the performance of a facility under different climate scenarios so that the resources are spent on useful and needed analysis, as well as using high-level and simplified approaches as a first step before undertaking detailed analyses. Similarly, at the adaptation steps include potential for using a detailed economic analysis to inform adaptation if the costs are not small. Overall, the ADAP is a useful process that is general and applicable to developing the high-level framework of vulnerability and adaptation planning.

Vulnerability Assessment and Adaptation Framework

This report by FHWA presents a process for evaluating vulnerability of transportation systems to climate change impacts and how to plan for adaptation. The FHWA (2017) Guidance presents a series of steps:

1. Articulate objectives and define study scope
2. Obtain asset data

3. Obtain climate data
4. Assess vulnerability
5. Identify, analyze, and prioritize adaptation options
6. Incorporate assessment results in decision making
7. Monitor and revisit

These steps closely resemble the steps presented in earlier guidance developed for Caltrans, titled *Addressing Climate Change Adaptation in Regional Transportation Plans: A Guide for California MPOs and RTPAs* (Caltrans 2013). Both of these reports provide detailed information for addressing each step with a focus on highway transportation systems.

Natural Infrastructure Guidance

Guidance for use of natural infrastructure to manage shore response to sea level rise in California has been developed to support consideration of alternatives to traditional coastal armoring (Newkirk et al. 2018; ESA 2018a). The use of natural ecological systems or processes to reduce vulnerability to climate change related hazards is emphasized, while increasing the long-term adaptive capacity of coastal areas by perpetuating or restoring ecosystem services (Newkirk 2018). This approach is prioritized in the California Coastal Commission's Sea Level Rise Policy Guidance (2018). A summary of guidance provided by Newkirk (2018) on natural infrastructure shore elements is as follows:

- 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 in order to provide habitat, wave dissipation, erosion protection and accommodation space; tidal benches are similar to horizontal levees[4] and living levees[5];
- 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 guidance is at a conceptual level, intended to identify natural infrastructure typologies that are worthy of additional evaluation.

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

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

1.13 Policies, Laws, and Regulations

Moving projects from planning 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 State engages on environmental planning and regulation through a variety of agencies responding to state and federal environmental regulations.

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 integrated into many state environmental regulations. Multiple agencies, including the Army Corps of Engineers, Regional Water Quality Control Board, and Coastal Commission, will have criteria and review processes for ensuring that any wetlands impacted by an adaptation project will be adequately replaced, or mitigated. These 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.

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.

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 United States Army Corps of Engineers (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.

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 review may be triggered by projects proposed on Humboldt Bay.

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.

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 local agency but involves review of many state, and potentially federal, agencies.

California Coastal Act

The State of California authorizes the California Coastal Commission to implement the Coastal Act. 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 on climate change adaptation, as discussed elsewhere. It issues Coastal Development Permits (CDPs), or authorizes local jurisdictions with LCPs, in this case Humboldt County and the City of Eureka, to issue them on their behalf. The Coastal Commission also performs Federal Consistency Determinations to ensure that projects within the Coastal Zone adhere to federal policies, where such determination is required. As discussed further in Section 8.2.2 – Regulatory Considerations, Coastal Act policies can conflict with one another. For example, under Section 30233 (Diking, filling, or dredging), the Coastal Act does not allow for the diking, filling, or dredging of waters or wetlands for shoreline protection unless such actions could reasonably be nested under restoration purposes, nature study, or another permissible activity. However, Section 30235 (Construction altering the natural shoreline) allows for revetments, retaining walls, and other structures to protect existing structures and public beaches in danger from erosion.

The State Lands Commission also exercises authority over tidelands, submerged lands, and the beds of navigable rivers, streams, lakes, bays, and estuaries including waterfront lands and coastal waters.

California Porter-Cologne Act

The Porter-Cologne Act is also the California Water Code, 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 permits will also provide coverage of Porter-Cologne.

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 will likely require a 1600 Permit.

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.

PART II - VULNERABILITY ASSESSMENT

2. EXISTING CONDITIONS

2.1 Description of Study Area

The study area encompasses parts of unincorporated Humboldt County and the City of Eureka that have been identified through previously studies as having a high vulnerability to sea level rise. The study area includes a diverse landscape of subtidal sloughs, intertidal mudflats, salt marsh riparian areas, agricultural pasture, industrial, transportation, commercial and residential land uses as can be seen in the photos to right. The study area boundary includes the Humboldt Bay shoreline from Highway 255 to just south of Bracut, the edge bottomlands to the southeast to Indianola Cutoff in Humboldt County, Old Arcata Road/Myrtle Avenue to Ryan Slough, the edge of bottomlands to the south to Park Street in Eureka, to Myrtle Avenue, to R Street (Exhibit 1-1). The diverse land uses, multiple jurisdictions and critical resources encompassed within the study area warrant careful consideration in assessing vulnerabilities to sea level rise.

U.S. 101 at Eureka Slough

Fay Slough and CDFW Wildlife Area

U.S. 101 adjacent to Brainard

The transportation corridor is the most critical land use within the study area, comprised of U.S. Route 101, the Humboldt Bay Trail, and the North Coast Railroad Authority right of way. Route 101 is the primary connector between the cities of Eureka and Arcata, and, as part of the national highway system, is an important regional connector. The Humboldt Bay Trail will be a significant non-motorized connector for the region when it is completed in 2022/2023.

Substantially developed areas include the Jacobs Avenue commercial and residential area bounded by Eureka Slough and Highway 101; Eureka's

Bridge District, a mix of residential, industrial and commercial uses, bounded by Highway 255/R Street, the Humboldt Bay shoreline, and 4th Street; and a residential area between Myrtle Avenue, Park Street, 5th Street, and the Eureka Slough. Also, significant developed areas include the Murray Field airport, Mid-City Motor World, and Brainard.

Important utility infrastructure also traverses the study area. Pacific Gas & Electric (PG&E) maintains natural gas and electrical distributions systems, while the City of Eureka and Humboldt Community Services District operate water and sewer collection systems.

A majority of the study area is comprised of former tidelands under current agricultural production protected by levees and other linear landscape features. Fay Slough Wildlife Area owned by CDFW is a coastal and seasonal freshwater wetland area managed for wildlife habitat and is also used for hunting. Intertidal mudflats and salt marsh comprise the Bay shoreline and interior sloughs. Fragmented riparian habitat areas persist along transition gradients or salt-freshwater tributaries.

2.2 Physical Setting

The landscape of the study area has been shaped by the interplay of human activity and the interaction of water and sediment. Mixing of tides and freshwater from coastal rivers and streams formed the salt marshes, slough channels, and mudflats that characterize Humboldt 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 raised structures that held back tidewaters.

Despite these alterations, the Eureka Slough, a large tributary to Arcata Bay, remains a tidally influenced estuarine channel that receives freshwater flows from Ryan Creek (and Slough), Freshwater Creek (and Slough), Cochran Creek, Fay Slough (with tributaries Quail Creek and Redmond Creek), First, Second, and Third Sloughs, and smaller unnamed sloughs and drainages. Where these waterbodies would have once dissipated their energy by spreading water and sediment over the low-lying areas of the study area, today, their deposits are confined within Eureka Slough and Humboldt Bay due to leveed shorelines. The levees have fixed the shorelines in-place and have altered flow patterns and exchanges of sediment. These altered processes result in topographic variation across the study area.

2.2.1 Ground Surface Elevations and Vertical Datum

Contemporary ground surface elevations reflect the historical character of the study area (Exhibit 2-1). Leveed agricultural lands remain low in elevation, typically lower than adjacent roads and most developed areas. Elevations between 3 and 9 feet dominate the study area, with agricultural land between 5- and 9.5-feet elevation. Slough channels are typically lower in elevation, between 0 and 3 feet. High marsh fringe, gullies around urban sloughs, and developed areas are primarily situated between 7- and 10-feet elevation. Unless noted otherwise, all elevations presented in this report are referenced to the North American Vertical Datum 1988 (NAVD 88).

2.2.2 Habitats

The habitat types within the study area are shown in Exhibit 2-2. Intertidal mudflat, saltmarsh, and brackish marsh can be found along the sloughs and bay adjacent to the constructed landforms. The shorter cross-sectional areas available for habitat establishment result in relatively narrow fringes in saltmarsh habitat adjacent to the toes of the levees. Where the levees are wider relative to the flow and energy of the slough, more sediment may have accreted, allowing more diversity in the saltmarsh prism to also develop. Fay Slough offers an example of this, with an elongated prism of saltmarsh, brackish marsh, freshwater marsh and deciduous forest along its alignment. Freshwater Slough's habitats are more limited, probably due to the lack of sediment deposits and habitat establishment. Agricultural wetlands, dominated by non-native grasses, are the principal habitat type of the study area. In addition to supporting cattle and other agricultural uses, these lands are used by a range of wildlife species for grazing and habitat. Smaller pockets of evergreen, deciduous and mixed woodlands exist along the upland fringes of the study area (Schlosser and Eicher 2012).

2.2.3 Property Ownership

Approximately 71% of the parcels within the study area are in private ownership with the balance owned by public entities. Approximate 52% of all parcels within the study area are greater than 50 acres (Exhibit 2-3). Some of those parcels extend beyond the study area into Humboldt Bay's surface waters. Approximately 29% of the study area is dedicated to conservation or natural resource protection uses, such as the Fay Slough Wildlife Area owned and managed by the California Department of Fish and Wildlife (CDFW).

2.2.4 Shoreline Structures

This subsection describes the shoreline structures within the study area and draws heavily on the sea level rise assessments performed by Aldaron Laird (Laird et al 2013, 2016). Humboldt Bay's current shoreline boundary is largely defined by earthen diking. Much of the almost 25 miles of shoreline in the study area has been modified (Exhibit 2-4). The dominant modification is earthen s (levees), covering 15 miles, or 60%, of shoreline. Transportation improvements such as railroads and roads that traverse the shoreline are constructed with fill that also function like levees and cover almost 4 miles of the shoreline. Bulwarks and bridge abutments, boat ramps, tide gates and other fortifications and fill characterize other alterations to the shoreline. About 16% or 4 miles of shoreline is not altered, of which about 5% or over one mile is higher elevation bluff or cliff, leaving under 3 miles or 11% of the shoreline a more natural prism with gently increasing grades to upland and developed areas (Table 3).

Table 3. Shoreline Structure and Cover Types

Shoreline Structures			
Structure Type	Length (ft)	Length (mi)	Percent Shoreline
Boat Ramp	23	0.00	0.02%
Bridge Abutment	282	0.05	0.22%
Bulwark	1,275	0.24	1%
Cliff/Bluff	6,721	1.27	5%
Levee	79,167	14.99	61%
Fill	7,061	1.34	5%
Fortified	970	0.18	1%
None	14,587	2.76	11%
Railroad	16,186	3.07	12%
Road	3,858	0.73	3%
Tidegate	105	0.02	0.08%
Grand Total	**130,236**	**24.67**	**100%**

Shoreline Cover Type			
Cover Type	Length (ft)	Length (mi)	Percent of Shoreline
Concrete	5,527	1.05	4%
Exposed	7,036	1.33	5%
Rock	12,921	2.45	10%
Rock/Concr	1,022	0.19	1%
Vegetated	102,846	19.48	79%
Wood	884	0.17	1%
Grand Total	**130,236**	**24.67**	**100%**

The shoreline is covered by a range of materials (Exhibit 2-5). Almost 80% of the shoreline is vegetated. This category includes natural shoreline, bluffs and cliffs, as well as extensive areas that are leveed, in which vegetation has established through or over rock structures. Rock or combinations of rock and concrete armoring comprise the second largest category of shoreline cover material. Approximately 7,000 linear feet (1.33 miles) is exposed (earthen) to the elements.

Levees are not managed by a single authority. As privately managed segments of a system that functions as a whole, the levees present a range of elevations that afford different levels of tidal and/or flood protection. Exhibit 2-6 demonstrates the elevations found throughout the shoreline. Variability throughout the system can be seen, with elevations as low as 5 feet in some areas up to 15 feet in others. The lowest elevations tend to correlate with either natural or undeveloped shoreline areas and the eroding rail prism.

2.3 Transportation Infrastructure

Transportation infrastructure is an important feature of the study area and these facilities are shown in Exhibit 2-7. People fly, drive, bicycle, kayak, and walk within the study area. Trains and shipping were also once an active feature of the study area; while the infrastructure for rail is still physically present, the only remains of the docks that once berthed ships are decaying pier structures. As the expanse separating to significant economic and residential zones of Humboldt County, maintaining connectivity and existing transportation uses is of critical importance.

2.3.1 US-101

U.S. Highway 101 (US-101) is significant connector between communities in Humboldt's North Bay and north County areas and the South Bay, southern County, and beyond. Approximately 4.1 miles of US-101 bisect the study area. US-101 is managed as a Safety Corridor, to limit speed to 50 miles per hour. It is the County's most highly used road. Traffic volumes from 2017 are indicated in Table 4.

Table 4. Traffic Volumes, US-101 (Caltrans, 2017)

Description of Location	Peak Hour		Peak Month		Average Annual Daily Traffic	
	S/B	N/B	S/B	N/B	S/B	N/B
4th Street /Myrtle Ave	2,100	1,900	25,000	22,500	22,800	20,000
4th Street/ Hwy 255, End Left Align	1,900	2,100	22,500	20,400	20,000	19,000
@ Cole Avenue	3,900	4,000	36,500	38,000	34,300	35,900
@ Airport Road	4,100	4,100	38,000	38,000	36,200	36,200
@Indianola Road	3,300	4,300	39,500	40,500	36,800	37,600

In 2017, Caltrans updated the US Route 101 Transportation Concept Report (TCR) which identified long range planning improvements for Highway 101 in District 1. Two planning horizons were designated in the plan and referred to as a 20-year Facility Concept for projects that would be implemented by 2037 and the Ultimate Facility Concept for improvements that would be needed past 2037. For the Eureka-Arcata Corridor segment of US-101, the plan identified safety and bicycle/pedestrian improvements within the 20-year planning horizon. Current projects include eliminating non-standard crossings, such as Indianola Cutoff, which are the subject of current safety planning by Caltrans and tide gate replacements. Other improvements include elongated on- and off-ramps, an overhead left turn interchange from Indianola to US-101 South, and reduced U- or left-turns in the highway. The Ultimate Facility Concept (post 2037) designated the Eureka-Arcata Corridor as a "Climate Resilient Corridor" to address the impacts of sea level rise in all future projects, however specific projects were not identified (Caltrans 2017).

Caltrans is currently constructing a series of projects collectively called the Eureka-Arcata Corridor Improvement Project. The individual projects include the following:

- Indianola Undercrossing & Half Signal Project
- Jacoby Creek/Gannon Slough Bridge Rail/Bridge Replacement Project
- High Tension Cable Median Barrier Project
- Acceleration/Deceleration Project
- Tide Gates Replacement Project
- Offsite Wetland Mitigation

The total cost for these projects (including preconstruction, right-of-way, construction, and mitigation) is over $110 million.

The elevations of US-101 within the study area range from 8.2 to 24.4 feet. Alternate routes to US-101 include Highway 255 and Myrtle Avenue/Old Arcata Road, however these routes do not meet current service standards equivalent to the Highway 101 traffic volumes tabulated above.

2.3.2 North Coast Railroad Authority (NCRA) Railroad Corridor

The NCRA railroad corridor is constructed along the Humboldt Bay shoreline on an embankment with periodic bridge crossings. Along Humboldt Bay, the railroad corridor comprises most of the "outermost" bay-facing protective structure.

Senate Bill 1029 authorizes the creation of the "Great Redwood Trail for hiking, biking, and riding." An assessment by the Transportation Agency, with input from the Natural Resources Agency, will recommend "the most appropriate way to dissolve the North Coast Railroad Authority and dispense with its assets and liabilities." While much of the region's NCRA right-of-way will be converted to trail uses, portions of the Humboldt Bay segment may include recreational rail use. The elevations of the NCRA railroad corridor range from 8.8 to 12 feet within the study area.

2.3.3 Murray Field Airport

Murray Field Airport is a 131-acre County-owned and operated airfield with general aviation uses. A primary advantage of this airport is the direct access to Eureka. Murray Field provides approximately 30,000 operations (landings and takeoffs) annually. The primary services provided by Murray Field include:

- Emergency medical air transportation in and out of the Humboldt region.
- U.S. Coast Guard mission support, training, and accessibility to the North Coast.
- Pilot training.

- Aircraft maintenance, fuel, and storage services. The airport has 51 hangars and 6 tiedown areas, for a total of 57 based aircraft.

FedEx Express uses this airport for package delivery. A Civil Air Patrol and charter service also operate out of Murray Field. In 2006, an Airport Master Plan for Murray Field Airport (EKA) was developed and since completion of the Plan, some projects have been implemented (ESA, 2008). The airport is at 4.1 to 11 feet elevation.

2.3.4 Humboldt Bay Trail South

The Humboldt Bay Trail is a multiuse trail that is partly constructed outside of the study area and is currently under planning within the study area. The trail's alignment is between US-101 and the NCRA ROW. While short portions of the trail are intended to share the railroad prism, it mostly will be built on adjacent to the railroad, to enable future rail-with-trail use and sea level rise adaptation. For most of its length, the trail will be adjacent to US-101, except where it goes over Eureka Slough on the railroad bridge and at former CRC Mill site, where it follows the outer levee, reconnecting with an alignment between US-101 and the railroad after that point. The design elevations of the trail are between 9.2 and 18.2 feet.

2.3.5 Eureka Waterfront Trail

The Eureka Waterfront trail is a multiuse trail that flanks the Eureka Waterfront from the Elk River through Old Town, along the undeveloped Commercial Bayfront District, and up Eureka Slough to Tydd Street. It crosses two small sloughs and crosses under US-101. Within the study area, its elevations range from 9.3 to 34.9, with most of it between 9.5 and 12 feet.

2.3.6 City and County Roads

Numerous city and county roads are within the study area. Many of these are on higher ground, serving residential and commercial areas, such as Myrtletown and the Bridge District. Low and High Elevations of City and County Roads with the study area are presented in Table 5.

Table 5. Low and High Elevations of City and County Roads with the Study Area

City and County Roads with Low Elevation Segments				
Road	Elevation (ft)		Functional Classification	Jurisdiction
	Low	High		
1st St	7.1	23.6	Local	City of Eureka
2nd St	9.3	26.5	Local	City of Eureka
3rd St	9.9	31.4	Major Collector	City of Eureka
4th St	11.3	36.7	Other Principal Arterial	Caltrans / City of Eureka

City and County Roads with Low Elevation Segments				
Road	Elevation (ft)		Functional Classification	Jurisdiction
	Low	High		
5th St	11.9	41.3	Other Principal Arterial	Caltrans / City of Eureka
6th St	10.1	42.9	Major Collector	City of Eureka
7th St	14.5	16.7	Local	City of Eureka
Bay St	9.1	38.8	Local	City of Eureka
Cole Ave	7.2	11.2	Local	City of Eureka
Devoy Rd	6.4	14.8	Local	Humboldt County
Front St	9.8	11.8	Local	City of Eureka
Gallagher Ln	13.2	19.8	Local	City of Eureka
Hoover St	11.9	45.5	Local	Humboldt County
Indianola Cutoff	7.8	56.0	Local	Humboldt County
Indianola Rd	6.4	36.4	Major Collector	Humboldt County
Jacobs Ave	4.1	9.4	Major Collector	City of Eureka
Lombard Rd	9.5	24.3	Local	Humboldt County
Myrtle Ave	3.9	52.1	Other Principal Arterial/Minor Arterial/Major Collector	Humboldt County
Oak Ridge Terrace Ln	7.5	34.7		Humboldt County
Park St	7.9	74.1	Major Collector	Humboldt County
US-101	8.8	24.5	Interstate	Caltrans
S St	10.1	41.6	Local	City of Eureka
T St	9.8	33.7	Local	City of Eureka
U St	14.7	28.4	Local	City of Eureka
V St	13.8	25.9	Local	City of Eureka
W 6th St	12.2	19.5	Minor Arterial	City of Eureka
W St	13.5	22.8	Local	City of Eureka
Walker Point Rd	14.2	76.8	Local	Humboldt County
Waterfront Dr	9.3	12.2	Local	City of Eureka
West Ave	13.5	50.7	Other Principal Arterial	City of Eureka
X St	12.3	17.9	Local	City of Eureka
Y St	10.1	12.7	Local	City of Eureka
(blank)	2.9	134.4	Local	n/a

2.3.7 Private Roads and Access Drives

Due to development patterns, some homes on large lots exist along edges of developed areas, adjacent to wetlands and sloughs at lower elevations. These may be served by private roads or long access drives off public streets. Elevation maps suggest that some of these properties may be within potential future inundation zones. These include properties off 1st Street, Marsh Street, PLB Williams Circle, Park Street, Trinity Street, Oakridge Terrace, Myrtle Avenue, Lombard Street, Walker Point Road, Indianola Cutoff, Indianola Road, US-101, and Jacobs Avenue.

2.3.8 Bus Service

Humboldt Transit Authority (HTA) is a joint powers authority which manages Redwood Transit Service (RTS), the main north-south transit line offering service between Scotia and Trinidad, and Eureka Transit Service (ETS), which offers service within greater Eureka. There are two RTS transit stop located in the project area (at 4th and V Street and 5th and V Street) and currently 11 ETS transit stops. HTA provides daily bus service between Eureka and Arcata along US-101. HTA estimates that the weekday average ridership between Eureka and Arcata is 340 passengers northbound and 357 southbound.

An estimated 941 passengers board ETS each weekday and 325 each Saturday (ETS Line Feasibility Study, 2018). ETS has its highest boardings and alightings at transit stops that also serve a transfer to the RTS system, which are all outside of the study area. The Purple Route and Green Route serve northeast Eureka and Myrtletown which lie within this study area. An estimated 198 passengers utilize the ETS Purple Route each weekday, 207 utilize the ETS Green Route each weekday, and an estimated 76 utilize the Purple Route each Saturday (there is no Green Route on Saturdays). Within the project area the ETS stop at Silvercrest (a low-income apartment complex) on Tydd Street near West Avenue has high ridership (an average of 38 weekday boardings) and serves as a transfer stop between the ETS Green Route and ETS Purple Route (Exhibit 2-7). A survey of 193 ETS transit users conducted in winter 2017-18 indicates that the majority (57%) of ETS survey respondents have a household income of less than $15,000, 76% do not have access to a vehicle, and the largest age group of users were over 64 years old (34%).

CAE Transport is a private company that operates ambulance service for the majority of the Humboldt County area and also operates Dial-a-Ride service in Eureka and Arcata through a contract with HTA. Dial-a-Ride is a shared ride system for eligible seniors and people with disabilities who are unable to use fixed route public transportation. Dial-a-Ride service is required by ADA standards wherever there is fixed route service – in this case within the coverage of ETS and RTS. However, Dial-a-Ride service as authorized by HTA and operated by CAE Transport does extend further than current ETS and RTS routes and does pick up Dial-a-Ride participants along Myrtle Avenue within the project area and also one participant on Jacobs Avenue. Dial-a-Ride service currently traverses either Highway 101 or Myrtle Avenue/Old Arcata Road about ten times each weekday and 2-3 times each Saturday. Myrtle Avenue/Old Arcata Road is as far inland as CAE operates Dial-a-Ride service; however, participants just east of this boundary such as in

Freshwater can be picked up if they pay the equivalent of a cab fare from their pick-up location to the Dial-a-Ride boundary at which they can utilize their Dial-a-Ride tickets.

CAE Transport also operates the pilot on-demand Old Arcata Road transit service under a contract with HTA. There are designated pick-up/drop-up locations along Myrtle Avenue/Old Arcata Road including within this project area from which anyone can call for service the day prior. Rides are $3 for a regular fare and participants are picked up in a cab or Dial-a-Ride mini-bus and taken to their desired transit hub in north Eureka or Arcata. The service started November 1, 2018 but has not attracted many participants which could limit its longevity as a service.

City Ambulance is a now a separate company that operates ambulance service for the majority of the Humboldt County area, from Garberville and Shelter Cove north to about the Indianola Cut-off. City Ambulance will also be dispatched to areas further north if Arcata-Mad River ambulances are busy. City Ambulance is dispatched to emergency calls throughout the project area, and the existing transportation network is essential to accessing those emergencies.

Area 1 Agency on Aging (A1AA) provides services for seniors and people with disabilities, their families, and caregivers. A1AA advocates for seniors and participates in local advisory roles such as the SSTAC. A1AA also operates a volunteer driver program which matches up community volunteers with seniors to assist them in getting to and from healthcare appointments and up to two trips to the grocery each month. 350 people are registered in the Volunteer Driver Program although about 35 seniors use the service each month. Many seniors who register for the Volunteer Driver Program express having trouble getting to transit stops because of mobility issues or have expressed confusion in how to navigate a bus transfer.

Humboldt Senior Resource Center (HSRC) supports seniors and their caregivers through activities programs, nutrition programs, and adult day health services. HSRC also operates a transportation program which allows seniors to access HSRC services. HSRC has over 300 participants that live as far north as Patrick's Point to Blue Lake to Ferndale and south to Carlotta and Stafford for whom they provide non-emergency transportation to HSRC programs and medical appointments. The HSRC transports 50-70 people a day to the Adult Day Health Center and also 50-70 people a day to the PACE Center, which provides all-inclusive medical care for seniors. There are quite a number of participants that live within this project's geographic scope. The HSRC has provisions in place to help seniors shelter in place at the center should a tsunami event or flooding occur.

Tri-County Independent Living is a community based, cross disability non-profit which supports people with disabilities and their families and also advocates for the rights of and access for people with disabilities

2.3.9 Navigable Waterbodies (Waters of the US)

While not considered usable for commercial transportation today, local navigable waterbodies represent a nexus between interstate commerce, transportation policy, and clean water regulation. They remain usable for recreational transportation uses such as kayaking, canoeing, small, motorized boat activity, and paddle-boarding. These include Humboldt Bay/Arcata Bay, Eureka Slough, Ryan Slough, Fay Slough, and tributary waters. Boat launches exist in the City of Eureka at Halvorsen Park and adjacent to Target.

2.4 Utility Infrastructure

Utilities in the study area (Exhibit 2-8) include resources traversing the City of Eureka and unincorporated Humboldt County. The types of utilities and ownerships vary and are briefly described below.

2.4.1 City of Eureka

The Mad River water transmission lines run from the Humboldt Bay Municipal Water District's facilities on the Mad River to the City of Eureka. This is the primary distribution line of wholesale water to the City. The transmission lines consist of two parallel 24-inch diameter pipes, one ductile iron and the other high-density polyethylene (HDPE). The HDPE line was installed recently to replace the aging ductile iron pipe, and while only one is needed to meet the City's demand, the ductile iron pipe remains in service as a redundant line. The City owns easements along the pipeline that cross private agricultural land, Quail and Redmond Creek, and Freshwater Slough and exit the study area near Oakridge Terrace. There is also a booster pump station for the water line located within the study area adjacent to Ryan Slough near Myrtle Avenue. City of Eureka water distribution mains are also found throughout the study area and predominantly located under city streets. Sewer collection and transmission mains are located throughout the study area including Jacobs Avenue and Y Street lift stations and the Tydd Street pump station.

2.4.2 Pacific Gas & Electric

An overhead electric transmission line enters the northeast end of the study area at Indianola Cutoff approximately 0.1 mile north of Myrtle Avenue, paralleling it through agricultural areas, crossing Myrtle Avenue again about 1,200 feet east of Pigeon Point Road, where it then continues south outside of the study area. The lowest elevation noted along the transmission line right of way (not necessarily where towers are located) is 2.85 feet.

A major underground natural gas line bisects the study area in north-south direction. This supplies natural gas to Arcata from its depot in Eureka. The size, material type and burial depth of this main are currently unknown.

Additional overhead electrical and underground natural gas lines are known to exist within the study area beyond those shown in this report.

2.4.3 Humboldt Community Services District

The study area falls within the eastern region of the Humboldt Community Services District (HCSD). HCSD is a public agency chartered to provide water, sewer, street lighting, recreation and storm drainage (HCSD 2015). Within the study area, sewer, drinking water, and street lighting are provided. Sewer collection and transmission mains including lift stations on Hoover Street on Edgewood Road are significant assets within the study area.

Additional water distribution facilities are known to exist within the study area beyond those shown in this report.

2.4.4 Communications

Seven communication towers are within the study area and includes the KEKA-FM radio station. Ground elevations at the base of the communication towers range from 6.6 to 27.6 feet in elevation.

2.4.5 Water Control Structures

Multiple water control structures exist within the study area and include culverts, tide gates and flashboard risers. Commonly the water control structures are owned and maintained by the property owner or through drainage easements.

2.5 Critical Resources

The 2019 Humboldt County Hazard Mitigation Plan define critical facilities and infrastructure as "those that are essential to the health and welfare of the population", and "become especially important after any hazard/natural disaster event occurs" (TetraTech 2019). The following categories of critical facilities and infrastructure were established in the hazard mitigation plan and facilities that are characteristic of these categories within the study area have been shown on Exhibit 2-9.

Medical and Shelter Facilities and Vulnerable Populations. This includes locations that may be sheltering or community gathering areas, and structures housing populations with limited physical mobility. Example facilities include but are not limited to hospitals, schools, skilled nursing facilities, board and care homes, pharmacies, clinics, fairgrounds, community centers, ambulance services, and veterinary hospitals.

Emergency Response. Police, fire, and other local, state, and federal emergency response facilities and operation centers. This also includes related equipment and vehicle storage, and emergency response staging areas. The Humboldt County Public Works garage and Corporate Yard are relevant facilities within the study area.

Utility Services. Facilities described above in Section 2.4. Aviation is also included. Radio stations and Murray Field are facilities that fall under this category.

Levees. As described above in Section 2.2.4.

Hazardous Facilities, including Risk Management Plan Hazardous Material Sites and Additional Hazardous Material Sites. These are described as facilities that "use or store acutely hazardous materials as defined by California Code of Regulations Title 19, Division 2, Chapter 4.5, Section 2770.5" and "hazmat sites (that) may include nuclear material storage sites, retail and wholesale fuel facilities, hazardous materials yards, and pulp mills." According to the State Water Resources Control Board's Geotracker website, the study area has four currently open contaminated Cleanup Program Sites. There are also three current Leaking Underground Storage Tank (LUST) sites near the study area boundary (Exhibit 2-9).

2.6 Land Use and Regulatory Boundaries

2.6.1 City of Eureka General Plan

The City of Eureka adopted its 2040 General Plan in 2018, with updates to Land Uses. Core Land Use plan areas that overlap with the study area include portions of the Commercial Bayfront and Myrtle Avenue, and the entirety of the North Gateway District, Bridge District, Jacobs Avenue to Indianola and Brainard Industrial Park. Understanding the intended development patterns and potential maximum development endpoint for these areas can aid with risk assessment including cost-estimating potential losses or damages related to sea level rise, and selection of appropriate adaptation strategies. The General Plan indicates the following expected development trajectories:

Commercial Bayfront: "future development is expected to include dense multi-story buildings at the back of the sidewalk that include pedestrian scaled shops, storefronts, restaurants, museums and cultural facilities, art galleries, theaters, lodging facilities, other related uses lining the sidewalks, and a range of office and residential uses in non-street facing portions of buildings and above the first floor." The preferred Land Use of Bayfront Commercial (BC) dominates this area. Natural Resource (NR) land use is also adjacent, creating a buffer along a reach of the Eureka Waterfront Trail.

Myrtle Avenue: "this area is envisioned to continue to serve the commercial needs of surrounding neighborhoods." Preferred Land Uses along this core area include Medium Density Residential (MDR), Public/Quasi-Public (PQP), General Commercial (GC), and High Density Residential (HDR).

North Gateway District: "this area is envisioned to continue to grow as an area of diversely intermixed service commercial uses." This District includes General Commercial, Natural Resource, and High Density Residential Preferred Land Uses.

Bridge District: "is a home to medium-density residential uses as well as a diverse mix of business-serving commercial uses, offices, and light manufacturing. The Bridge District is envisioned to continue to grow as an area of diversely intermixed uses." The Preferred Land Use preferred is General Commercial.

Jacobs Avenue to Indianola: Jacobs Avenue is a unique combination of service, commercial, light industrial, warehousing, and mobile home park uses. (It) is envisioned to continue providing a diverse mix of service commercial uses." General Commercial, Public/Quasi-Public, Natural

Resources, Agriculture (A), and Estate Residential (ER), and Water Conservation (WC) are Preferred Land Uses in this area.

Brainard Industrial Park: “This area has traditionally accommodated industrial uses and is environed to become a major center of employment within the City following the construction of a variety of new buildings.” The Preferred Land Use for this area currently undergoing annexation is General Industrial (GI).

The Preferred Land Uses (Exhibit 2-10) prescribe densities and intensities of land development. The General Plan includes many policies which are pertinent to the study area, coastal planning, and sea level rise adaptation planning. The policies included broad affirmations for cost-sharing; inter-agency coordination and participation in regional hazard and emergency preparation planning; tribal resource protection and tribal consultation and coordination; coastal development; conservation and preservation of natural resources and open space areas; and compliance with state and federal regulations and programs, including floodplain regulations and insurance programs; as well as more direct objectives relating specifically to sea level rise.

The following are specific policies for adapting to sea level rise which were included in the General Plan to establish the City’s vision and priorities for the development of its Local Coastal Program (LCP).

SL–1.1 Maintain and Enlarge Shoreline Protective Structures. Maintain and enlarge existing shoreline protective structures to protect development from sea level rise related hazards, including storm events, wave run-up and coastal erosion.

SL-1.2 Design of Shoreline Protective Structures. Require shoreline protective structures be designed for multiple urban purposes, connect to the public access system, ensure shore and structural stability, limit impacts on coastal resources, incorporate soft coastal protection, minimize aesthetic impacts and neither create nor contribute significantly to erosion, or cause geologic instability.

SL-1.3 New Development. Require new development along the shoreline to assure stability and structural integrity, neither create nor contribute significantly to erosion, not cause geologic instability or destruction of the site and surrounding area or in any way require the construction of protective devices that would substantially alter natural landforms along bluffs and cliffs and ensure that risks to life and property are minimized and that new development is safe from and does not contribute to flooding.

SL-1.4 Raise Structures. Require new development and substantial improvements to existing development that are located in areas not protected from coastal flooding to have raised structures to minimize risks to life and property.

SL-1.5 Natural Shoreline Areas. Encourage the preservation and habitat enhancement of natural shoreline areas as identified in the most recent shoreline mapping assessment.

Adaptation Measures

SL-1.6 Protect Key Coastal Assets. Prioritize the development and implementation of adaptation measures to protect key coastal assets.

SL-1.7 Coordinated Protection System. Establish and maintain a coordinated Sea Level Rise protection system for low lying areas. Consider establishing an Assessment District to fund the maintenance and improvement of coastal flood protection measures.

SL-1.8 Protection Management Strategy. Protect developed areas and areas designated for urban uses by maintaining and enlarging existing shoreline structures, addressing gaps in the City's coastal flooding lines of defense, and periodically updating and amending sea level rise vulnerability assessment, adaptation plans, and mapping based on best available science until such time as the magnitude of sea level rise is such that the protection management strategy can no longer be achieved.

SL-1.9 Fill Material in the Bay. Place safe fill material in the Bay to protect existing and planned development from flooding and erosion, consistent with requirements of the Coastal Act.

SL-1.10 Relocate Development. Abandon developed areas if it is determined that it is no longer feasible to construct and maintain shoreline structures from the effects of sea level rise. Modify or remove shoreline protective structures if currently developed areas are abandoned and development is relocated outside the coastal hazard areas.

SL-1.11 Reduce Damage from Peak Tidal and Storm Events. Explore and encourage innovative solutions to reduce damage from peak tidal and storm events, including the installation of hard engineered tidal barriers, installation of temporary sea gates, pump stations and offshore structures, construction of soft engineered islands, reefs, marshes, and living shorelines, utilization of safe local waste material to implement adaptation measures, and construction of stormwater detention basins.

SL-1.12 City Projects. Integrate resilience to anticipated sea level rise impacts into City project designs when repairing and replacing aging infrastructure.

Disclosure, Education, and Collaboration

SL-1.13 Disclose Sea level Rise Impacts. Disclose the potential for sea level rise impacts with the use of the following tools: zoning code requirements, sea level rise hazard maps based on best available science, and risk disclosure requirements.

SL-1.14 Education. Work with community partners, property owners, and managers of assets at risk to enhance local understanding of sea level rise and identify best management practices that reduce vulnerability and risk from sea level rise hazards.

SL-1.15 Collaboration. Collaborate with stakeholder groups, other agencies, local tribes, and the public to develop local and regional strategies that collectively improve the community's ability to adapt to sea level rise in ways that advance or maintain economic prosperity, social equality, and environmental protection.

2.6.2 Humboldt County General Plan

Humboldt County adopted its Humboldt County General Plan for the Areas Outside the Coastal Zone in 2017. Given that the portions of the study area that are within unincorporated Humboldt Count are entirely within the Coastal Zone, and the County's Local Coastal Program is in development, specific policies are not discussed here. Land Uses that have been identified within the study area (Appendix B) though the County's online GIS web viewer, however, are discussed here for general reference about development trajectories. The LCP may modify the development criteria.

The general areas of unincorporated Humboldt County include Myrtletown, agricultural bottomlands, and Brainard, which as noted elsewhere is in the process of annexation by the City of Eureka.

Land Uses designated within the study area include the following:

RL 1-7 – "for areas suitable for residential use where urban services are available or are anticipated to be available. Single family units on individual lots are the dominant use, but the designation can accommodate a mix of housing types including townhouses and common-wall clustered units."

RM – "areas with full urban services and common-walled units an apartments are appropriate, including duplexes, townhouses, and apartments and manufactured home park developments."

CG – "lands that because of their location, access, and availability of services are suitable for commercial development…"

MG – "provides for general industrial and manufacturing uses, typically in urban areas, convenient access to transportation systems and full range of urban services are available…may be accommodated in rural areas…"

NR – "the purpose of this designation is to protect and enhance valuable coast fish and wildlife habitats, and provide public and private use of their resources, including hunting, fishing and other forms of recreation."

AE – "applies to bottomland farms and lands that can be irrigated; also used in upland areas to retain agricultural character. Typical uses include dairy, row crops, orchards, specialty agriculture, and horticulture…"

RR – denoted as Rural Residential in online Land Use layer of Humboldt County Web GIS. Not described in Land Use Element but may be described by Residential Agriculture (RA) designation.

RX - denoted as Rural X-Urban in online Land Use layer of Humboldt County Web GIS. Not described in Land Use Element.

There is potential for an intensification of land use in some parts of the study area, principally in the City of Eureka. While some of this development may occur at lower elevations in the Commercial Bayfront and Brainard Core Areas, most intensification will occur at higher elevations. There is also potential in both City of Eureka and Humboldt County agricultural areas for additional residential development to house farmworkers or property caretakers. These residences would be within flood hazard and sea level inundation areas.

Table 6 summarizes the minimum and maximum elevations of the different Land Uses within the study area.

Table 6. Minimum and Maximum Elevations for Zoning Designations in Study Area

Zoning	Code	Min. Elev.	Max Elev.
Agriculture	A	-0.2	42.5
Agricultural Exclusive	AE	-0.2	73.9
Bayfront Commercial	BC	3.9	21.9
Commercial General / Rural Residential	CG/RR	14.1	20.8
Commercial Recreation	CR	8.9	25.1
Estate Residential	ER	7.1	84.3
General Commercial	GC	0.2	51.0
High Density Residential	HDR	2.6	50.3
Industrial General	MG	2.0	26.6
Neighborhood Commercial	NC	3.0	36.5
Natural Resources	NR	-1.4	40.9
Professional Office	PO	13.5	37.9
Public / Quasi-Public	PQP	-0.1	22.1
Parks and Recreation	PR	28.7	45.7
Residential Low Density	RL	-1.2	74.1
Residential Medium Density	RM	51.6	73.1
Rural Residential	RR	1.6	142.8
(unknown county code)	RX	5.5	146.9
Water Conservation	WC	-1.6	21.8
Water Development	WD	-1.4	11.3

Municipal Land Use Zones are shown on Exhibit 2-11. Land Use describes desired future potential development such as maximum densities and FARs, and while zoning is essential for permitting development projects, it is not discussed in detail here.

2.6.3 California Coastal Commission Jurisdiction

The California Coastal Act applies to three jurisdictional coastal zone boundaries (Local, Appeal and State jurisdiction). The Coastal Commission delegates most development review authorities to local jurisdictions upon certification of a Local Coastal Program (LCP), which is the jurisdiction's policies and procedures for reviewing development permits and conforming with the Coastal Commission's regulations. The areas under this authority are called the Local Coastal Zone jurisdiction. The areas are approximately represented by the overlap of the study area boundary with developed area footprints of the City of Eureka and Humboldt County. The Coastal Commission retains permit authority over tidelands, public trust lands, and other specified lands, designated at the State Coastal Zone jurisdiction. An Appeal Zone jurisdiction consists of lands generally situated between the Local and State Zones and may possess public trust. The study area is located within the Coastal Zone as shown on a previous Exhibit.

2.7 Disadvantaged Communities and Environmental Justice

The California Government Code defines a "disadvantaged community" as "an area identified by the California Environmental Protection Agency pursuant to Section 39711 of the Health and Safety Code or an area that is a low-income area that is disproportionately affected by environmental pollution and other hazards that can lead to negative health effects, exposure, or environmental degradation." Health and Safety Code Section 39711 elaborates that the disadvantaged community's designation is "based on geographic, socioeconomic, public health, and environmental hazard criteria." State and federal agencies have developed screening tools to facilitate in determining the disadvantaged status of communities. Environmental justice is a related concept that, as defined by the United States Environmental Protection Agency (USEPA/EPA), ensures "the fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income, with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies. This goal will be achieved when everyone enjoys the same degree of protection from environmental and health hazards, and equal access to the decision-making process to have a healthy environment in which to live, learn, and work.

Disadvantaged communities are characterized by a range of metrics. The USEPA provides the EJSCREEN tool to evaluate potential environmental justice issues in communities. Within a smaller demographic subset in the city of Eureka, between R Street and Highway 101, the resident population ranked at 95-100 percentile low income, defined by a ratio of household income to poverty level. It also ranked in the 74th percentile for adults with "less than high school" education, and 77th percentile for linguistic isolation. It also ranked this area in the 94th percentile for traffic proximity, 90th percentile for potential lead paint exposure, 72nd percentile for proximity to a hazardous waste treatment storage and disposal facility, and 71st percentile for the respiratory hazards index (a set of indices established by the EPA). Overall, the EPA ranks the site in the 69th percentile for environmental justice communities. The portion of the project site between Myrtle Avenue and Eureka Slough, bounded by Highway 101 and Second Slough, ranked in the 60th percentile for environmental justice communities, while the remainder of the project study area ranked in the 53rd percentile.

The California Environmental Protection Agency (CalEPA) Office of Environmental Health Hazard Assessment (OEHHA)'s Calenviroscreen website developed rankings related to potential toxic exposures. The study area ranks on the lower end of the statewide range for pollutant exposure, with threats noted in a more populated tract to include relatively low percentile exposures to particulate matter, ozone, diesel, toxic releases and impaired water, moderate percentile exposures to traffic and cleanups, and high percentile exposure to groundwater threats related primarily to leaking underground storage tanks. Disadvantaged health and welfare criteria that also factored into this tract included a high percentile ranking for asthma (94th percentile), poverty (87th percentile), cardiovascular rate (78th percentile), and housing burden (74th percentile). Note that percentiles are rankings based on all data collected nationwide, not percentages of exposure by the population.

The California Department of Water Resources (DWR) developed a different disadvantaged communities screening tool, the DAC Mapping Tool, which ranks communities by median household income. Under this tool, much of the inhabited areas of the project study area are ranked a "Disadvantaged Place," meaning the median household income is between $38,270 and $51,026. This ranking is influenced by the census block group that overlays a City of Eureka study area community bounded by the Humboldt Bay shoreline and R Street to Second Slough and Myrtle Avenue that is ranked as Severely Disadvantaged, with median household incomes of less than $38,270 (Exhibit 2-12). There are three mobile home parks in the study area, dominated by low-income populations yet outside of the Severely Disadvantaged DAC area. Two of these mobile home parks are adjacent to Eureka Slough, have a high level of exposure to sea level rise, and are isolated from city services, food stores, and transit stops located across Eureka Slough and is reachable only from Highway 101. Jacobs Avenue does not have any transit service and as it is reachable solely from Highway 101 it has no walking or biking connectivity to the rest of the Eureka. Carless households on Jacobs Avenue would only have the option of walking, biking, or carpooling to work, school and services. The Lazy J Mobile Home & RV Park between approximate elevations 4 and 7, and Shoreline RV Park between approximate elevations 8 and 12 feet. Both are behind shoreline protection structures. Regardless of state or federal designation, residents within the study area living at low elevations are exposed to flood risks on a seasonal basis. This risk will only increase as sea levels rise. Low-income residents, including the elderly, disabled, and homeless, may have particular mobility challenges and restricted options for temporary or permanent relocation in the event of a flood or other natural disaster. Inclusion of their concerns will be important to adequately prepare adaptation strategies.

3. GEOMORPHIC SETTING

This section describes the natural landforms and human-made landscape features within the study area and the physical processes that affect their shapes and functions. In order to more accurately predict how the coastal landscape will respond to flood events and sea level rise, it is important to understand how landforms have evolved and been altered through natural processes and human intervention over time. Important sources for this section include recent studies addressing sea level rise vulnerabilities (Caltrans 2014; Laird and others 2013; 2015; 2018; NHE, 2015), hydraulics (FEMA 2014; NHE 2016), groundwater (Willis 2014), sediment management (CSMW 2017), ecology (Schlosser et al. 2009) and land-use planning documents (City of Eureka 2018; Humboldt County 2017).

3.1 Existing Site Geomorphology

The study area extends along the east shore of Arcata Bay from Eureka Slough to Indianola Cutoff, and across the backshore lowlands tributaries of Freshwater Slough to Myrtle Avenue. Arcata Bay is the northern, shallow basin of Humboldt Bay, and is connected to the South Humboldt Bay (South Bay) and the Humboldt Bay entrance by a relatively narrow channel about five miles long that fronts the City of Eureka. Arcata Bay is a tidal basin, with a mean tide range of 4.8 feet, diurnal range of 6.7 feet, and a maximum range of about 11 feet during spring tides. Although Arcata Bay is sheltered from large, off-shore swell waves, strong wind events can generate local, short-period wind waves across the approximately four-mile-long fetch (ESA 2018).

Extensive mudflats are located immediately offshore of the western boundary of the study area, with portions of remnant tidal marshes located in patches along the shore. As documented by Laird et al. (2013), much of the shore was leveed in the 19th century to convert the marsh areas to agricultural uses and to construct the Northwest Pacific Railroad. While only small, isolated portions of marsh are still present along the shore, the mudflats have persisted over time and support an abundance of eelgrass.

Constructed landscape features along the Bay shore include the levee around the Brainard former mill site and the North Coast Railroad Authority (NCRA) railroad prism, which were built on former tidelands. The railroad prism was constructed over 100 years ago and portions have deteriorated due to erosion of the ballast and fill materials. The Humboldt Bay Trail South project will result in a new trail located between the NCRA railroad prism and Highway 101 for approximately 3.25 miles and on top of the Brainard levee for approximately one mile.

The railway, levees and Highway 101 are a partial barrier to coastal flooding with elevations ranging from about 9 to 20+ feet NAVD 88. Much of the railway located along the Bay shore is in a degraded condition. Bay water overtopping the railway typically drains into a drainage ditch, but during extreme high water events portions of Highway 101 can flood. High Bay water levels also affect the interior lowlands directly via Eureka Slough and tributary Freshwater and Fay Sloughs. Historically, interior flooding has been caused by overbank flooding from the creeks (NHE 2015).

Low areas behind levees are also subject to localized ponding of stormwater during rainfall events, although this exposure is managed with hydraulic structures, culverts and pumps.

The study area comprises a mix of artificial or constructed and natural features, including mudflats, tidal marsh, tidal sloughs, and low-lying leveed agricultural areas. The interior lowlands in the study area and shore conditions are described by Laird and others (2013) as consisting primarily of subsided former tidal marsh that are used for agriculture or wildlife areas and protected by artificial levee structures. Three major tidal branches of Eureka Slough include Fay Slough, Freshwater Slough and Ryan Slough. The watersheds provide important brackish and freshwater conditions for fishery habitat, particularly rearing habitat for juvenile salmonids. Much of the area was leveed along Eureka Slough, and the upper portions of Freshwater and Fay Sloughs include open channel/unleveed bottom land and brackish marsh habitat, respectively.

Variations of the surface sediments in Humboldt Bay, including silt, clays, and coarse material (e.g., sand, shell fragments, etc.) typify the morphology of the bay (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, wave action or commercial oyster harvesting has resulted in accumulation of relatively coarser materials. Based on the field measurements, dredged channels have larger components of gravel and mud than non-dredged channels. 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 0.2 to 0.4 cm/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, 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.

3.2 Historical Geomorphic Conditions

3.2.1 Influence of Sea level Changes

During the last ice age (approximately 15,000 to 20,000 years before present), sea level was 100 to 200 meters lower than it is at present (Barnhart and others 1992). Following the end of the ice age, sea levels rose as ice melted. 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 (Barnhart and others 1992; Costa and Glatzel 2002; Schlosser and Eicher 2012).

3.2.2 Historical Morphology

Barnhart and others (1992) summarizes historical morphology of the Bay reported in prior studies. Humboldt Bay was a river valley drowned by sea level rise over the prior thousands of years. Several thousand years ago, the Mad River probably still discharged into the Bay. As sea levels rose, 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). Figure 5 presents an oblique aerial image of the study area that shows these three habitat types. Subtidal channels are tidal channel features with a bottom elevation that is below the lowest tides, and which retains a residual depth at these low tides. Subtidal channels are formed and equilibrate in size proportional to the tidal prism that is exchanged over a tidal cycle (Williams et al. 2002). Mudflats are the expansive tidal flats that establish in the intertidal zone. The mudflats of Arcata Bay are further subdivided into a flatter portion just below low tides (e.g., MLLW) and a steeper portion up to high tides (e.g., MHW) where the marshes exist. A typical Bay profile is shown in Figure 6. 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 is periodically inundated by extreme high tides.

3.2.3 Effects of Navigation Dredging

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 which included dredging in the North Bay to deepen a navigation channel to the Arcata pier. Bay entrance modifications were initiated around 1889 which included construction of rock jetties (Rohde 2020), and the existing entrance configuration was constructed in the 1970s. Glatzel (2002) 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, is removed from the system via navigation dredging, disposed of offshore and outside the Eureka Littoral cell, therefore is no longer available for resuspension and distribution throughout the Bay. While Glatzel (2002) mentions the effects of the deepened and stabilized Bay entrance have had on tidal hydraulics and sediment transport through the Bay, they are not quantified in the study area (Arcata Bay).

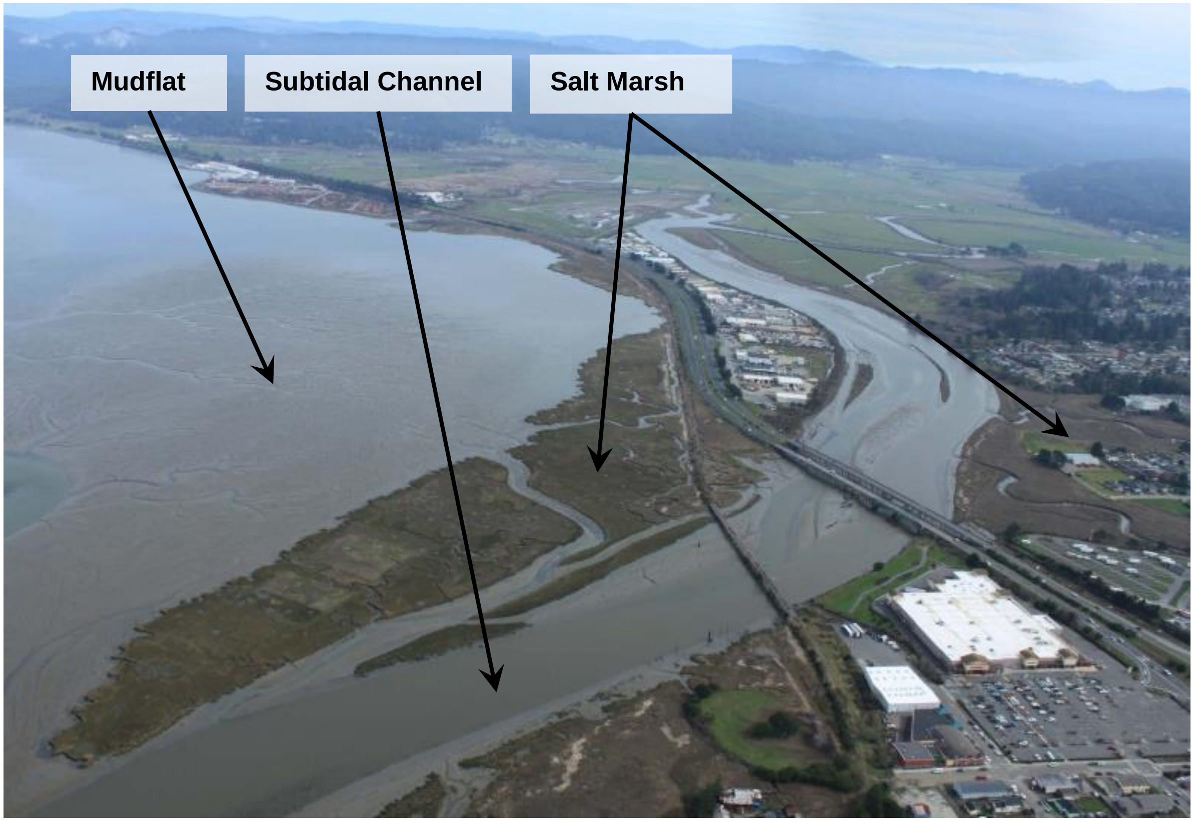


Figure 5. Oblique Aerial Image of study area showing the mix of distinct habitat types: subtidal channels, mudflats, and salt marshes

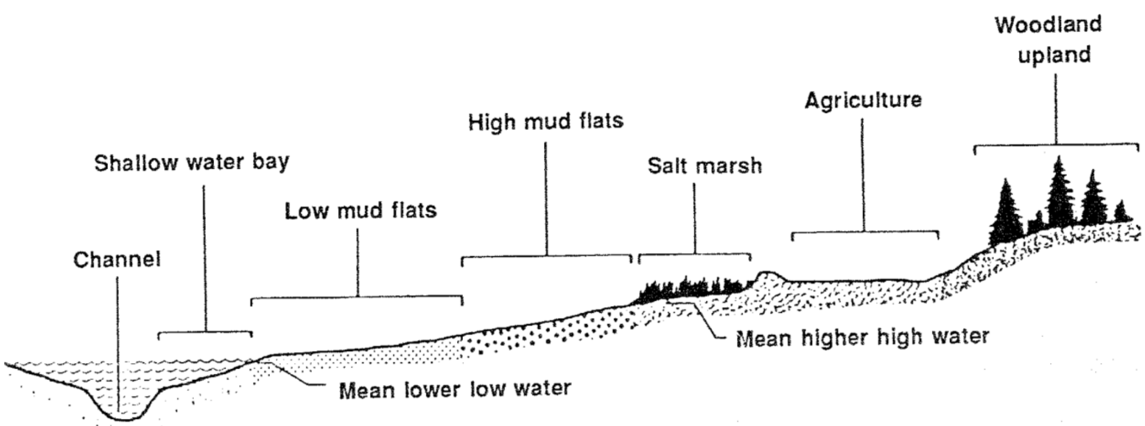


Figure 6. Typical Arcata Bay shore profile. Source: Barnhart (1992) from Monroe (1973).

3.2.4 Effects of Transportation and Reclamation Infrastructure

While Spanish and Russian sailors explored the vicinity in the 1500s – 1700s, and anchored in the lee of Trinidad Head, Humboldt Bay was not discovered until1806 (Coy 1982), and then settled in 1850 (Barnhart and others 1992). Development was spurred by the gold rush of the 1800s but frustrated by the less-than-convenient marine and land access. Humboldt Bay entrance was challenging due to shallow depths at its entrance and landward travel was challenging due to marshes, dense redwood forests and the surrounding mountains. Still, towns began to form in the vicinity of the study area around 1850, notably Union (Arcata) and Eureka. Rail lines, primarily for transporting redwood logs from inland forests, were constructed in the late 1800s. The heavy timber forests and inland marshes in the study area impeded land transport until a road was finally constructed between Arcata and Eureka around 1862 (Coy 1982), but this roadway was inland of the study area, likely in the vicinity of the existing Myrtle Avenue, see historic maps from 1854 (Exhibit 3-1) and 1870 (Exhibit 3-2).

A railway was constructed along Freshwater Slough in the 1880s to convey redwood logs harvested at Freshwater Canyon to tidal waters where the logs were dumped into the water and rafted to mills. The railway operated from the 1880s to 1940s, at which point the railway was abandoned (SVK 2006, Roscoe 2007). The railway ran along the right (west and north side) near Jacobs Avenue Industrial area and Murray Field airport (Figure 7 and Figure 8) and see historic maps from 1890, 1916, 1921 and 1933 (Exhibit 3-3, Exhibit 3-4, Exhibit 3-5, and Exhibit 3-6, respectively).

Between 1895-1898, the salt marsh edge along the Bay between Bracut and Brainard was leveed as part of a dredging effort further described below. Following the diking, two parallel rail prisms were constructed landward of the levees in 1900, however tracks were only placed on the eastern prism and the western prism was never completed nor used for its intended purpose. A review of maps indicate that the initial diking blocked tidal channels immediately north and south of Brainard resulting in a progressive conversion of wetlands to other land uses (Barnhart 1992 and Rohde 2020).

Based on a review of historic maps, Highway 101 (2-lanes) was constructed between 1918 and 1925 paralleling the railway, and subsequently widened to the existing condition in 1955 (Rohde 2020). Similar to the initial marsh edge diking and subsequent rail prism construction, the highway also blocks tidal exchange. A drainage ditch paralleling Highway 101 discharges to Eureka Slough just south of Murray Field airport via a water control structure.

Conversion of marsh to grazing and agricultural lands initiated in the northern part of the study area in 1895 and progressed to Freshwater Slough by 1900 (SVK 2006). Historical maps indicate that the marsh drainage network of earthen levees and levees and drainage channels and water control structures has been further developed over the last century.

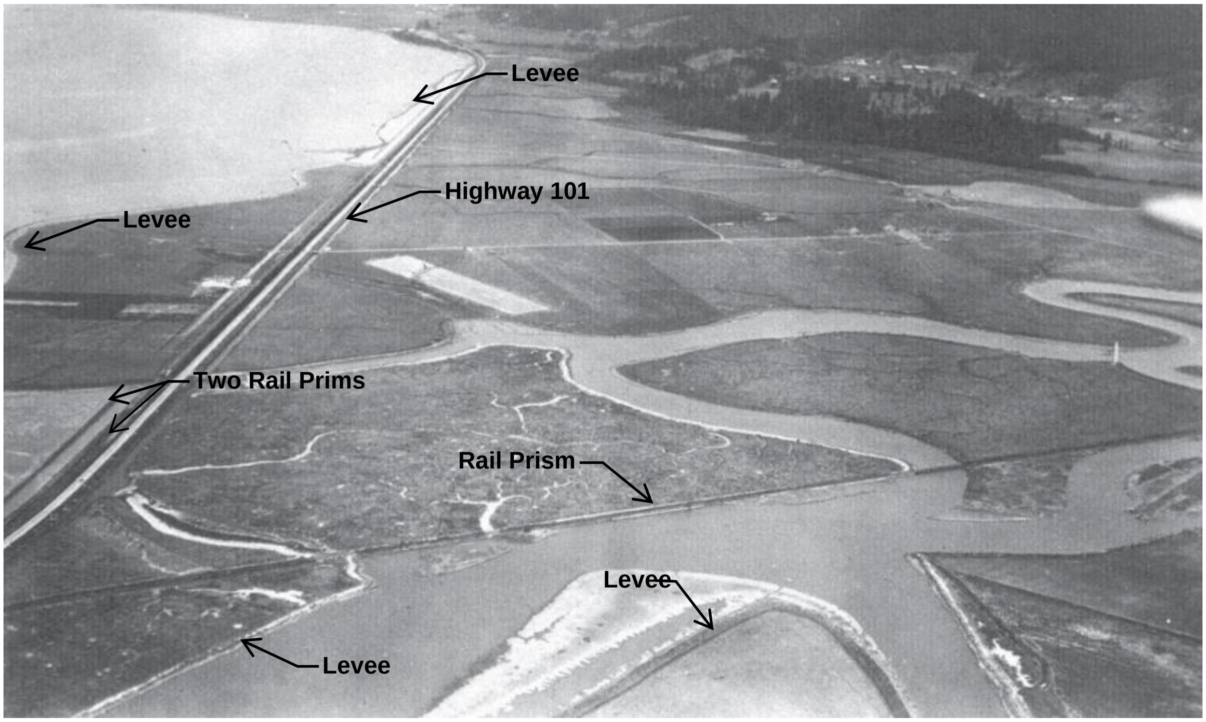


Figure 7. Aerial photo taken by Kenny Kilburn in 1927 (Roscoe 2007).

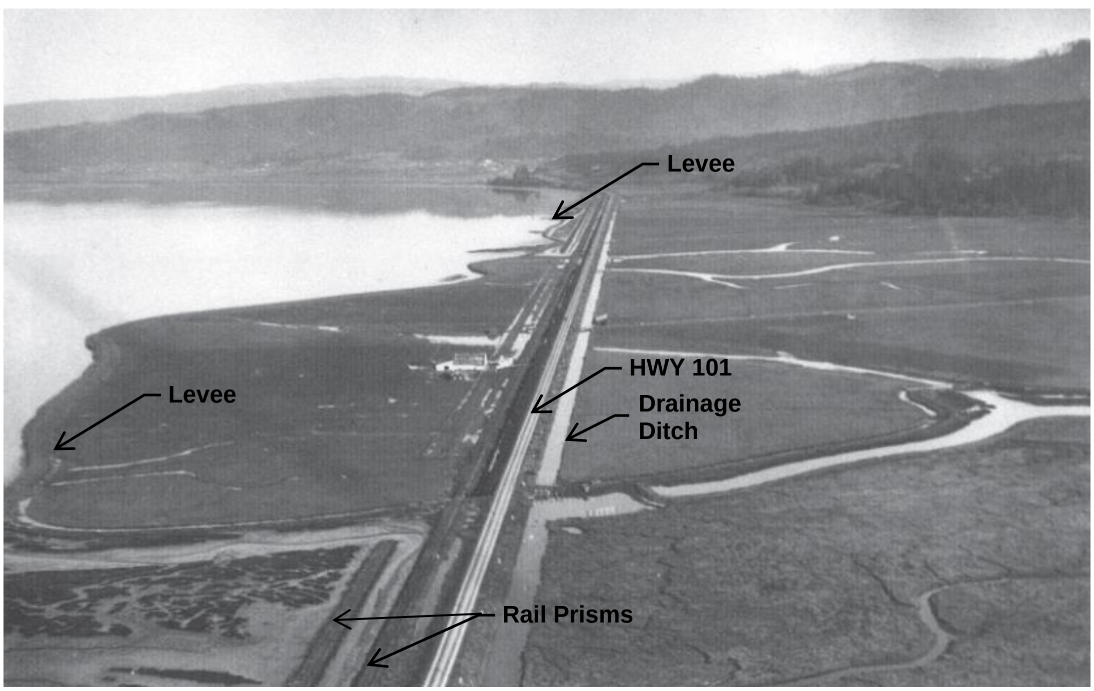


Figure 8. Aerial photo taken by Kenny Kilburn in 1927-1929 (Roscoe 2007).

The construction of Highway 101 and the reclamation of tidal marsh has profoundly changed the project area (Laird and others 2013, Rohde 2020). Marshes were directly impacted by the "footprint" of fill and diking and draining. The marshes were indirectly affected by removal of tidal connection and reduction of tidal prism, and likely increased sediment delivery from deforested areas and other watershed changes. Overall, most tidal marshes were converted by 1929 as indicated by (Barnhart and others 1992, Figure 9) and as illustrated in Exhibit 3-5 which shows the remaining tidal marsh in the study area as mapped by USDA in 1921. However, many of the former tidal marshes converted to grazing and agriculture remained seasonal wetlands due to their low elevations (HBHRCD 2007). The Bay and slough marshes have since eroded and former inland marsh lands have subsided, resulting in degraded ecology and exposure to risk of damaged due to flooding, as addressed later in this report.

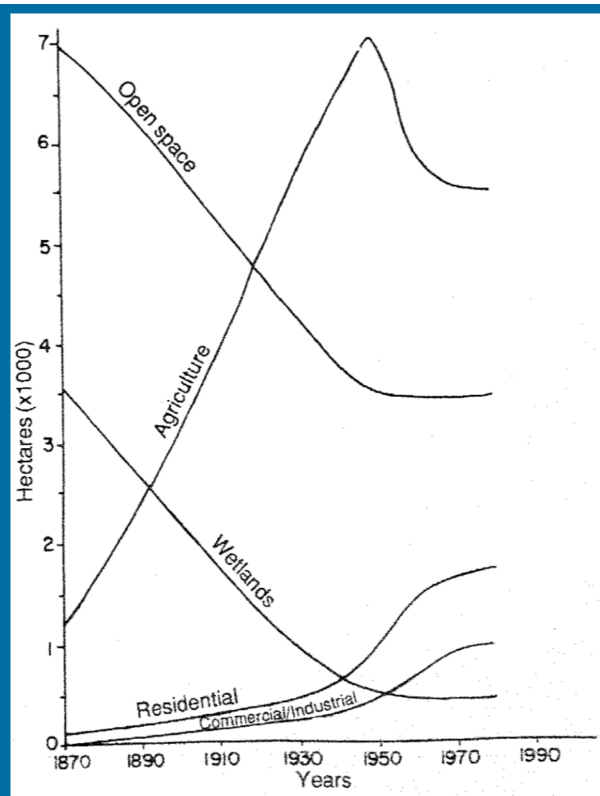


Figure 9. Alteration of wetlands, primarily tidal marsh, due to land uses and primarily agriculture, especially in Arcata Bay and particularly in the study area (Source: Barnhart and others 1992; modified from Shapiro and Associates, Inc. 1980. Humboldt Bay wetlands review and baylands analysis, final report. U.S. Army Corps of Engineers, San Francisco. 668 pp.)

In the 1950's, much of the Jacobs Avenue area was develop from the condition shown in Figure 10 and Figure 11. Additionally, the Murray Field Airport was expanded and an additional lane was added to Highway 101. The progression of this development is depicted in Exhibit 3-7, Exhibit 3-8, Exhibit 3-9, and Exhibit 3-10, most notably the filling of the Fay/Freshwater Junction Slough as part of the airport runway expansion and the presumable borrow site used on Walker Point as depicted in the 1958 aerial map (Exhibit 3-10).

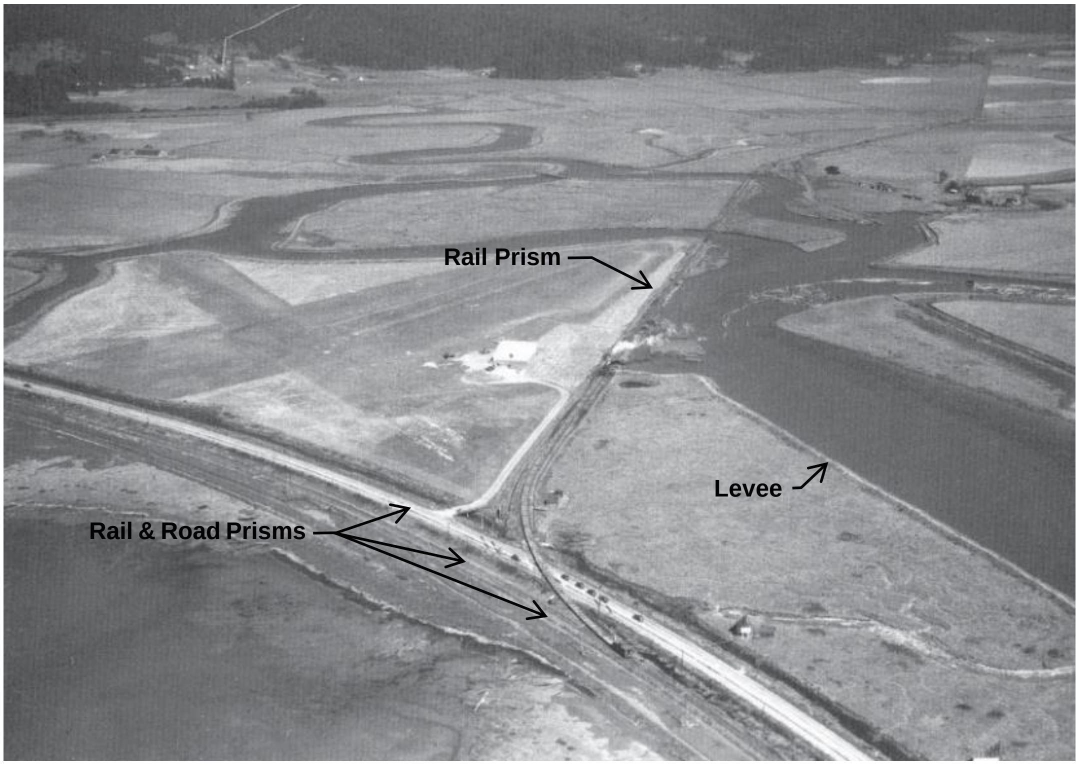
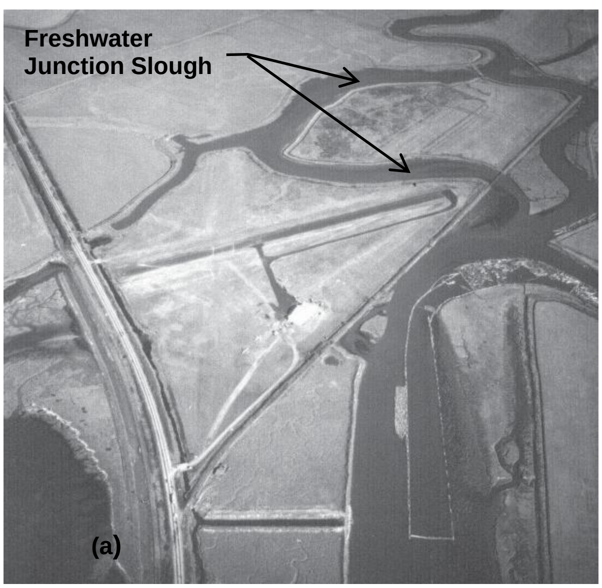


Figure 10. Aerial photo taken 15 March 1941 (Roscoe 2007).



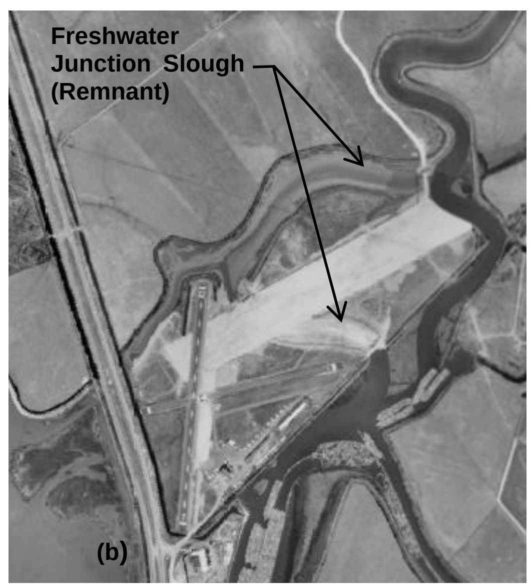


Figure 11. (a) November 1946 aerial photo taken by Merle Schuster (Roscoe 2007) and (b) 1958 Aerial photo. Murray Field runway was expanded by leveeing, draining and filling the Freshwater Junction slough in the 1950's.

Table 7 provides a partial list of previous landscape alterations within the study area. A more complete timeline of historical cultural influences within the study area is provided in Rohde 2020.

Table 7. Historical Timeline of Landscape Alterations in the Study Area

Time	Activity
Holocene Epoch	Drastically lower sea levels relative to current and Mad River may have discharged into Humboldt Bay
~4,000 Before Present	Salt marshes were first established around Humboldt Bay
January 1700	Major Cascadia subduction zone earthquake followed by a tsunami that flooded inland waters
Mid/Late 1800s	Logging era began and initial use of logging railroads and logging rafts
Approx. 1854-1890	Canal channeling Mad River through Mad River Slough into the bay
1862	Road constructed between Eureka and Arcata (Current Myrtle Avenue/ Old Arcata Road)
Approx. 1870s-1915	Land reclamation through diking of tidelands. Levee construction begins along Fay and Freshwater Sloughs and Bay shore in 1895.
1881	Dredging of Eureka and Arcata navigation channels begins
1880s – 1893	Logging railroad from Freshwater to sloughs (Excelsior Redwood Co.)
1901 – 1904	Railroad line between Eureka and Arcata completed
1916 – 1941	Pacific Lumber Co. logging railroad connected to NWP
1918-1925	2-Lane road connecting Eureka and Arcata graded (Current Highway 101)
1921	Road surfaced with gravel (Current Highway 101)
1925	Road improved to become paved, two-lane highway (Current Highway 101)
1930s	Jacobs Avenue levee built
1930s-1950s	Construction of Murray Field airport and realignment of Fay Slough
1934	Land for Murray Field purchased
Late 1930s	Murray Field hangar and runway built
1950s	Property along Jacobs Avenue subdivided/developed and runway expansion
1955	Additional 2-lanes added to Highway 101 east of the existing 2-lane prism for total of 4-lanes
1970-1972	Construction of Samoa bridge

3.2.5 Summary of Historical Condition and Interventions

The geomorphic evolution of the study 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
- Geomorphic features, including subtidal channels, mudflats, and salt marsh suggested an equilibrium condition of sediment and hydrologic processes, and these distinct units are also closely related to the unique habitats of the Bay
- Dredging of navigation channels likely influenced sediment distributions in the vicinity of the study area, although much of the information is not quantified.
- Construction of transportation and reclamation infrastructure on the former tide lands in the early 1900s was implemented without regard to potential fluctuations in sea levels and regional and local ground subsidence.
- The rail prism originally constructed in the early 1900s along the western boundary of the study area serves as a levee and has experienced significant degradation over time.
- Levees constructed along the interior sloughs isolated the tidal marsh areas that were converted to agricultural areas used for grazing, and which have subsequently experienced high rates of local subsidence.

3.3 Physical Shore Profile

Figure 12 depicts a conceptual shore profile for Arcata Bay within the study area depicting the contemporary and pre-developed landscape described above. Shore profile definitions are described below with reference to existing landscape features.

- ***Offshore*** is defined as beyond low tide (labeled as Mean Lower Low Water MLLW). Offshore areas include Arcata Bay and slough channels.
- ***Foreshore*** is defined as the intertidal range up to at least high tide (labeled as Mean Higher High Water (MHHW). For practical reasons, Foreshore may extend to higher water levels, as high as the annual high tide level (labeled as 1-year to indicate an annual exceedance). The foreshore typically includes tidal marshes and transitional areas between marshes and levees.
- ***Shore*** is defined as the location of a high to supra-tidal feature and would include the rail prism embankment as the typical shore feature, but in places, the feature is a levee or other artificial structure.
- ***Backshore*** is defined as the transitional area that is subject to limited tidal action or occasional flooding from the offshore via surface water. The backshore includes the drainage channels adjacent to Highway 101 and borrow ditches landward of levees within diked former tidelands.

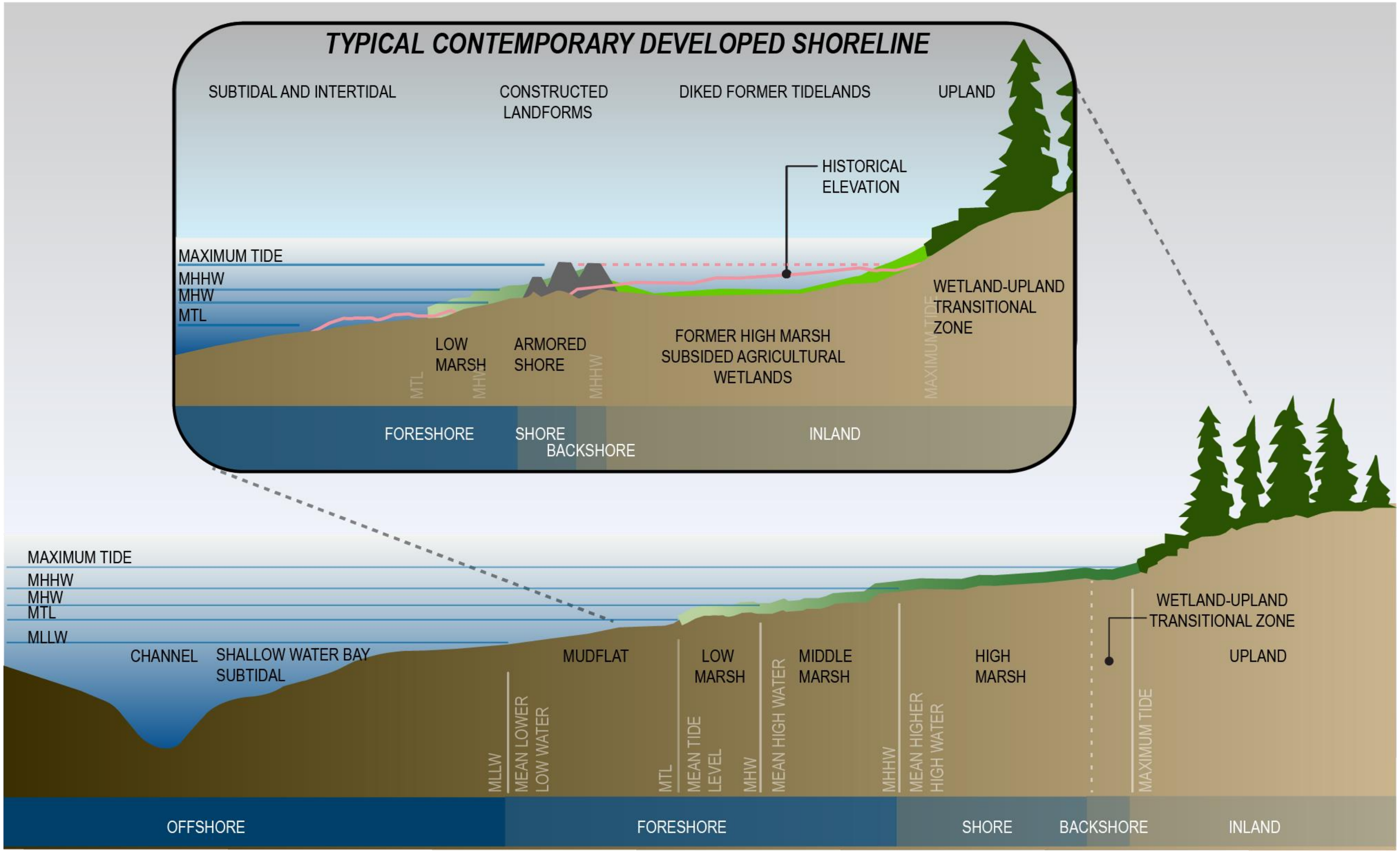


Figure 12. Arcata Bay Conceptual Shore Profile with Geomorphic Units Adapted from Barnhart (1992) and Monroe (1973)

- ***Inland*** is defined as the area farther landward and not typically inundated by surface water flows from offshore. Much of the inland areas are diked former tidelands and within the 100-year flood plain. Some of these inland areas are lower elevation than the foreshore.

The study area is modified by constructed features that define the shore and hence the locations of shore, backshore and inland are ambiguous, and may become even less defined with sea level rise. The purpose of the terminology defined herein is not academic but rather for ease of communication.

3.4 Geomorphic Units

Geomorphic units provide a spatial representation for areas that have similar landscape characteristics, elevations, and exposure to physical processes that maintain their form and function. The study area has been divided into four (4) geomorphic units as shown in Exhibit 3-12 and are defined below. In subsequent sections, these geomorphic units are re-visited in the context of future geomorphic response to physical processes.

1. **Subtidal and Intertidal:** These can be flood basins and flood sources subject to tidal waters from the Bay, rainfall runoff from freshwater tributaries, coastal storm surge, wind waves and sediment transport. Landforms include subtidal sloughs, intertidal mudflats, tidal marsh, and tributary creeks.
2. **Constructed Landforms:** These features include constructed earthen levees and railroad prisms that protect Highway 101 and inland areas. These features create boundaries of high ground that affect overland flows and overtopping of freshwater tributaries and coastal storm surge.
3. **Diked Former Tidelands:** Protected by constructed landforms that affect overland flows, these areas have altered sediment transport characteristics. Elements include remnant sloughs, drainage channels, water control structures, and other topographic features used to control runoff.
4. **Uplands:** These areas are located at higher elevations not subject to tidal flooding and comprise the balance of the study area, such as Walker Point and the areas above First, Second and Third Sloughs.

3.4.1 Subtidal and Intertidal

3.4.1.1 Arcata Bay

The study area is located on the eastern shore of Arcata Bay, in the northern part of Humboldt Bay. Humboldt Bay is a tidal estuary with an entrance stabilized for navigation (jettied and dredged). The western side of Arcata Bay is a littoral ridge, separating the bay from the ocean, formed by the wave- and wind-induced sand transport of the Pacific Ocean Shore. The northern and eastern sides of Arcata Bay are formed by sediments likely supplied by stream discharge and organics produced by emergent marsh vegetation. Arcata Bay is a shallow basin apparently shaped by locally generated wind waves and tidal currents. The waves and currents have apparently resulted in a roughly circular shape of Arcata Bay.

The mean low water (MLW) and mean high water (MHW) of Arcata Bay are 0.58 feet and 5.93 feet respectively. A Mean Higher High Water (MHHW) of 7.0 feet and Mean Lower Low Water (MLLW) of -0.72 feet contributes to the diurnal range of 6.7 feet. During spring tides, when the greatest differences between high and low tide occur, the range can reach approximately 11 feet. The highest astronomical tide (HAT) of 8.6 feet and lowest astronomical tide of -3.13 feet exhibit the range of extreme tides contributing to the study area.

The wind fetch across the Bay incident to the study area is approximately 4 miles, which results in significant wave height of approximately 2 to 3 feet (ESA 2018). Imposed upon this natural geography are structures primarily for transportation and flood control, allowing land uses such as agriculture, grazing, industrial activities and residential development, as well as an airport.

Typical daily low tides expose extensive mudflats throughout Arcata Bay and along the edges of tributary slough channels. Patches of tidal marsh dot the shoreline along the bay, between mudflats and higher elevation landforms. High diurnal tides inundate the marshes with much of the inland low-lying lands buffered from tidal waters by landforms created by human intervention.

3.4.1.2 Tidal Sloughs

The study area includes four prominent sloughs described below and their respective contributing watersheds.

- **Eureka Slough:** Eureka Slough is the primary tidal channel providing tidal action into the interior slough network. This slough provides the only tidal connection remaining from the historical conditions. Three tributary sloughs (First, Second and Third) extend inland between upland mesas that are developed primarily as residential areas.
- **Freshwater Slough:** Freshwater Slough is one of two smaller sloughs tributary to Eureka Slough. Freshwater Slough is tidal and fed by runoff from three tidally-influenced creeks, Ryan, Wood and Freshwater Creeks.
- **Fay Slough:** Fay Slough is one of two smaller sloughs tributary to Eureka Slough. Fay Slough is tidal and fed by runoff from three creeks, Cochran, Quail and Redmond Creeks. Unlike the tributaries to Freshwater Slough, these three tributaries enter Fay Slough through tide gates penetrated through levees, which prevent tidal exchange.
- **Ryan Slough:** Ryan Slough is a small slough tributary to Freshwater Slough. Ryan Slough is tidal and fed by runoff from Ryan Creek.

3.4.2 Constructed Landforms

3.4.2.1 Rail Prisms

The North Coast Railroad Authority (NCRA) railroad prism dominates the western shoreline of the study area, adjacent to Arcata Bay. The bay-facing slope of the railroad prism is largely a mix of low growing vegetation; rock slope protection of various sizes, connection/disconnection between rocks, and thickness; and areas of exposed gravel and other materials used to create the fill prism. Tracks and ties remain along the length of the railroad prism and are in varying states of disrepair. In areas where gravel slopes are exposed, ballast rock has evacuated from between ties due to periodic overtopping of high tidal water levels that can be elevated by high ocean water levels and local wind waves and wind setup. Some ties hang in the air, held in place by the bolting to the railroad tracks. In other areas, vegetation grows between the ties, rooted in the ballast rock.

3.4.2.2 Levees

The Brainard former mill site extends into Arcata Bay west of the railroad prism, surrounded by a levee. The bay-facing slope of the levees along the Brainard shoreline is protected with a thick layer of rock slope protection and the top of the levee is vegetated.

Along the interior tidal sloughs, much of the shoreline is comprised of earthen levees that vary in condition and height as previously described. These levees are exposed to tidal and fluvial flow velocities however do not have the same exposure to wind generated waves from the bay fetch.

3.4.3 Diked Former Tidelands

Much of the low-lying land interior to the levees are agricultural or wildlife grassland areas with pockets of development adjacent to Highway 101. The narrow strip of land, tucked between Highway 101 and Eureka Slough, is a dense mix of commercial, industrial and low-income residential parcels. A remnant tidal slough sits between the County Airport and Mid-City. Small gravel roads, levees, ditches and the remnants of levees, railroad prisms, and slough channels scatter the interior landscape. Remnant sloughs, levees and ditches convey drainage from rainfall, seeps along hillsides, and small creeks to tide gates penetrating the surrounding levees.

Highway 101 crosses Eureka slough in the southwest of the study area and runs along the entire length of the western study area boundary, inland from the railroad prism. The railroad prism and Brainard levee separate Highway 101 and parallel drainage channels from tidal waters in Arcata Bay. A drainage channel is located adjacent to the southbound travel lanes, between the highway and railroad prism, and another is located along the eastern edge or northbound travel lanes. A low-lying median separates the two directions of travel. The median and drainage channels convey runoff from the highway and adjacent lands to a common point in Eureka Slough, between the Murray Field Airport and Jacobs Avenue businesses. In the event of Bay water overtopping the railroad prism, it is conveyed in the adjacent drainage channel, but during extreme high water events, portions of Highway 101 have flooded.

Historically, the sloughs identified above were hydraulically connected to each other and or Arcata Bay by a network of slough channels, since filled or isolated from tidal exchange with levees. The remnant of Freshwater Junction is the most prominent on the landscape, historically discharging to Arcata Bay from an area where stream discharge from Freshwater and Fay channels converged. The channel has been isolated at the Bay by the Highway 101 Ditch and the slough end with a tide gate and levee. Many other, smaller remnant slough channels no longer exist or now function as storm water drainage channels.

3.4.3.1 Flood Cells

The diked former tidelands were delineated into individual flood cells which are low areas that are hydraulically distinct from one another. Flood cells in the study are primarily leveed historical tidelands. The Freshwater-Fay Slough basin was historically emergent wetlands, likely brackish in most areas but potentially fresh in some areas seasonally or perennially, and salty in the vicinity of Eureka Slough. These former wetlands were separated from inundation by earthen levees which were, in most locations, constructed adjacent to the sloughs and creek channels. The land was then primarily converted to grazing and agriculture. Several areas were developed for commercial activities and protected with earthen levees to provide localized flood protection. Subsequently, additional levees and channels were constructed to provide runoff storage during high tides, with water control structures to discharge during low tides. The farther inland creek channels also have earthen levees, which provide flood protection to adjacent lands from high creek flows. The resulting situation is a series of leveed-off areas which are labeled as individual “cells.” Conceptually, a breach or overtopping at any location along the perimeter of a cell may result in flooding, and hence flood risks can be organized by flood cell. It is likely that these cells are subsiding due to soil consolidation resulting from dewatering, as well as oxidation of organic sediments likely produced by the pre-leveed wetlands.

The watershed areas contributing runoff into each cell is shown in Exhibit 3-13. A description of each cell’s interior drainage is provided below. The interior drainage network description is based on review of topographic maps, water control structure mapping (USFWS 2007 and Laird 2013), Highway 101 as-built plans (Caltrans 1950 and 1953), Eureka Storm Water Resources Plan (GHD 2018), review of other previous studies and limited field observations. The drainage network described below and presented in corresponding maps is not comprehensive of all drainage facilities however does show primary infrastructure intended to support this landscape scale assessment.

Cell A: Cell A includes Jacobs Avenue, Brainard, Murray Field Airport, Fay Slough Wildlife Area and Indianola Cutoff. The cell perimeter is generally defined by linear landscape features including the Bay shore or railroad prism on the west, Bracut on the north, Walker Point on the east and the levees along Eureka and Fay Sloughs on the south (Exhibit 3-14). Much of the cell was historically comprised of tidal marsh with sloughs and much of the perimeter are constructed landforms to accommodate development and prevent tidal exchange. The watershed area contributing to the cell is small relative to the cell size, so a majority of the rainfall runoff is generated from within the cell perimeter. Much of the existing interior drainage infrastructure associated with the cell was constructed in the 1950s as part of the Highway 101 improvements (Exhibit 3-15) and earlier levee construction efforts. A majority of the rainfall runoff from within the cell and occasional bay overtopping is conveyed through managed channels/ditches and culverts to a Caltrans maintained tide gate consisting of a double 5'x5' concrete box culvert with gates that discharge into Eureka Slough adjacent to Murray Field. The gates were recently replaced with side hinge gates equipped with habitat doors as part of an emergency project (Caltrans pers. comm. 2019). Other culverts with flap gates along Jacobs Avenues and a stormwater pump at Brainard also provide drainage outfalls from this cell as depicted on the Exhibit 3-14.

The Fay Slough Wildlife Area within the cell is owned and managed by CDFW for freshwater wetland habitat benefiting migratory waterfowl and agricultural grazing. Flashboard risers are used within the Wildlife Area to manage water levels during the winter months for waterfowl habitat. During the winter months when groundwater elevations are elevated, low lying areas within the cell inundate for extended periods as rainfall runoff generated within the cell can exceed the tidal outfall capacity, as the tide gates only discharge during low tides. As a result, during winter months, the cell serves as a shared-basin that stores runoff generated from the multiple property ownerships within the cell.

Cell B: Cell B includes the area south of Indianola and is bound by Walker Point on the west, Indianola Cutoff/Myrtle Avenue to the northeast and Fay Slough levees to the south (Exhibit 3-16). Drainage from an unnamed tributary is conveyed into the cell through a series of County maintained ditches and culverts. Drainage discharges out of the cell through a tide gate in the Fay Slough levee. Similar to other cells, during winter rainfall events, low lying areas within the cell are inundated for extended periods as rainfall and inflow into the cell exceed the tidal outfall capacity, as the tide gates only discharge during low tides. As a result, during winter months, the cell serves as a shared-basin that stores runoff generated from the multiple property ownerships within the cell.

Cell C: Cell C is predominantly comprised of private agricultural land and is bound by Fay Slough levees on the north, Myrtle Avenue on the east, and Freshwater Slough levees on the south and west (Exhibit 3-16). Cell C is further divided by former railroad grade into two sub-cells, referred hereinafter as C1 and C2. Cochran, Quail and Redmond Creeks all flow directly into C1 and discharge into Fay Slough through tide gates. Much of the internal drainage network in C1 reflect the remnant tidal slough channels that drain in a northwest direction and are intercepted by constructed drainage ditches on the inboard side of the levees. These inboards ditches collect and convey runoff to tide gates that discharge into the tidal sloughs. Cell C2 receives overbank flooding from Freshwater Creek during flood events.

Cell D: Cell D includes property predominantly owned by the North Coast Regional Land Trust and is managed for public access, agricultural grazing and habitat restoration. The cell is bound by Freshwater Creek to the north and northeast, Myrtle Avenue on the south and Freshwater Slough levees on the east (Exhibit 3-16). Wood Creek and a small unnamed tributary flow directly into the cell and discharge into Freshwater Slough through a water control structure that has been retrofitted to improve tidal exchange into the cell.

Cell E: Cell E includes a small rural residential/commercial area north of Myrtle Avenue and bound by Freshwater Slough levees and an elevated road prism of Myrtle Avenue (Exhibit 3-16). Drainage is conveyed into the cell from an unnamed tributary through a culvert under Myrtle Avenue. Drainage discharges out of the cell through a tide gate in the Freshwater Slough levee. Similar to other cells, during winter rainfall events, low lying areas within the cell are inundated for extended periods as rainfall and inflow into the cell exceed the tidal outfall capacity, as the tide gates only discharge during low tides. As a result, during winter months, the cell serves as a shared-basin that stores runoff generated from the multiple property ownerships within the cell.

Cell F: Cell F is predominantly comprised of private agricultural land and is bound by Freshwater Slough levees and Myrtle Avenue (Exhibit 3-16). Drainage is conveyed into the cell by a small, unnamed tributary through a culvert under Myrtle Avenue. Drainage discharges out of the cell through a gated culvert in the Freshwater Slough levee.

Cell G: Cell G is predominantly comprised of private agricultural land and is bound by Freshwater Slough levees on the north and east, Ryan Slough levees on the south and the study area boundary on the west (Exhibit 3-16). Drainage is conveyed into the cell from the developed watershed area through a conventional storm drainage system comprised of curbs, gutters and culverts. Cell G is further divided by an earthen linear feature (presumably the PG&E access road for the underground gas line) into two sub-cells, referred hereinafter as G1 and G2. Much of the internal drainage network in G1 reflect the historic tidal slough channels and a perimeter drainage ditch system along the inboard side of the levee. These inboard ditches collect and convey runoff to tide gates that discharge into the tidal sloughs. During 2019 king tides, tidal water was observed sheeting across Park Street into the northern end of Cell G2.

Cell H: Cell H includes combined residential and agricultural areas and is bound by Eureka Slough levees to the north, Freshwater Slough levees on the east, the study area boundary on the south and adjoining watershed divide on the west (Exhibit 3-16). The watershed area contributing to the cell is smaller relative to the cell size however is comprised entirely of residential development. Drainage is conveyed into the cell through a contemporary storm drainage system comprised of curbs, gutters and culverts. The drainage discharges out of the cell through a tide gate in the Freshwater Slough levee. Similar to other cells, during winter rainfall events, low lying agricultural areas within the cell are inundated for extended periods as rainfall runoff contributing to the cell exceeds the tidal outfall capacity, as the tide gates only discharge during low tides.

Cell I: Cell I includes developed residential and commercial areas of Eureka. Unlike previously described cells, this cell is not bound by levees. Runoff enters this cell from three tributaries (First, Second and Third Sloughs) via culverts under Myrtle Avenue. Second and Third Slough culverts are equipped with tide gates. The outlet of the First Slough culvert is open, however the steep slope prevents upstream tidal exchange (Exhibit 3-16).

Figure 13 and Figure 14 show the extent of flooding within the above-mentioned cells following storm events in 1975 and 1997, respectively. The photographs depict how the constructed landforms (levees and rail prisms) form the cells boundary creating tidal and fluvial overland flow barriers however these barriers become less effective during extreme events. In contrast, Figure 15 show Cells A and C1 during dry conditions.

3.4.4 Uplands

Uplands exist along the south and east perimeter of the study area situated above diked former tidelands. The larger contiguous upland areas include the developed areas of Eureka, separated by First, Second and Third Slough, Walker Point, and segments of Myrtle Avenue that are perched above the low-lying lands along the south and eastern boundary, meandering on the fringe of the forested hills and residential development. These areas are generally not vulnerable to flooding and exhibit freshwater dominated vegetation. At the lower elevations juxtaposed to tidal or fluvial flooding exposure, underground utilities and vegetation communities are susceptible to impacts from sea level rise and extreme tidal or fluvial events.

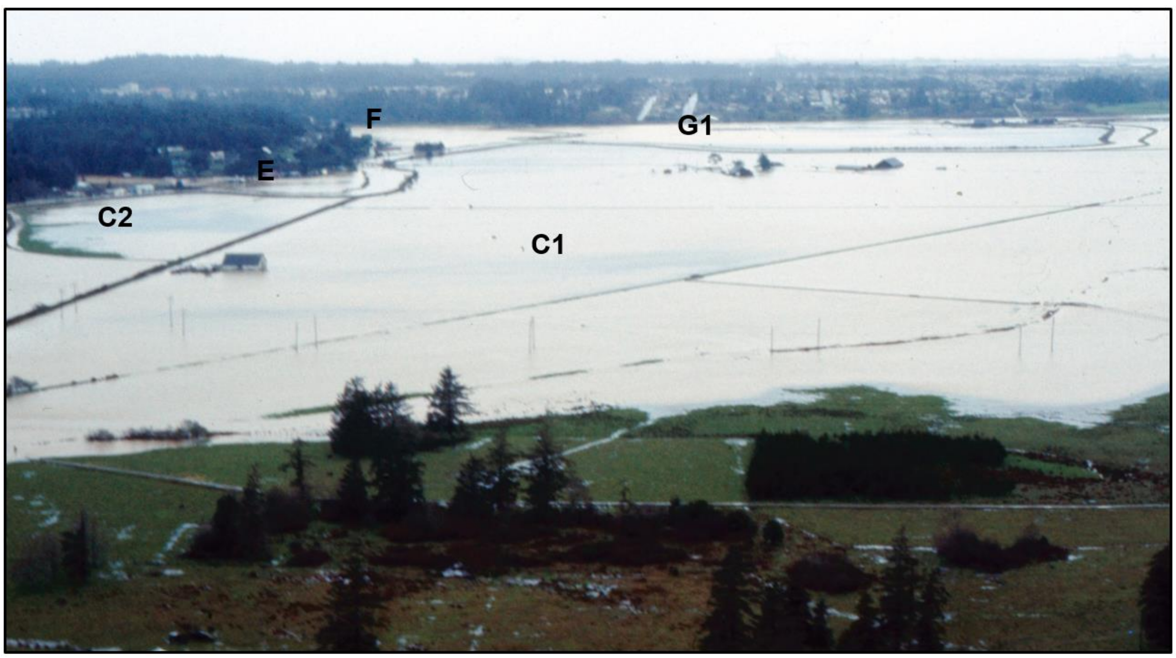


Figure 13. Cells C, E, F and G on March 18, 1975 (Humboldt County)

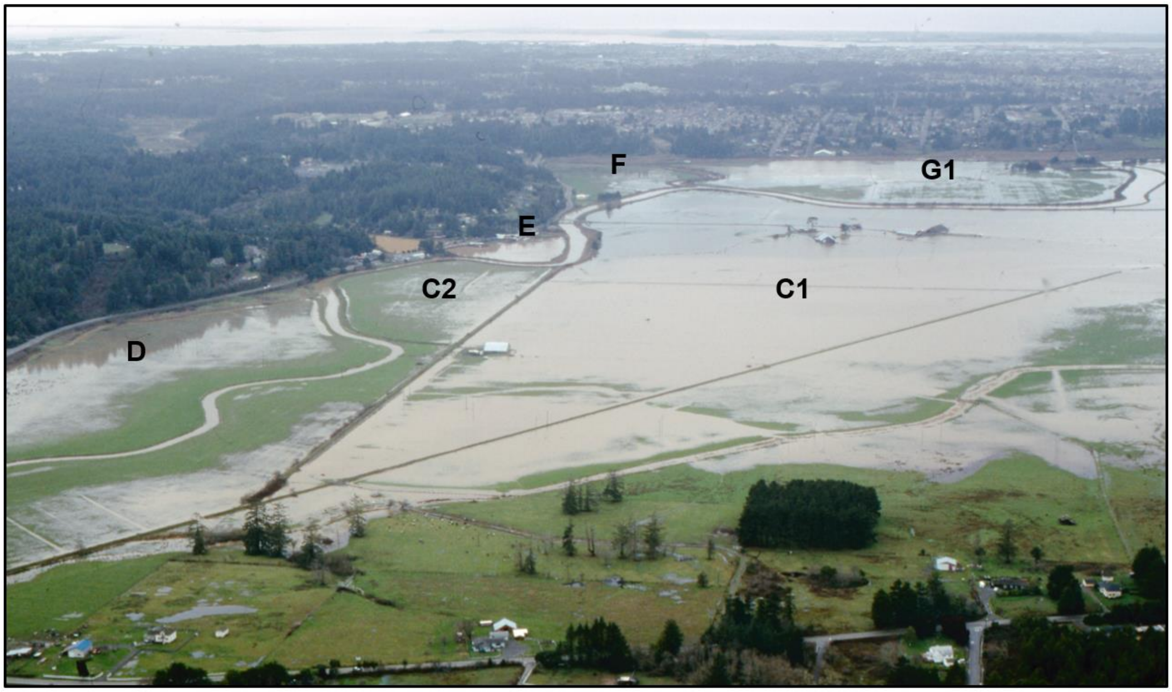


Figure 14. Cells C, D, E, F and G on January 2, 1997 (Humboldt County)

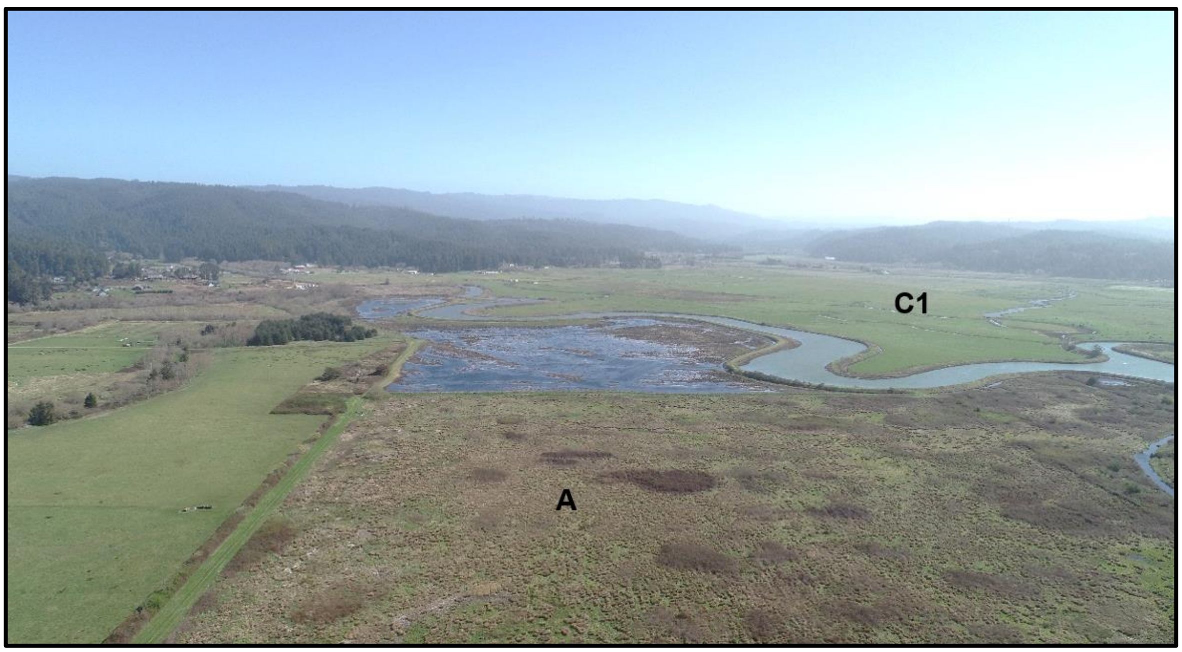


Figure 15. Cells A and C1 separated by Fay Slough during dry conditions in 2020 (Humboldt County)

3.5 Geomorphic Trends

Tidal, fluvial and human intervention events and processes have shaped the shoreline within the study area. Based on observed shoreline conditions in previous studies and the 1870 US Coast Survey, trends for lateral shoreline migration and vertical land motion are described below.

3.5.1 Lateral Shore Migration Trends

Example of a Salt Marsh Scarp along Arcata Bay in Study Area

Within the study area, there is a range of shore types that exist and are exposed to different physical processes or hazards. While some portions of the shoreline within the study area are more natural, comprised of mudflats and tidal marsh, the majority of the shore is comprised of levees or railroad prisms making up approximately 75% of the total 25-mile shoreline, as previously presented. Exhibit 3-17 shows a comparison of the 1870 US Coast Survey shoreline relative to the current shoreline position and Exhibit 3-18 includes cross-sections at locations along the Arcata Bay and interior slough shorelines. While the linear landscape features have remained fixed in position since constructed and vary in condition, as described in Section 2, lateral migration of the salt marsh edge along Arcata Bay is shown on Exhibit 3-17.

The existing salt marsh edge along the southern shoreline of the study area, between Eureka Slough and Arcata Bay, is similar to that of the 1870 US Coast Survey. Moving north along the Bay shoreline, the lateral migration of the salt marsh edge varies from 0 to 300 feet, between Eureka Slough and the develop area of Brainard. The extent of lateral migration suggests a rate of 0 to 2 feet per year. North of Brainard, few remnants of salt marsh are present. Historically, the salt marsh edge extended 100 to 500 feet further into the Arcata Bay, resulting in an estimated lateral migration rate of 1 to 3 feet per year, with the rail prism preventing further lateral migration of the shoreline, where salt marsh is no longer present. Farther north, the shoreline was extended into Arcata Bay and developed between 1870 and present.

Along the interior shoreline of the sloughs, the extent of salt marsh is typically limited to small areas, between levees and slough channels, typically 0 to several feet wide. The most extensive salt marsh is located near the junction of Freshwater, Fay and Eureka Sloughs and appears to have maintained a similar shoreline location. Salt marsh is no longer present in locations where significant erosion of the slough-facing slope of levees is indicated and/or leveed and drained.

3.5.2 Vertical Land Motion Trends

Humboldt Bay is subsiding regionally as a result of plate tectonics, and the rate is estimated to range from 0.25 to 3.56 mm/yr (Patton and others 2014). For the purposes of this study, the subsidence rate for North Spit, where the NOAA tide gauge is located, is used to represent the regional subsidence, and is 2.33 mm/yr. Higher rates of land subsidence are believed to occur locally in diked former tidelands, and perhaps due to fill placement for land development. The higher subsidence is attributed to consolidation of marsh soils that resulted from dewatering of the leveed lands for agriculture and other land uses. Oxidation of organic soil may also contribute to elevation loss and apparent subsidence rates. Marsh areas are known to produce organic soil and trap mineral soil and rely on emergent plants to maintain these processes and counter the consolidation and compression of their soils (Orr and others 2003; Stralberg and others 2011). Hence, the leveed inland areas tributary to Freshwater Slough are likely subsiding at a rate higher than the regional rate. The subsidence is apparent due to the existing ground elevations around +5 feet NAVD which is lower than the typical estuarine emergent marsh around +7 feet NAVD, as shown in elevation transects across the study area (Exhibit 3-17 and Exhibit 3-18). A cursory review of historical information indicates that the Freshwater – Fay remained intact as of 1875 (Coy 1982[6]). Similarly, maps from the Humboldt Bay Historical Atlas indicate that marsh was largely intact as of 1890[7] but largely converted to agriculture by 1916[8]. Diking of the marshes in the study area started around 1894 between Brainard and Fay Slough areas, and around 1898 extended southward to Freshwater Slough (SVK 2006). Therefore, draining the marshes started in the 1890s, or about 120 years ago. The 2 feet change over 100 years is 0.02 feet / year or about 6 mm/yr. Subtracting the regional subsidence used in this study (2.33 mm/yr, North Spit), a local additional subsidence rate of about 3.5 mm/yr is calculated. This is an approximate calculation subject to verification by subsequent focused study.

3.5.3 Summary of Trends

These trends provide an understanding of the geomorphic response to historic and current conditions for sea level rise and extreme tidal or fluvial flood events. Based on current projections, future sea level rise is projected to accelerate beyond historic rates which will alter the rate of physical processes and the response to exposed geomorphic units. Additionally, extreme tidal and fluvial events will also continue to occur. The following section describes observable indicators of shoreline change as a means to monitoring the geomorphic response to increased relative sea level rise and extreme tidal or fluvial events.

[6] Illustration 14. Map of public lands patented in Humboldt Land District

[7] 1890 US Survey General Township Plat Map

[8] 1916 US Army Corps of Engineers Tactical Map

3.6 Indicators of Geomorphic Change

Observable indicators can provide valuable insight on shoreline conditions, current exposure to physical processes and the trajectory of future geomorphic response. This section provides a framework for monitoring changing conditions of natural and constructed shores of the study area. Indicators for monitoring changing conditions of shoreline structures over time include both hazards and their effects on the shore. The objective of this section was to develop observation protocols and guidance so that shoreline conditions can be documented based on standard practice and guidance.

3.6.1 Relevant Studies

Previously completed studies, existing conditions mapping, and known areas of erosion and shoreline retreat were considered in developing an observation protocol. Previous studies within the study area that were referenced include:

1. Humboldt Bay Shoreline Inventory (Laird 2013) which included mapping the shoreline and cover types within the study area.
2. Humboldt Bay Trail South Shoreline Assessment (GHS 2017) which included an assessment of the railroad prism along the bay shore. The assessment of the shore includes summaries of observations made by GHD staff at several locations along the bay shore, photographs, and sketches. The conditions show that much of the railroad prism is degraded and vulnerable to overtopping during coastal storms and even annual high tides. Additional analysis by ESA for the Humboldt Bay Trail South project described in subsequent sections of this report are useful in assessing shore vulnerability and configuration, including shore transects that were compiled from various elevation data.

3.6.2 Supporting References

In addition to reviewing available studies within the study area, the following were drawn upon for developing observation protocols for this Study.

1. USACE (2014) Interim Policy for Rehabilitation Program – an inspection report and protocol: to determine whether a non-Federally constructed flood protection structure meets the minimum criteria and standards set forth by the USACE for initial inclusion into the Rehabilitation and Inspection Program; to verify proper maintenance, preparedness, and operation for continuing eligibility; and to evaluate the system's original design criteria versus current design criteria.
2. NHC (2015) conducted an assessment of multiple miles of levee in British Columbia, Canada, using ratings similar to those presented in USACE guidance above. The rating items are rated on a numeric scale from 1 to 4 to indicate conditions on a range from unacceptable to good, respectively. The evaluation criteria were developed for the project using this and USACE (2014) materials. Rating items are based on the indicators of change.

3. CIRIA (2013) International Levee Handbook – guidance for all-things levee, an international perspective. This reference included information on the safety, assessment, management, design and construction of levees. Includes protocols for inspections.
4. USACE (1987) Guidelines for Rehabilitation of Non-Federal Levees in the Sacramento-San Joaquin Legal Delta – This document includes information similar to the more recent USACE (2014) described above but applied to the Sacramento-San Joaquin Legal Delta.
5. Water control structure observation protocols – structure assessment form prepared by ESA
6. Rock revetment observation protocols – structure assessment form prepared by ESA

3.6.3 Observation Protocol Constraints

The following constraints were considered in developing the observation protocol with specific regards to ease of replicating over time.

1. Property ownership and accessibility.
2. Desired monitoring resolution, scalability and frequency.
3. Required qualifications and cost to conduct, report and maintain records.
4. Prioritization of shoreline segments relative to vulnerability and/or critical infrastructure.

3.6.4 Alternative Observation Protocol Methods

Various approaches for conducting observations and collecting data are listed below.

1. UAV – This method would include use of an Unmanned Aerial Vehicle (UAV) flight, also referred to as drone to capture high resolution video of the shoreline from a low altitude and slow speed. The UAV would video the foreshore and backshore during low tides to identify biological (vegetation) and physical (erosion/accretion) indicators of change between monitoring periods to document trends. Based on desired altitude/speed and access, the shoreline within the study area could be videoed in several days and then interpretation of the results would be based on desired outcome and needs.
2. Remote Sensing – This method would use commercially available satellite imagery in combination with available LiDAR to track shoreline trends using GIS software. Data resolution limitations may prevent desired detail and therefore field verification is often required to confirm ground cover signatures relative to the satellite imagery.
3. Field Observations – This method would be conducted by qualified professionals (e.g. engineers, scientists, biologists, etc.) to record current conditions. The observations would follow specific protocols based on shoreline type/structures, desired detail/outcome and with regards to the considerations listed above. Field observation protocol could range from a rapid

field assessment photographing indicators of changes to detailed shoreline transects surveyed for vegetation composition (species/percent cover), soil type/grain size, elevation and physical conditions.

3.6.5 Observation Protocol

Based on the information presented above, an observation protocol was developed following option 3 above and applied to discrete shore segments in the study area. The completed observation logs and map depicting the segments surveyed are located in Appendix B. These surveyed segments can be revisited in the future to determine rate of change. Additionally, the observation protocols can be further refined as needed to measure and document specific indicators of change.

Preliminary observations were conducted by boat along Eureka and Fay Sloughs and by foot along the shoreline and rail prism of Arcata Bay. The objective of the preliminary observations was to identify observable indicators of change and general representative locations within the study area for further detailed observations. The Arcata Bay shoreline, between Brainard (former CRC) and Bracut, Caltrans tide gate discharging to Eureka Slough, and Eureka Slough shoreline along Murray Field (Airport) were selected for further detailed observations. These locations were selected for their observable indicators of change, access, and representative characteristics and exposure within the study area.

The shoreline was walked and observation forms were completed when indicators of change were encountered. Approximate locations were noted in the field and later verified or corrected by comparing site photographs and reference points to 2019 aerial imagery. Each location was then given an identifying name (i.e., RR1, Airport 1). Exhibit B-1 (Appendix B) presents the locations of observed indicators of change. Each observation log contains field notes and measurements identifying the indicators of change. Observation logs are accompanied by photographs, aerial imagery and cross references (measurements, noted features).

Common indicators of change along Arcata Bay include scarp erosion of the bay-facing slope, erosion across the rail prism crest, displacement of ballast rock along the land-side rail, and deposition of eroded crest and land-facing slope material within the land-side drainage channel (Figure 16). Common indicators of change along Eureka Slough include sloughing of the slough-facing slope and erosion of the entire slough-facing slope to the hinge point of the crest (Figure 17).

Figure 16. Common indicators of change along the rail prism of the Arcata Bay shoreline.

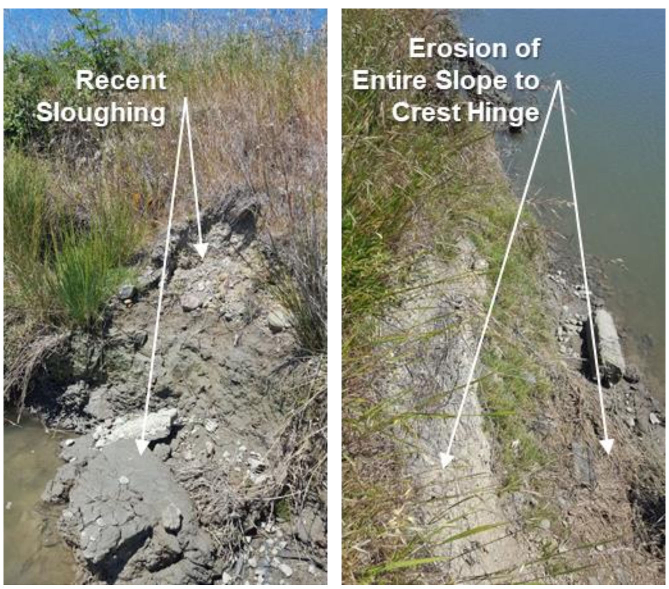


Figure 17. Common indicators of change along Eureka Slough levee shoreline.

4. CONCEPTUAL FRAMEWORK TO ASSESS FUTURE GEOMORPHIC CHANGE

4.1 Overview

This section provides a framework to predict how the geomorphic units within the study area will respond to sea level rise and other physical drivers over time. This conceptual model of geomorphic response has been adapted from the Intergovernmental Panel on Climate Change (IPCC 2019) and presents the primary **physical drivers**, **physical processes,** and **physical responses of the geomorphic units**, which are described further in the sections below. This conceptual model should be considered a tool to help anticipate the dynamic landscape response to flooding associated with sea level rise (Figure 18). This approach is more realistic than approaches that project potential flood impacts on a static landscape and consequentially more useful for designing adaptation measures that will be effective in protecting critical resources.

4.2 Physical Drivers or Interventions

Physical drivers (conditions such as sea level rise) and Interventions (such as shore armoring or tide gates) affect and interact with physical processes and can create a geomorphic change. For example, the physical processes such as breaking waves cause geomorphic change (e.g. erosion), while drivers (e.g. sea level rise) affect the rate and trajectory of the geomorphic change. Described below are the primary physical drivers that apply to the study area.

4.2.1 Relative Sea Level Rise

Sea level rise is a primary driver of shore change, as it directly affects several physical processes and how those processes interact on the physical shore features. Sea level rise projections are described in Section 1.7 of this report. In general, recent state guidance projects that sea level could rise between 3 and over 10 feet by 2100 under a series of probabilistic cases. An increase of about 7.5 feet of sea level rise is associated with probability of 0.005, or a 1-in-200 chance. Regardless of the ultimate amount of sea level rise that will occur, the increase in tidal water levels will pose fundamental changes on shoreline processes that include flooding and sediment movement. Elevations of existing flood protection features within the study area are relatively close to extreme tides and storm water levels, and therefore the study area has a low capacity for sea level rise. In other words, relatively small amounts of sea level rise, on the order of one to three feet, could have large implications on flooding of the site features and physical landscape changes. Therefore, sea level rise is the primary driver of shore change that is considered in this study.

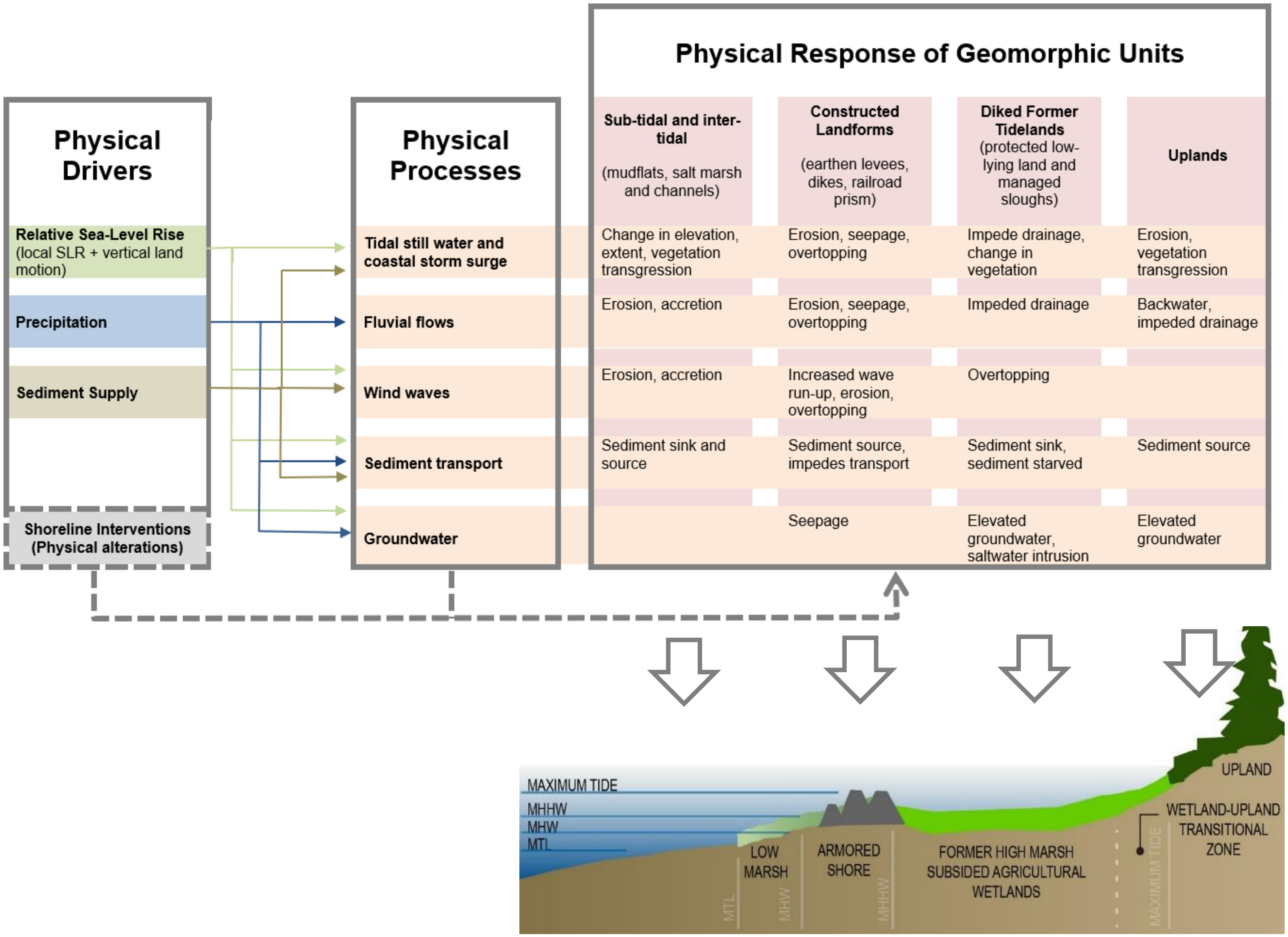


Figure 18. Conceptual Model of Geomorphic Response to Sea Level Rise and Extreme Tidal or Fluvial Events (Adapted from IPCC, 2019)

As previously described, relative sea level rise combines vertical land motion (tectonic subsidence) with increase sea levels. The relevance of the vertical land motion to the study area is that the regional and local subsidence increases the rate of relative sea level rise affecting the Humboldt Bay region as opposed to other areas of California, which have lower rates of subsidence. Further, the variable rates of subsidence within the study area will affect adaptation interventions, which will need to account for ground movement as part of their long-term performance expectations.

4.2.2 Sediment Supply

Sediment supply affects geomorphic response to water level changes in both estuarine (Williams and Orr 2002) and littoral environments (Bruun, 1962). The contributing watersheds provide a direct sediment supply or source to the study area whereas mudflats and salt marshes provide both sediment sources and sinks. With adequate sediment supply, sediment deposition would raise the grades of marshes and mudflats to keep up with a rise in sea level. Adequate can be defined as that sufficient to allow the shore form to be maintained and hence is relative to the rate of sea level rise:

- High sediment supply – vertical accretion
- Moderate sediment supply – transgression up and landward
- Low sediment supply – submergence.

The response of tidally-influenced creek channels to sea level rise can affect fluvial flood hydraulics. If the channel thalweg accretes vertically with sea level rise, the flood profile will also rise for the same flowrate. However, if the thalweg does not rise, the flood profile will not rise as much as the tailwater (sea level) owing to the greater flow area in the deeper channel. In addition, there are other potential effects of river flood hydraulics which are potentially of greater impact, such as increased rainfall associated with climate change.

Sediment supply is relevant to the study area because it could amplify flooding issues by raising fluvial and slough channels if the sediment supply is high, or it could introduce difficulties in maintaining existing habitats and implementing certain nature-based adaptation measures.

4.2.3 Precipitation

Predicting changes in precipitation patterns was beyond the scope of this study. A climate change study recently completed for the Elk River watershed (tributary to the South Bay portion of Humboldt Bay) concluded that the 24-hour, 100-year rainfall depth is predicted to increase approximately 11-16% by mid-century and 11-20% by late-century (ESA 2019). An increase in precipitation intensity would increase runoff rates and fine-sediment delivery to the study area. However, the increase in run-off rates could also increase flow velocities contributing to an increase in erosional forces along creek and slough banks.

4.2.4 Interventions (Physical Shoreline Alterations)

Interventions are defined here as anthropogenic actions that result in geomorphic change. The Interventions considered important to this study are:

- Water Control Structures, which are used primarily to prevent tidal inundation and to facilitate drainage of rainfall, change the local hydrology, ecology and can induce settlement.
- Levees which change overland flow to impede flooding otherwise manage water, to facilitate desired land uses. These structures can affect sediment deposition and restrict channel migration. Roadway embankments (e.g. Highway 101) can have similar effects and are often integrated into a flood protection system by local landowners.
- Shore Armor protects land from 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.

Earth or other fill has been placed to raise grades and levees for land development purposes. The fill can result in settlement of the fill footprint and nearby areas.

4.3 Physical Processes

The second component of the conceptual model of geomorphic response is the physical process. The physical processes that occur along the bay shore and tidal sloughs of the study area can alter landforms and change the flood exposure along both natural and developed shores. Physical processes that occur during typical conditions (e.g., tides and wind waves) strongly influence the shapes and sizes of natural features, such as tidal channels, beaches, and marshes. During storm events, extreme flooding and wave action can cause the greatest rates of geomorphic change. Throughout the study area, flood hazards are primarily associated with extreme coastal and fluvial storms, when water levels increase above the elevation of the levees along tidal sloughs and waves and storm surge overtop the railroad prism along the bay shore. With sea level rise, flood events are expected to occur more frequently, and in some locations typical high tides could cause flooding.

The physical processes that were identified as the primary influences on the geomorphic unit response are:

- Tidal water levels and coastal storm surge (still water)
- Wind waves
- Fluvial flows
- Sediment transport
- Groundwater levels and saltwater intrusion

Exhibit 4-1 presents a schematic of the spatial distribution of the physical processes or hazard types in the study area. The bay shore is exposed primarily to tides, coastal storm surge, and wave action. The shores of the interior slough network are exposed to tides, coastal storm surge, and fluvial flooding. Wave and surge overtopping of the natural and constructed shore structures (e.g., levees) exposes additional low-lying areas to flooding by direct overtopping and by triggering the potential failure of a protective structure by erosion or other means. Therefore, estimation of the hazard extents needs to consider long-term geomorphic change, storm or event erosion, and their feedback on the flood hydraulics.

4.3.1 Tidal Water Levels and Coastal Storm Surge

Tides in Humboldt Bay exhibit a mixed semi-diurnal signal that amplifies 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 study area are approximately 0.5 feet higher than at the entrance, and the low tides are slightly lower (NHE 2016). Extreme still water levels representative of tidal conditions plus coastal storm surge also vary spatially within the Bay (NHE 2015). Table 8 presents values of the extreme still water levels and a selection of tidal datums for the study area as computed by NHE and extracted from their Humboldt Bay hydraulic model. 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. The difference between an extreme storm elevation and a typical monthly high tide is about 2 feet, which indicates that a relatively small amount of sea level rise could increase tidal elevations into today's extreme conditions.

Table 8. Tidal Extreme Still Water Levels [1] for Study Area

Water Level/Datum	Elevation (feet NAVD)	Description
100-year SWL	10.59	100-year still water level
50-year SWL	10.41	50-year still water level
10-year SWL	9.94	10-year still water level
5-year SWL	9.70	5-year still water level
2-year SWL	9.30	2-year still water level
HAT	9.01	Highest Astronomical Tide[2]
MMMW	8.33	Mean Monthly Maximum Water
MHHW	7.00	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 study 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.

The natural and built landforms around the Bay are linked closely to the tide elevations. The natural ecotone from low-tide mudflats to salt marsh wetlands that occur near high tide elevations, and the constructed railroad prism located a few feet above high tide elevation, were all constructed or formed around a long-term stable sea level. A key question is how these landforms will be affected as the water levels increase with sea level rise. This is discussed in subsequent sections of this report.

The tidal water levels and coastal storm surge elevations are expected to increase with sea level rise. NHE (2015) used a sophisticated modeling approach to evaluate the future conditions water levels in Humboldt Bay over a 100-year period and found that the increases in both tidal and extreme still water levels was approximately linear with the amount of sea level rise. Therefore, future conditions of tidal and storm still water levels for a specific location in Humboldt Bay could be computed by adding the amount of sea level rise projected over a given time period. This approach is further described in the subsequent Hazard Scenario section.

4.3.2 Wind Waves

Wind waves are surface gravity waves that are generated by wind blowing over the surface of the Bay’s open water. The approximate fetch length incident to the study area is approximately four miles. FEMA (2014) estimated a wind wave height of about 2.4 feet at 3 seconds during a wind event with a 50-year recurrence interval (45-mph). ESA (2018) used a wind wave generation model to check the FEMA (2014) calculation and found general agreement with the estimate. From a geomorphic perspective, wave processes play a major role in shaping the bay shore by inducing erosion and moving sediment, as well as their contributions to coastal flooding through runup and overtopping. Due to limited fetch across slough channels and topographic barriers, wind waves do not play a major role in the shaping of the interior slough network.

Sea level rise is expected to increase the wave heights that reach the shore. Along much of the study area, remnant portions of marsh dissipate wave energy by triggering wave breaking, which reduces the wave height that ultimately reaches the shore (ESA 2018). With sea level rise, the depth of submergence is expected to increase, and therefore the waves propagating over the remnant marsh will not be dissipated as much as they are under existing conditions. The net effect with sea level rise is an increase in wave heights breaking on the shore. Because the fetch length is not expected to change significantly with sea level rise, and assuming the extreme wind statistics are stationary, the deep water wind wave heights will remain relatively constant with sea level rise. Wind rose plots showing annual and January only wind speed frequencies for North Spit and Buoy 22 data are presented in Figure 19. The annual plots (top) show a north and northwest dominant wind speed, whereas the January only plots (bottom) show a south and southeast dominance which is typical with the onset of winter storms.

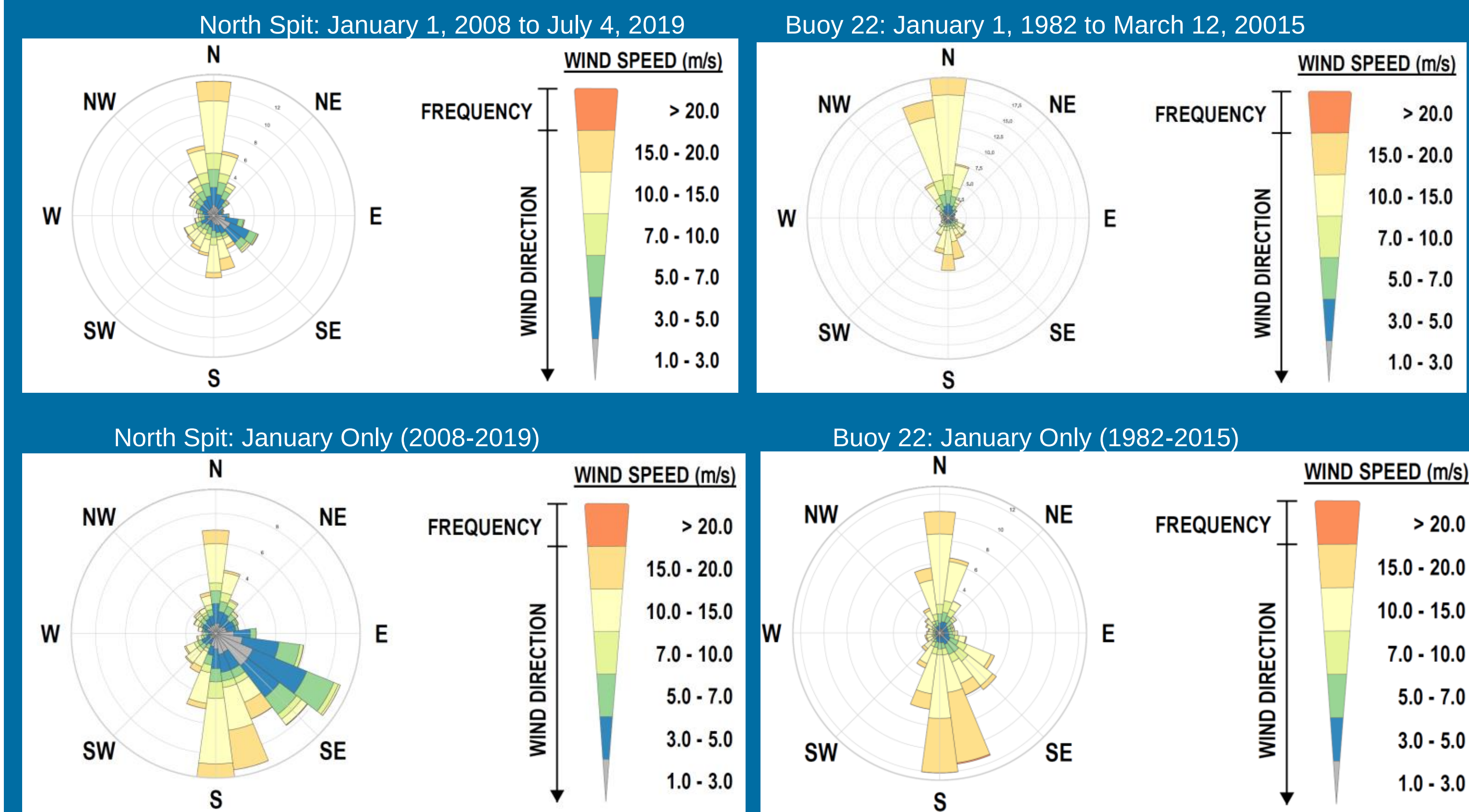


Figure 19. Comparison of Wind Rose Plots for North Spit (Station 9418767) and Buoy 22 (Station 46022) for both Annual (top) and January only (bottom). Meteorological Data Sources: North Spit; 2008 to 2019;1-hr; NOAA 2020 (https://tidesandcurrents.noaa.gov) and Buoy 22; 40.701 N 124.550 W; 1982 to 2015;1-hr; NDBC 2020 (http://www.ndbc.noaa.gov).

4.3.3 Fluvial Flows

Fluvial flows refer to creek discharge that drains from the coastal watersheds. The fluvial flows are associated with precipitation or rain events, which collect in channels and flow toward the Bay. The primary watershed of the study area is Freshwater Creek, which also includes the sub-watersheds of Ryan and Fay Sloughs. Fluvial flooding is an intermittent phenomenon that typically occurs as a response to a significant rainfall event. At the lower reaches of the watershed, the predominant tidal conditions formed tidal sloughs that are sinuous channels that formed in the historical marsh. Water levels in the tidal sloughs are affected by both the tidal water levels in the Bay and the fluvial flows draining from the watershed. However, the effect of high fluvial flows rapidly diminishes and is negligible in Eureka Slough during high tides. The main driver affecting the fluvial flows is a change in the rainfall intensity. However, estimating the change in flow rate due to changes in precipitation is beyond the scope of this Study.

4.3.4 Sediment Transport

Sediment transport is the movement of sediment by three primary physical processes: tidal currents, fluvial flows, and wind-waves. The hydraulic forces of the water moving through the system can move sediment from areas of erosion (sediment sources) to areas of deposition (sediment sinks). Sediment transport processes play an important role in forming the landscape. Sediment is transported into Humboldt Bay from the ocean through the mouth of Humboldt Bay, associated with the Eureka Littoral Cell, and from freshwater tributaries. A sediment budget for Humboldt Bay has not been developed and monitoring data regarding the relative contributions of ocean sources and freshwater inputs are limited (Curtis et al, 2019). Numerical models have been developed by GHD and NHE to assess tidal circulation within the Bay, however these models would require significant advancement, calibration, validation and peer review to predict future sediment circulation patterns within Humboldt Bay and the study area. Mid- and late-century climatic models predict an increase in precipitation intensity and associated streamflow from watersheds contributing to the littoral cell (Curtis et al, 2019 and ESA 2019). An increase in fine-sediment delivery to the Bay associated with the increase streamflow and the direct affects within the study area are unknown, as transport patterns must also consider the other physical drivers such as wind-waves and tidal circulation.

4.3.5 Groundwater Levels and Saltwater Intrusion

Groundwater levels can fluctuate seasonally due to recharge from precipitation and can vary substantially over short distances depending on aquifer characteristics. Sea level rise is anticipated to cause groundwater levels to rise in low-lying areas adjacent to the interior tidal sloughs and Bay (Willis 2014). This could result in flooding of underground infrastructure such as utilities or basements and alterations in vegetation communities. Due to the variability of groundwater levels and the lack of detailed studies of the extent that groundwater and salinity conditions will be impacted by rising sea levels, the evaluation of groundwater impacts on asset exposure around

Humboldt Bay has been qualitative. Areas that already experience high groundwater levels and salinity intrusion may be more at risk of higher, more saline groundwater levels as sea level rises. For example, some low-lying developments adjacent to Humboldt Bay rely on below-ground sump-pumps to reduce water levels adjacent to structures, most notably during rainfall events coinciding with high tide tides. Higher salinity may also corrode pipelines and pumping equipment not typically designed for saltwater exposure.

The County of Humboldt is currently developing a Groundwater Sustainability Plan for the Eel River Valley Basin including the estuary for compliance with California's Sustainable Groundwater Management Act. The Plan is anticipated to include a saltwater intrusion assessment to characterize the fresh-saltwater transition throughout the Eel River Coastal Plain. Given similar landscape characteristics such as the shallow unconfined aquifers, diked former tidelands and exposure to like physical processes that create seasonal stratification of salinity from freshwater input, conclusions from the Eel River Plan could provide insight on necessary further studies to better characterize saltwater intrusion from sea level rise within the study area.

4.4 Geomorphic Unit Response

The response of geomorphic units throughout the study area varies based on the site characteristics and exposure to drivers, physical processes, and actions that affect erosion, deposition and flooding. The following sections describe the physical or geomorphic response of each geomorphic unit to increased water levels resulting from sea level rise and extreme tidal or fluvial events. Each section also includes indicators of change which may be observable and can be monitored and/or measured over time as a means to assess geomorphic response rate of change.

4.4.1 Intertidal Mudflat Response

Intertidal mudflats are the result of sediment deposition and hydraulic shaping. Hydraulic shaping is typically accomplished by waves which initialize sediment entrainment, and currents which transport the sediment. In Arcata Bay, the waves are primarily locally-generated wind waves (rather than ocean swell which affects central Humboldt Bay) and ship wake, which may contribute but is presumed to be a minor factor. Currents generated by tides, winds, and shoaling waves "sweep" the flats, affecting the geometry (slope and extents) of the flats, which in turn affects the residual wave exposure at the landward edge of the flats.

The sediment type and size in the flats 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. Where waves are sufficiently powerful, sands and gravels can be transported onshore and then alongshore and form shoals and beaches. Although no beaches are known to have historically existed along the eastern shore of Arcata Bay, Thompson (1971) reported the existence of coarse oyster shell shoals. However, several small pocket beaches with gravel material have established along the existing Highway 101 corridor of Arcata Bay, with material likely sourced from the eroding railroad prism. Import of coarse sand and gravel material for construction of pocket beaches are a potential nature-based adaptation approach that could be considered within the study area, and therefore a discussion on the geomorphic response of sandy and coarse beaches is presented herein with the mudflat response.

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 flats in Arcata Bay steepen above low tide (Barnhart and others 1992). Erosion-resistant structures in this zone of tide and wave influence can influence the geometry of the mudflats.

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). These flora may reduce sediment suspension by wind waves, thereby reducing the mobilization of sediments from the mudflats to the marshes and affecting response to sea level rise: It is possible that eel grass beds may become more prevalent in Arcata Bay with sea level rise while marsh declines further (Merkel 2017, also citing Gilkerson 2013).

4.4.1.1 Indicators of Change

Based on the information summarized above, changes in mudflat morphology can be indicated by:

- Accretion or erosion of mudflat
- Loss of aquatic vegetation on mudflat
- Loss or drowning of mudflat over time
- Changes in grain size

4.4.2 Tidal Salt Marsh Response

Salt marsh species composition is controlled by the influences of tidal elevations and persist within Humboldt Bay between MHW and MHHW. Salt marshes in Humboldt Bay were classified by Eicher (1987) into three types based on elevation with corresponding differences in vegetation. The low marsh is commonly dominated by pickleweed (Salicornia pacifica). High and mid marsh, also referred to as mixed marsh contain the greatest diversity of species (over 20 species). These include pickleweed, salt grass (Distichlis spicata), jaumea (Jaumea carnosa), marsh rosemary (Limonium californica), and arrow-grass (Triglochin maritima), as well as two rare salt marsh annuals, Humboldt Bay owl's clover (Castilleja ambigua ssp. humboldtiensis) and Pt. Reyes bird's beak (Chloropyron maritimum ssp. palustre). Invasive dense-flowered cordgrass (Spartina densiflora) has infested an estimated 90% of salt marshes in Humboldt Bay and is documented in colonizing a broad elevation range from upper mudflat to high marsh (Pickart 2001).

Marsh response to sea level rise is partly dependent on sediment supply, as indicated in Figure 20. Typically, sediments in the offshore flats are re-entrained into suspension by wind waves and then deposited in the marshes. However, sediment may be supplied directly by river/creek discharge or other erosive sources, including erosion of the seaward face, or marsh scarp. If there is excess sediment, the fronting sediment may persist and even accrete. If there is not sufficient sediment, the vegetation will “drown” and the marsh will convert to a flat. The net effect of marsh loss is larger typical waves and stronger potential currents landward of the prior marsh.

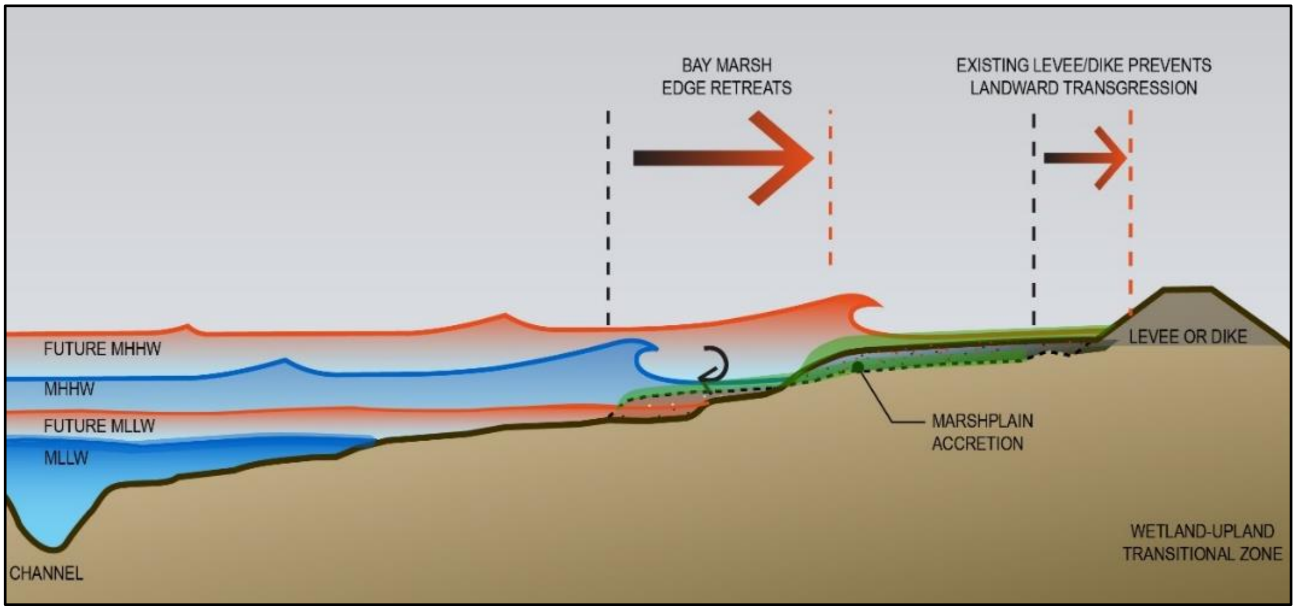


Figure 20. Marsh response to sea level rise, showing vertical accretion and horizontal migration (transgression)

Marsh response can be parsed into vertical and horizontal components as described below.

4.4.2.1 Vertical Accretion

The potential for marshes to “keep up” with sea level rise depends on mineral sediment supply, organic soil supply produced by the marsh vegetation and its rate of growth, and sea level rise: Conceptually, if the marsh accretion exceeds sea level rise, the marshes will be maintained (Orr and others 2003; Strahlberg and others 2011). For sea level rise around 0.5 meters / century (5 mm/yr) and suspended sediment concentrations (SSC) of at least 150 ml/l (equivalent to 150 ppt), salt marsh is expected to accrete fast enough to maintain itself (Strahlberg and others 2011). This rate is equivalent to the historic sea level rise rate in the study area, and the low-end projection through 2050. The representative SSC in the study area is not known, but 150 ml/l is thought to be potentially possible given the extensive mudflats in Arcata Bay and supply from tributary streams which likely discharge fine sediments. For a higher rate of sea level rise of about 1.65 m/ century (about 16.5 mm/yr) and SSC of 150 ml/l, salt marsh is not expected to accrete fast enough

(Strahlberg and others 2011). A maximum rate of salt marsh accretion of around 16 mm/yr is reported by Orr and others 2003, although higher rates, on the order of 40 mm/yr, are reported where there is high sediment supply. Based on sea level rise rates projected for the second half of the century it is likely that salt marshes in Arcata Bay area will not accrete fast enough and will drown.

A similar concern was reported by the USGS[9] based on a study of marsh accretion rates in Humboldt Bay, including Jacoby Creek Marsh in Arcata Bay north of the study area. Their data show 0 to 6 mm/yr sediment deposition and 0 to 3 mm/yr net elevation increase. They concluded that the North Bay has limited sediment supply, except locally such as the Jacoby Creek mouth which accreted. Further, they reported that future fine sediment delivery was likely to be less than that needed to compensate for the projected sediment deficit, largely computed based on maintenance dredging rates in the bay. On the "plus" side, the study modeling indicates that sediment discharge from drainages would likely increase with climate change due to increased precipitation intensity. Also of importance is their estimated erosion of mudflats at 1cm/yr which would produce 50,000 metric tons of sediment, about equal to the estimated sediment deficit.

We conclude that the loss of tidal marsh is not certain, for several reasons:

- The estimated subsidence rate for the area is in excess of 2mm/yr and the relative sea level rise rate is nearly 5mm/yr. Apparently the marshes have been accreting fast enough to compensate, indicating a sediment supply of at least 150 mg/l.
- The extensive mudflats are a sediment source, with a potential erosion rate of 1cm/yr (10 mm/yr)[10]. Given the large area of mudflats in Arcata Bay, the relatively smaller remaining marsh area, and the preference for deposition in marshes which act as "sediment sinks", a marsh accretion rate in excess of 10 mm/yr may be possible. The rate could be higher in the future, possibly achieving the 16 mm/yr maximum measured rate, depending on the intensity of wind wave action and increasing depth of the sediment flats.
- Measurements of mature marsh accretion does not necessarily represent the most rapid rate of growth but is more likely to represent the rate of relative sea level rise (Orr and others, 2003). Hence, the measured marsh accretion rates may not be the maximum possible marsh accretion rates.
- Maintenance dredging will likely diminish if sediment deposition slows, and beneficial reuse of sediment may be employed to maintain the sediment budget.

Fresh – brackish marshes can "keep up" with a faster sea level rise than salt marshes because the plants grow faster, produce more biomass and can withstand greater submergence than salt

[9] Humboldt Bay Symposium 2019: Fine-Sediment Supply and Salt Marsh Accretion, Humboldt Bay, CA by Jennifer Curtis, US Geological Survey, https://archive.org/details/humboldt_bay_symposium_fine_sediment_supply_salt_marsh_accretion_humboldt_bay_ca

[10] Ibid Humboldt Bay Symposium 2019

marsh species, and low salt marsh (e.g. cordgrass dominate) have higher measured accretion rates than mid salt marsh (e.g. pickleweed dominate) (Orr and others 2003). The rate of potential fresh and brackish marsh accretion is reportedly around 18 mm/yr (Orr and others 2003). This higher accretion rate together with the greater depth tolerance of fresh-brackish emergent vegetation indicate the potential to restore and sustain this habitat in the inland portions of the study area.

In summary, we assume that marshes will accrete sufficiently to keep-up with sea level rise at least through 2070 with 2 to 4 feet of relative sea level rise. While this amounts to an average required accretion rate of 24 mm/yr, which is above the estimated maximum rate of 16 to 18 mm/yr, we note that complete loss of vegetation will take many years after submergence is initiated. After 2070, marsh survival is uncertain without intervention and accommodation space for migration.

4.4.2.2 Horizontal Erosion

The bayward edge of the marsh is expected to erode with sea level rise (see Figure 20 and label "Bay Marsh Edge Retreats). This erosion is conceptually in addition to historical erosion which may occur for a range of reasons, but typically due to reduced sediment supply or increased wave attack. As previously described, historical data indicates the marshes along the Bay have receded several hundred feet since the late 1800s, early 1900s (Exhibit 3-17 and Exhibit 3-18)[11]. The erosion may be due to the reduction of sediment supply after the discharge from the Freshwater-Fay Slough junction area was blocked, and potentially also due to subsidence and resulting increased wave exposure. Presuming the erosion occurred since the railway (constructed by 1916)[12] and Highway 101 (constructed by 1933)[13] were built, the erosion occurred in the last 100 +/- years (railways) to 80 years (highway), the average marsh scarp erosion rate is on the order of (approximately) 2 feet / year. This contrasts with the estimated 5 cm/yr wetland retreat rate reported for monitored marshes in Humboldt Bay[14].

Marsh scarp erosion is also apparent along Eureka Slough adjacent to the Jacobs Avenue levee. This erosion is likely due to scour along the channel bank, which is on the outer side of a bend in this location. The rail prism and existing airport levee and the Jacobs Avenue levee appear to have encroached toward the historic bank and floodplain of the slough system in this vicinity, or the slough has migrated.

4.4.2.3 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, a wave will break when the depth of water (D) is equal to the wave height (H), as shown in Figure 21. Under

[11] Humboldt Historical Atlas, 1870 Coast Survey and 1960 US Army Corps of Engineers Tactical Map

[12] Humboldt Historical Atlas, 1916 US Army Corps of Engineers Tactical Map

[13] Humboldt Historical Atlas, 1933 State of California

[14] op cit Humoldt Bay Symposium 2019

these conditions, waves are considered to be depth-limited when the depth of water is less than or equal to the wave height.

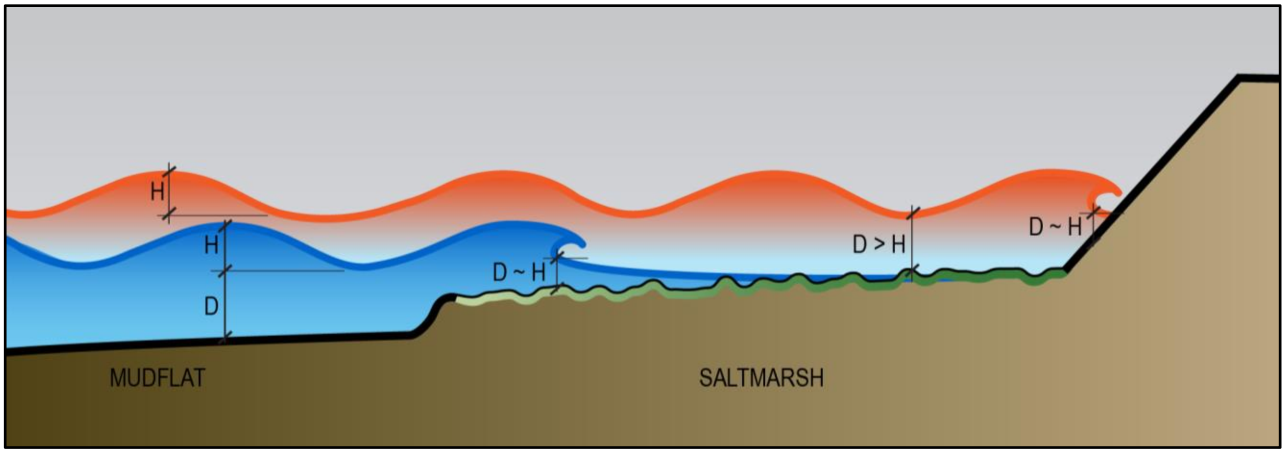


Figure 21. Wave attenuation associated with salt marsh.

The dominant topographic features along the shoreline of Arcata Bay 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 (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.

4.4.2.3.1 Indicators of Change

- Changes to vegetation:
  - New growth/colonization of marsh veg
  - Conversion of vegetation types
  - Loss of vegetation, conversion to mudflat
- Erosion of seaward scarp accelerates, moves
- Accretion/erosion of marshplain

4.4.3 Tidal Slough and Creek Response

Tidal sloughs are formed by tidal exchange 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). Consequently, with adequate sediment supply, we expect the channel cross-sections to lift with sea level rise. However, increased tidal prism associated with sea level rise or changes in upstream hydraulics, the channel size can be expected to enlarge and the increased channel width could conflict with the space between existing levees that constrain the channels. Without setback of the levees, erosion of the levee prisms occurs. Armoring of levees reduces the erosion potential in that location, typically resulting in erosion of the opposite bank or incision of the channel if both banks are armored. Figure 22 depicts the lateral erosion that can occur along tidal slough banks as a result of increased water levels and/or tidal prism that induce additional hydraulic forces on the existing levees. This process of erosion is evident throughout the Eureka Slough Hydrographic Area, typically on outside bends and downstream of historical slough channels that diverted upstream flow to other locations.

Similar to upper reaches of tidal sloughs, creeks are potentially affected by sea level rise in their lower reaches due to upstream encroachment of tailwater conditions and the salt-fresh mixing zone. The likely responses are elevated water levels that diminish with distance upstream and potential inland shift of maximum sediment accretion zone. There is a potential that salt water will migrate farther inland resulting in a localized conversion of to emphasize salt tolerant vegetation, which may facilitate bank erosion.

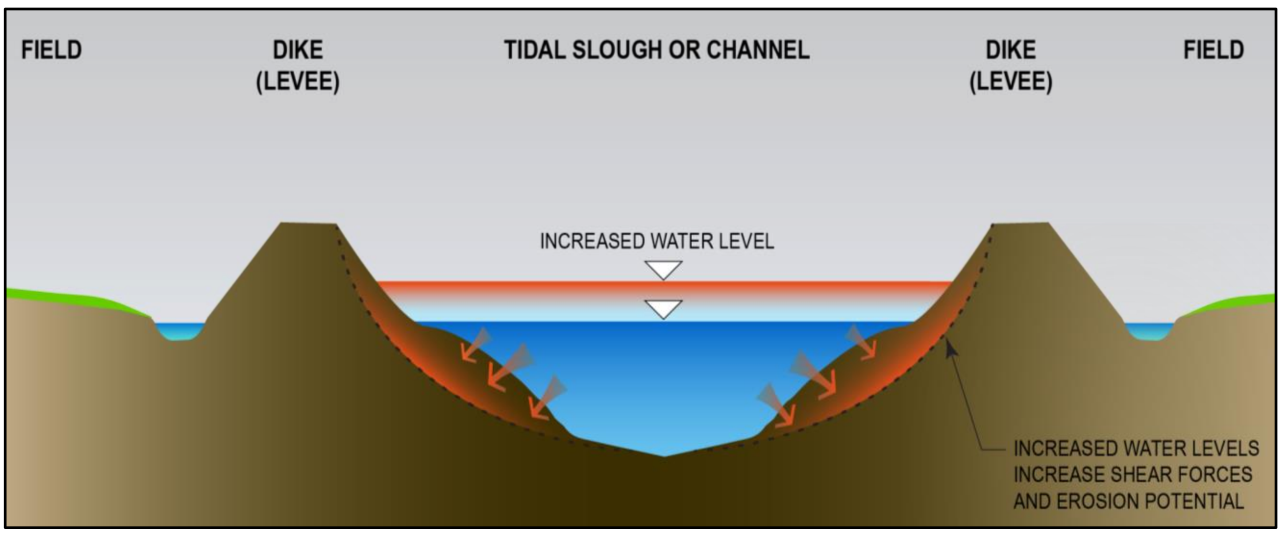


Figure 22. Conceptual geomorphic response of tidal slough channel to increased water levels. Width expected to increase and bottom elevation may increase depending on sediment supply

Note that tidal and fluvial channels are often banded by slightly elevated deposits of mineral soil, often called "river levees" where apparent on larger systems (PWA and others 2004). Removing flood control levees will allow higher water levels to spread out laterally, depositing coarse sediments to maintain the natural "levees" and depositing additional sediment in the adjacent floodplain, resulting in vertical accretion of the flood plain. These natural levees, albeit often of very subtle elevation difference, support transitional and in some places riparian plants which provide high water refuge for animals.

4.4.3.1 Indicators of Change

- Reduction in cross-section owing to deposition of sediment or encroachment into flow area
- Increase in levee erosion owing to increase depth/shear stresses
- Major change in vegetation can indicate change in salinity and hydraulics.
- Scarps indicating down-cutting of the channel bed.
- Steepening of the banks and bank erosion

4.4.4 Constructed Landform Response - Armored Shores

Armored shores refer to constructed shorelines comprised of erosion-resistant materials configured with a steep aspect ratio (height / width) in order to provide flood protection with the minimum use of space and material volume. Armored shores may have been engineered specifically to provide flood protection (e.g. a rock revetment, reinforced concrete seawall or compacted earth levee), or may have an armoring effect despite having been designed for another purpose (e.g. a railway embankment or highway). Armored shores are, by definition, comprised of materials that are not natural and are configured into an unnatural shape. Therefore, armored shores typically affect nearshore processes and morphology to some degree. The effects on nearshore processes and morphology are:

- Footprint: The structure covers and hence removes natural conditions within its limits, or footprint. The removed natural area can be considered a loss of habitat (e.g. beach, wetland).
- Dissipation: The structure reduces the space available for wave and current dissipation. Hence, increased wave reflection, scour and turbulence can occur resulting in changed sediment transport patterns and rates, and modified nearshore geometry. The effect of dissipation is first the result of structure shape changing dissipation in the structure footprint. Secondly, since the structure impedes shore migration, the effect on dissipation is cumulative and progressive with time and with sea level rise. To explain further, shore migration allows the zone of wave and current dissipation to migrate inland, and energy is dissipated via the work done forming the new shore (via erosion) and via turbulence and drag spread over the new shore. However, the structure results in the energy dissipation being concentrated in a smaller area on and in front of the structure. This concentration may be reduced somewhat by an increased rate of dissipation on the structure (e.g. within the voids of armor stone in a rock revetment) and by wave reflection. However, wave reflection can also affect nearshore morphology. In summary, by preventing shore migration, the armoring can essentially foreshorten the shore profile otherwise shaped by waves and currents, causing the adjacent bayward profile to erode more rapidly. The extent of erosion depends on many factors, including the length of the armoring.
- Loss of Habitat: Scour of the nearshore can result in the loss of marshes and beaches. Eventually with extensive scour, the foreshore may be completely “drowned” resulting in subtidal or deep intertidal depths.

- Increased Loads: As scour and other nearshore changes occur adjacent to a structure, the depth of water increases at the bayward edge, or toe, of the structure. The greater depth allows larger breaking waves and stronger currents to impinge directly on the structure. Higher wave loads and greater wave overtopping result, likely increasing these loads above the levels for which the structure was designed, causing failure and or increased maintenance.

The effects of sea level rise on nearshore processes and morphology include additional loss of habitat along the bay shore and slough channels and increased loads along the bay shore. Figure 23 schematically describes the concept of increasing loadings on armor with sea level rise (Battalio and others 2016). An engineered rock revetment is shown along with a design profile, water level, depth and wave height. The wave height incident to the structure is related to depth of water at the structure toe (unless the water is too deep for waves to break). Sea level rise directly increases the water depth at the shoreline structure. The increased water depth allows a larger potential breaking wave, as indicated on Figure 23, which is linearly related to the increase in depth. Because wave loads increase non-linearly with wave height, rock stability can be compromised for delta as low as 0.5 (that is, an increase in wave height by 50%). This implies, for example, that a sea level rise of 0.5 feet that results in a depth increase of one foot, could increase a local wave height by a foot: If a rock revetment was designed for a breaker height of 2 feet, the resulting wave height of 3 feet could lead to structural failure. This concept relies on depth-limited wave conditions and a structure exposed to only non-breaking wave conditions (that is, already relatively deep water) would not realize the same sensitivity to sea level rise.

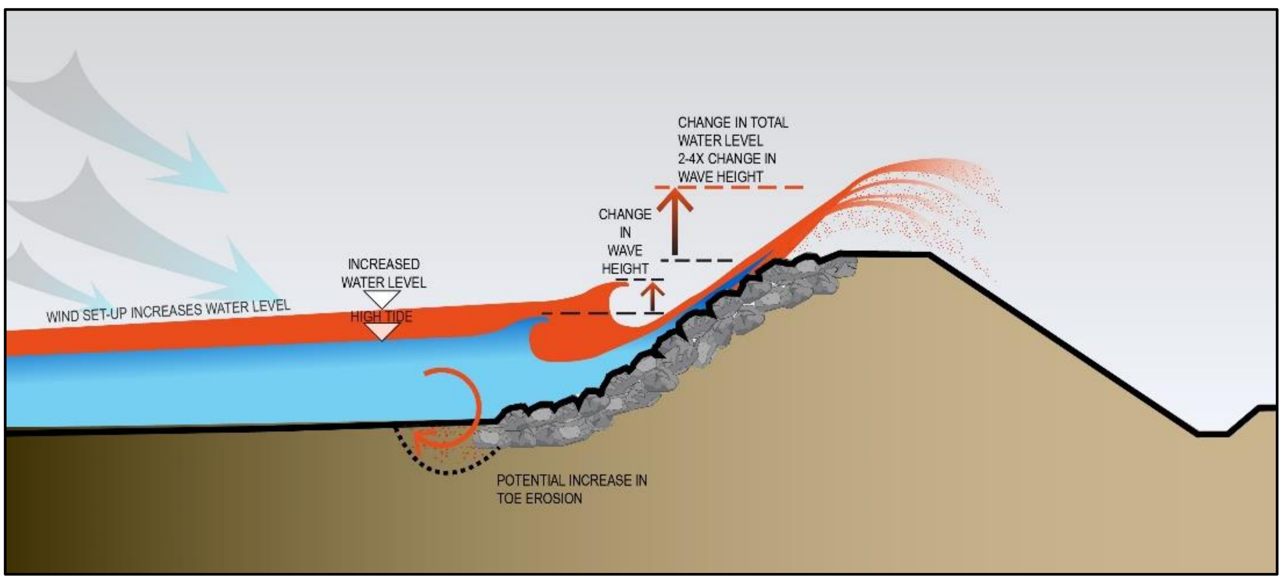


Figure 23. Effects of sea level rise on shore armor and increase in total water levels associated with increased water levels.

Sea level rise can also increase structure overtopping due to elevated wave runup. Intuitively it may be presumed that the potential height of wave runup, called total water level (TWL), will increase the same amount that sea levels rise. However, because the structure impedes shore migration and results in a larger incident wave at the structure, the TWL increases several times the amount of sea level rise. For depth-limited wave conditions in sheltered waters (e.g. locally generated, short-period wind waves) such as Arcata Bay, the multiplication factor (called "Morphology Factor") is about 2 to 4 (Battalio and others 2016). This means that the potential for wave overtopping of shoreline structures in Arcata Bay will increase with sea level rise, with the potential TWL increasing 2 to 4 times sea level rise.

4.4.4.1 Indicators of Change

- Displacement of rocks, creation of gaps
- Scour in front of structure
- Scour/erosion behind structure
- Flattening of the structure
- Erosion of earth behind the structure

4.4.5 Constructed Landform Response - Earthen Levees and Rail Prism

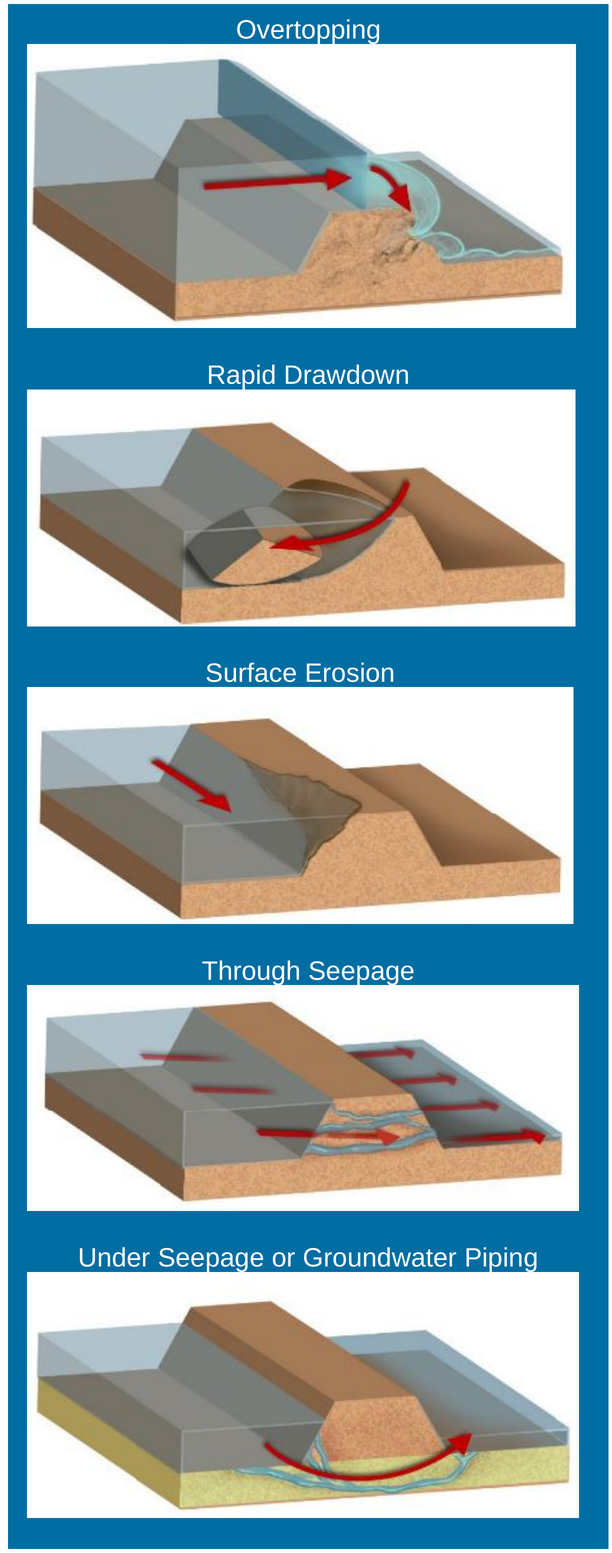
Eureka Slough and the tributary sloughs (First, Second, Third, Fay, Freshwater and Ryan) are primarily bordered by constructed levees to prevent tidal and high freshwater flows from inundating the low-lying areas between Highway 101 to the west and Myrtle Avenue to the east. Small patches of tidal marsh are scattered along the slough-facing toes of levees, but most slopes abruptly rise from the mud flat slough channel bottom. The condition of slough-facing slopes of levees varies throughout the study area. Some slopes are armored with rock, concrete rubble, wood or other debris, while others are densely vegetated. Many levee slopes exhibit a steep face of exposed gravels, sands and muds while others show scarping of the narrow tidal marsh along the toe of the slope. The tops and landward slope of the levees are largely vegetated varying from maintained grasses to thickets of trees and shrubs.

A geotechnical analysis of the Jacobs Avenue Levees is particularly pertinent to this study (CGI 2016). Earth embankments require maintenance and upgrades over time, as sea level rise can result in higher loadings and direct overtopping.

Much of the shore of the study area includes the railroad prism along the Bay shore, and levees along the interior tidal sloughs, which have different types of hydraulic loadings (e.g., tidal water levels and waves along Bay shore, tidal water levels and high velocity currents along tidal sloughs, etc.). Many of the levees in the study area were constructed from native soil obtained from either adjacent borrow ditches, dredge spoils, and/or imported soils. Much of the levee system was constructed between 100 and 120 years ago and records of material type and construction methods used do not exist. With the exception of the Jacobs Avenue levee assessed by CGI (2016), most of the levee within the study area have not been assessed relative to modern levee standards. The Jacobs Avenue levee was assessed for conformance with FEMA's NFIP criteria and was determined to not meet most of the performance guidelines for prism geometry, vegetation, liquefaction potential, seepage, slope stability, and seismic deformation. While similar assessments for the balance of levee system in the study area has not been completed, the outcome would likely be comparable.

There are multiple failure modes of constructed earthen levees in response to sea level rise which are shown in Figure 24, and the more common failure modes applicable in the study area are described below.

- Overtopping – Overtopping of landforms refers to the conditions when the still water level of the Bay or slough exceeds the elevation of a landform, resulting in water flowing over the landform. Overtopping by water levels higher than the levee crest directly floods the interior and represents a functional failure. Typically, overtopping causes degradation of the structure by eroding the crest and backside, allowing greater surface flows and potentially loss of section, which is a local structural failure. Still water or "surge overtopping" is connected to the tidal water levels, coastal storm surge, fluvial flows, as well as waves.
- Rapid drawdown – Structural shear failure of earth levees can occur when a rapid reduction of water level occurs after the levee earth is saturated during a high water event. The saturated soil weight can result



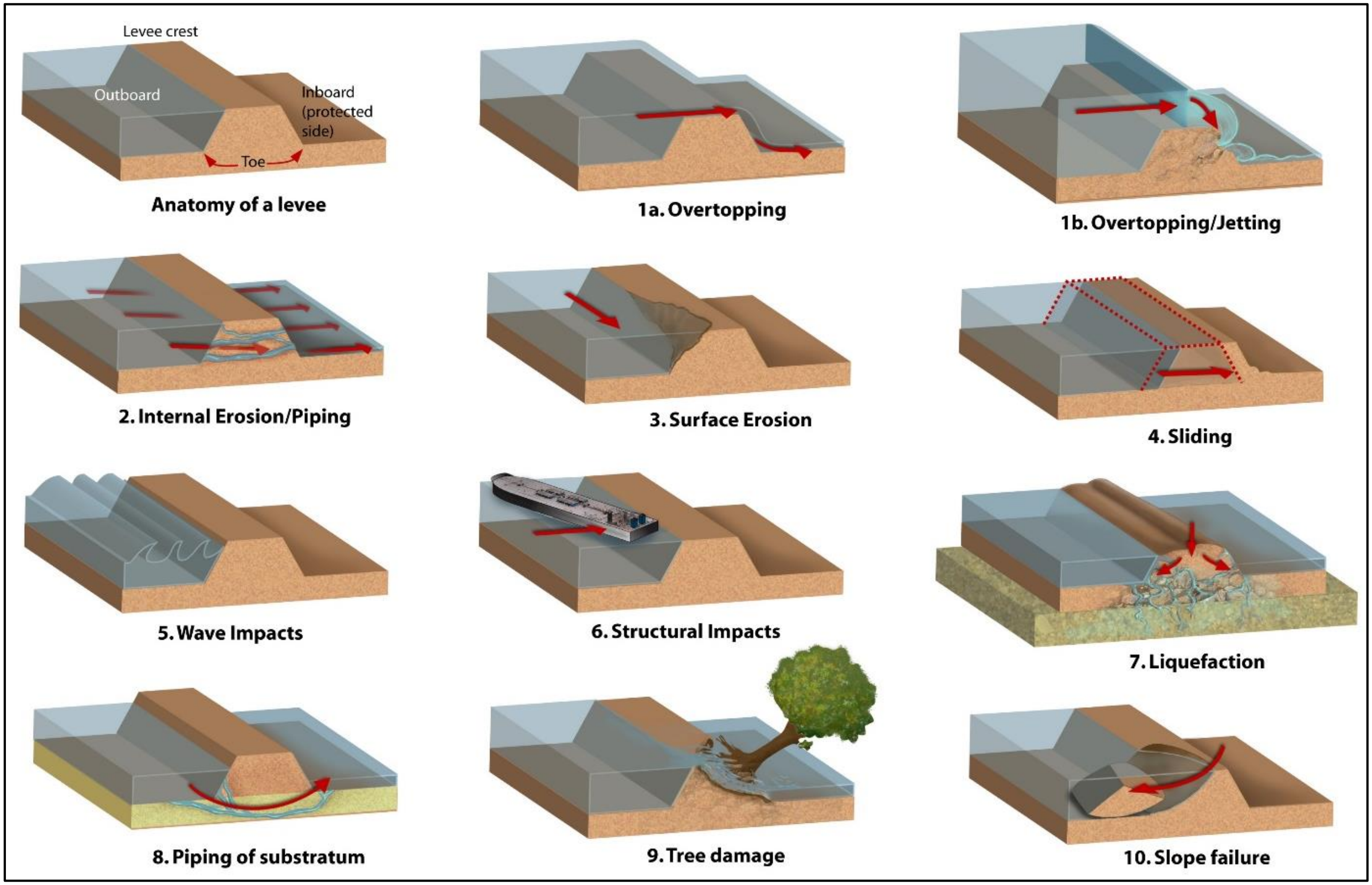


Figure 24. Earthen Levee Failure Modes (National Science Foundation 2020)

in soil shear stresses that exceed soil shear strength, resulting in a failure and mass sloughing of the section. Note that the levee fails “outward” toward the flood source. The rapid drawdown can occur in tidal waters as well as the falling side of a flood hydrograph. A special type of rapid drawdown failure occurs when leveed areas are flooded, adding a hydrostatic load. This condition has occurred where high creek flows overtop a leveed area, filling it, and then the creek and tidal waters recede with the tide. This situation is potentially hazardous to adjacent areas because of the pulse of water released, and a cascade of breaches can occur at adjacent lands. The interior slough levees exposed to fluvial flooding from the landward size would be exposed to this type of failure.

- Surface Erosion – Surface erosion occurs when the soil strength is reduced due to saturation and/or shear forces acting on the soils. Surface erosion can reduce the effective width of the levee and making it more susceptible to through seepage failure and overtopping failure. Indicators of surface erosion is very common along the rail prism and interior slough levees where armoring is absent.
- Through Seepage and Groundwater piping – High exterior water levels increase the water pressure in the ground beneath and on the “dry” side of the earth levees causing water to inundate the protected side. If the pressure is high enough, soil can be entrained resulting in soil “boils” indicating that foundation and full structural failure may occur. Seepage can also daylight on the face of the levee. CGI (2016) describes these processes as *underseepage* and *through-seepage*, respectively.
- Penetrations – Earth embankments are typically penetrated by drainage pipes and sometimes other structures. These structures can form a failure pathway due to increased permeability of surrounding soils, corrosion of the culvert wall of opening of joints between sections, and cavities caused by structure movements or collapse.

4.4.5.1 Indicators of Change

- Vegetation changes – large woody vegetation and wetland vegetation may indicate structural degradation
- Irregularities in the neat lines of the designed structure, such as scarping, erosion/bank caving, settlement, depressions/rutting, cracking, and animal burrows
- Irregularities in the ground surface in the vicinity, for example, saturated soils, recently deposited sediment, indications of soil movements
- Degradation of closure structures (stop Log, earthen closures, gates, or sandbag closures)
- Degradation of culverts/discharge pipes
- Degradation of riprap revetments & bank protection

4.4.6 Diked Former Tideland Response

Diked former tidelands, also previously referred to as flood cells, are generally situated at elevations below mean high tide and can therefore experience interior flooding when rainfall run-off into the cell exceeds the discharge capacity out of the cell. This commonly occurs when a precipitation event coincides with a high tide that reduces the water control structure outlet capacity. The drain-off of the cell is limited to low tidal periods only and can result in extended periods of temporary flooding. Impounded run-off over permeable ground (e.g. agricultural land) can promote infiltration into the soil horizons, which can seasonally increase groundwater levels throughout shallow unconfined aquifers (and also suppress salinization). Regardless of seasonal rainfall run-off patterns, diked former tidelands are anticipated to experience higher groundwater as sea levels rise. The higher groundwater may make dewatering difficult and may affect land use. The higher groundwater may slow subsidence by reducing the overburden weight on the compressible soils. If water levels rise to maintain inundation, oxidation of organic soils may reduce and subsidence may be further arrested. Finally, it is anticipated that wetland obligate vegetation will establish if flooding is persistent.

The elevated groundwater could also result in increased infiltration rates into sanitary sewer collections systems. Additionally, saltwater intrusion could impact domestic and irrigation wells. See **Figure 25**, for conceptual model of anticipated changes to diked former tidelands.

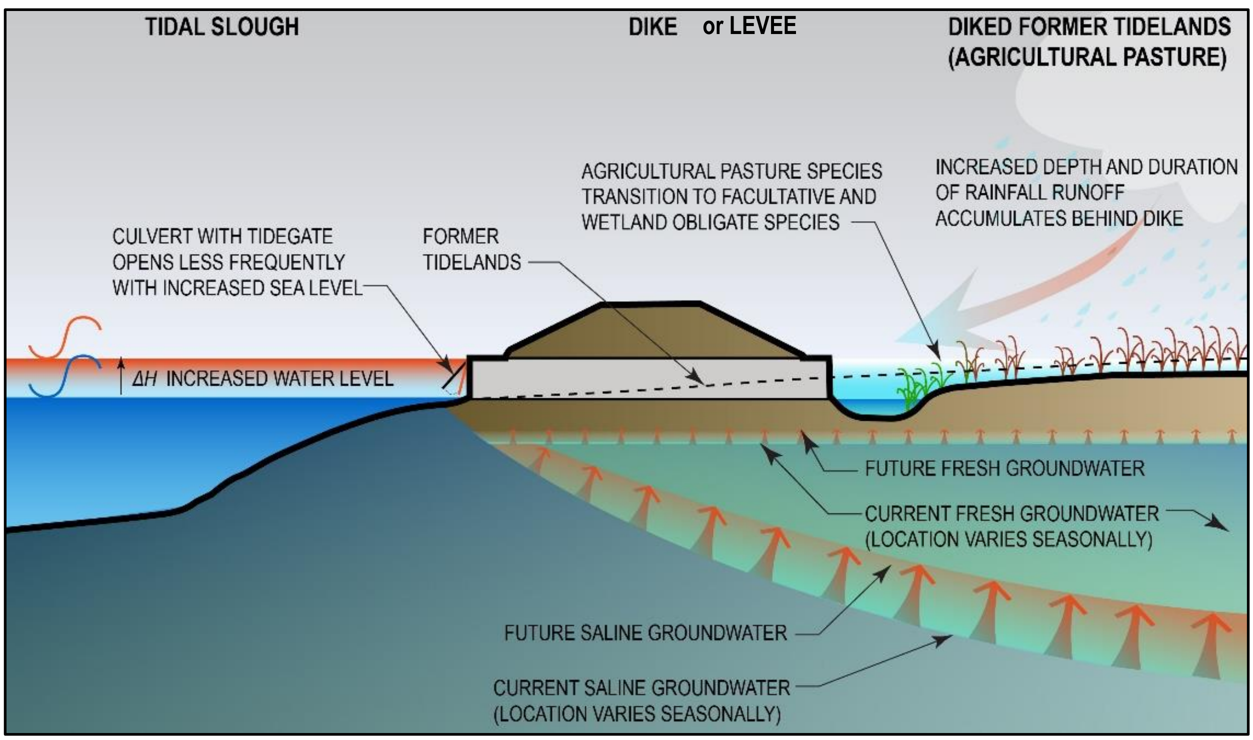


Figure 25. Conceptual model of anticipated changes to diked (leveed) former wetlands

4.4.6.1 Indicators of Change

- Standing water and areas of wetlands plants can indicate rising groundwater
- Bare areas (no plants) can indicate occasional ponding or salt accumulation
- Higher frequency and depth of emergent groundwater above the ground surface

4.4.7 Diked Former Tideland Response - Water Control Structures

Water control structures consist of culverts and gates to manage water flows. Water control structures that discharge to tidal waters typically have gates, called tide gates, to eliminate tidal flow, but allow drainage to the tidal waters during low tides. Culverts and tide gates degrade over time, and many structures allow some tidal exchange. With sea level rise:

- Low tides will be higher and hence drainage through the water control structures will be reduced and water levels will rise behind the structures,
- Groundwater will rise, resulting in higher base water levels and reducing flood storage capacity, and.
- At higher sea levels, the water will overtop the structure or housing feature (e.g. levee), and the inland area will be inundated to some degree depending on overtopping extent, duration and inland area. With sea level rise low tides will be higher and hence drainage through the water control structures will be reduced and water levels will rise behind the structures. Additionally, groundwater will rise, resulting in higher base water levels and reducing flood storage capacity.

4.4.7.1 Indicators of Change

An inventory of water control structures in Humboldt Bay developed by the U.S. Fish and Wildlife Service (FWS) used an inspection protocol that included the current status of the structure (USFWS 2007). The observer noted the current status of the inspected structures to be functional, broken-open, broken-closed, or leaking. These operational indicators are recommended to be used as indicators of change, along with any additional observation protocols. So, in summary, indicators of change for water control structures include the following:

- Operational functionality: functional, broken-open, broken-closed, or leaking
- State of design (e.g., eroding, intact, armored, etc.)
- Armor materials are degraded
- Apparent effectiveness is degraded
- Expected performance following major storm changes
- Wave exposure: overtopping event occurs or changes

4.4.8 Diked Former Tideland Response - Remnant Sloughs/Drainage Channels

Managed sloughs are typically remnant tidal channels or excavated drainage channels with hydraulic controls that prevent tidal inundation but allow drainage during low receiving water levels. These structures tend to slowly subside due to lowered water levels and consolidation and oxidation of former marsh soils but accrete with local sediment supply and other detritus trapped by the hydraulic controls, and the accumulation of vegetation. The geomorphic response to sea level rise is overshadowed by the management actions, except that rising ground water levels will likely diminish the flood management functions. Most managed sloughs are controlled by tide gates that open when the inboard water levels are greater than the outboard. This typically occurs during low tides, providing a limited period to drain the managed sloughs. As sea level rise, the low tides will elevate and the drain-off period of the managed sloughs will decrease, thereby resulting in an increase in depth and duration of inboard flooding. Managed sloughs within the study area include the Caltrans Highway 101 ditch, the Freshwater Junction Remnant Slough and other inboard ditches/drainage swales such as those located on the CDFW Fay Slough Wildlife Area.

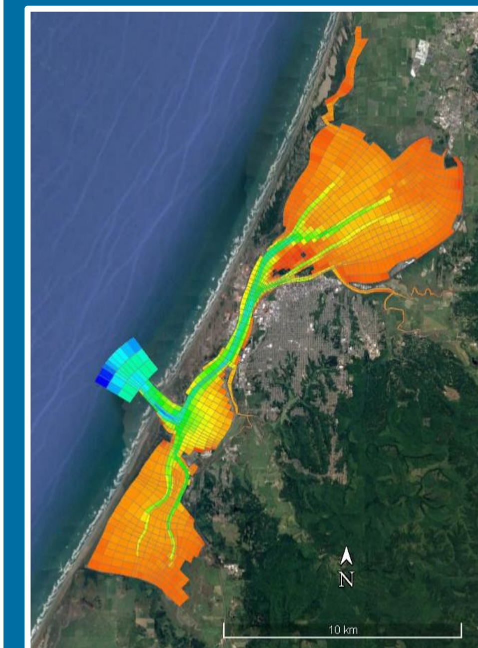
4.4.8.1 Indicators of Change

- Reduction in cross-section owing to deposition of sediment or encroachment into flow area
- Major change in vegetation can indicate change in salinity and hydraulics.

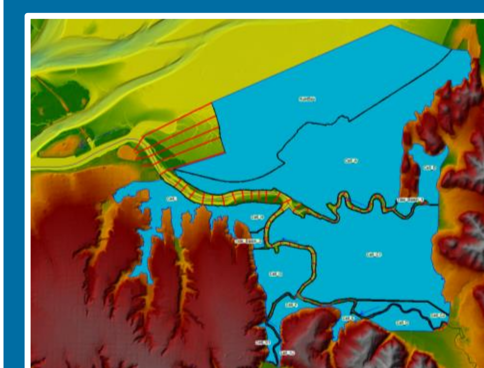
5. HYDRAULIC ANALYSIS

5.1 Overview

The primary drivers and physical processes that impact critical resources within the study area include sea level rise and extreme tidal and fluvial events. To assess the depth and duration of tidal and fluvial water levels throughout the study area, Northern Hydrology & Engineering (NHE) developed a 2-Dimensional hydrodynamic model for the study area building off the existing Humboldt Bay model (NHE 2015). The methods, results and discussion are included in the Hydraulic Technical Memorandum (Appendix C) and summarized below and within the following Hazard Scenario section.



Humboldt Bay Hydrodynamic Model Domain (NHE 2015)



Study Area Hydrodynamic Model Domain (NHE 2019)

5.2 Purpose

The purpose of the hydraulic modeling effort was to develop an analytical/quantitative tool to better understand the flooding and inundation regimes within the study area from both fluvial flooding and coastal extreme high-water events. As previously described, most of the critical resources within the study area are protected by an extensive system of levees and the railroad prism along Humboldt Bay and the interior tidal sloughs. Flooding within the study area can occur from both fluvial and/or coastal events that either overtop the levees and/or inundate the tidal wetlands. Most of the existing levees and railroad prism were constructed over 100-years ago and are vulnerable to overtopping from extreme events today. As sea levels rise, not only will the frequency of overtopping increase, but the inundation depth and duration of the protected study area lands will also increase. The hydraulic model was used to provide flooding/inundation regimes for existing conditions, and how these regimes will change into the future with sea level rise. This section also summarizes the wind wave analyses completed for the Humboldt Bay Trail Slough project and its use in the following Hazard Scenario section.

5.3 Fluvial and Coastal Surge (Recurrence Water Levels)

Tidal surge associated with coastal storms and fluvial watershed flooding can occur independently but may also occur simultaneously. Although coastal surge elevations have been studied extensively (e.g., FEMA 2014, NHE 2015, ESA 2018, etc.), much less is known about the flood elevations associated with fluvial processes along the slough network in the study area. As described in the Hydraulic TM, quantification of flood elevations associated with extreme fluvial flooding requires development and application of a hydraulic model of the slough system, where the fluvial flood hydrograph represents the upstream boundary condition and the tidal elevations of the bay represent the downstream boundary condition. The information below describes a brief methodology for this approach followed by a technical description of the modeling results completed for this study.

5.3.1 Hydrodynamic Modeling Methods and Detailed Analysis of Combined Coastal-Fluvial Water Levels

Hydraulic modeling of tidal slough system in the study area was conducted to determine joint occurrence statistics of fluvial and coastal flooding. Known quantities include the coastal still water level (SWL) elevations as a function of return period (or recurrence interval). These are described in detail by NHE (2015).

Water surface elevations were computed throughout the study area using a range of fluvial events (2-, 10-, and 100-year events) in combination with typical coastal surge elevation conditions representative of a neap-spring tide cycle without local storm surge. Transient model simulations of the fluvial hydrograph were synchronized with the peak of the tidal boundary condition.

Computation of the probabilities of combined coastal and fluvial water levels along the tidal sloughs in the study area were computed using FEMA guidance for the Pacific Coast (2005). The method uses the independent curves of water levels as a function of frequency (inverse of recurrence). For a given elevation, the frequencies associated with the coastal and fluvial events are added to yield the frequency of the combined event. This method was completed at discrete locations moving upstream from the Bay to develop profiles of probabilistic water level relationships that can then be used to refine the overtopping of the flooding. This method was repeated with sea level rise scenarios. Example return interval of flood elevations from fluvial and coastal surge sources at five locations in Eureka Slough and Freshwater Slough are shown in Figure 26 for existing conditions. The results indicate that tidal surge dominates in Eureka Slough (RM 1.11) however fluvial flows begin to dominate near Ryan Slough confluence (RM 3.82). The results are further described in the Hydraulic TM and flood inundation maps are presented in the following Hazard Scenario section.

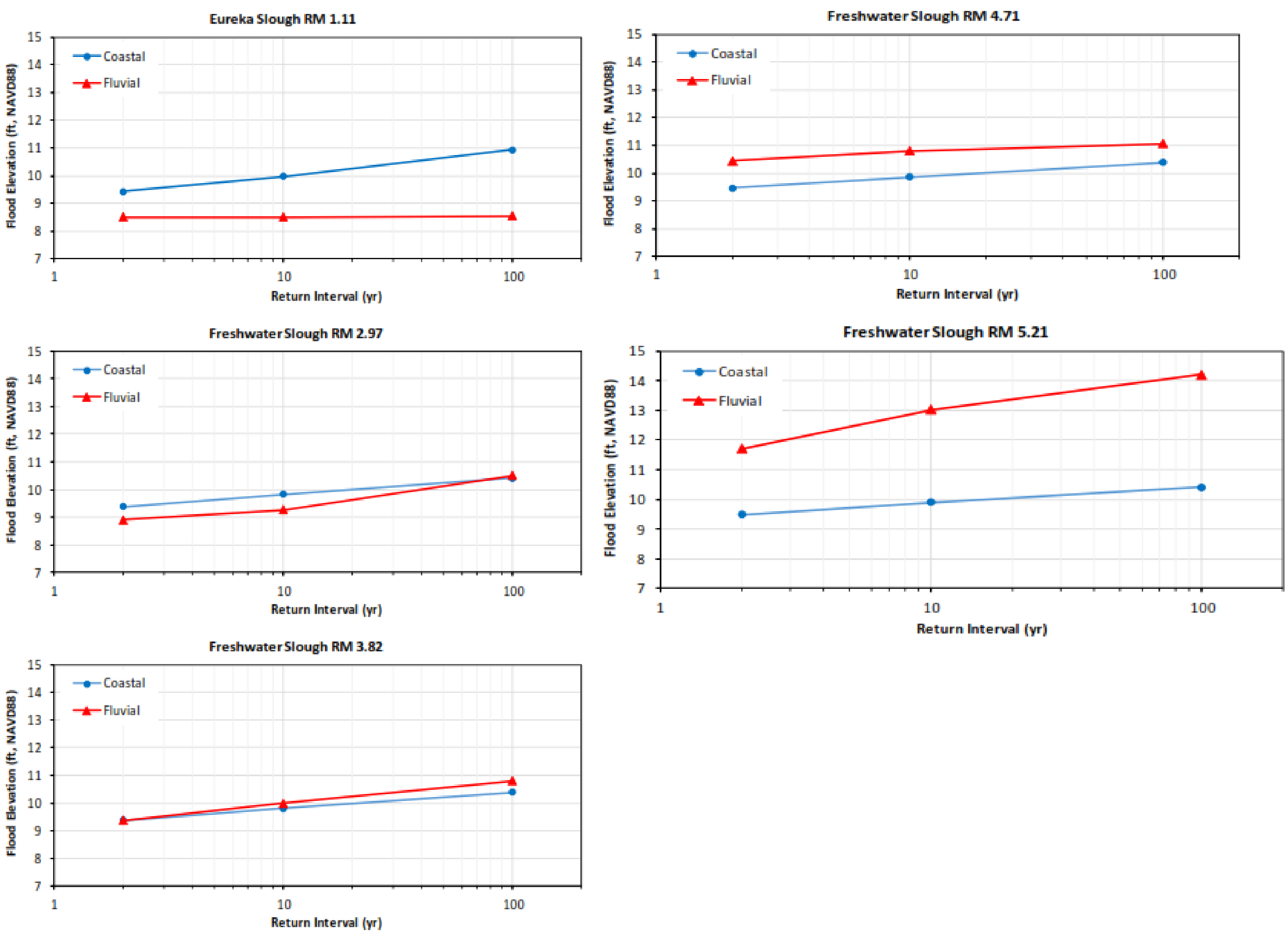


Figure 26. Return interval of flood elevations from fluvial and coastal surge sources at five locations in Eureka Slough and Freshwater Slough with RM numbers increasing in upstream direction.

5.4 Wind Wave Analysis (Total Water Level)

As previously described, the shoreline along Arcata Bay is exposed to wind generated waves. ESA estimated wave runup and total water levels for four cases along the Arcata Bay shore of the study area as part of a sea level rise analysis for the Humboldt Bay Trail South project (ESA 2018). The four cases were selected to represent total water level events with a range of likelihoods from annual to 50-year return periods. Each case was defined by a combination of the still water level (SWL) and incident wave height. Still water levels ranged from 6.5 feet (mean higher high water) up to the 10-year SWL of 9.97 feet (or 10 feet). Incident wave heights for three cases used the 50-year wind wave (45-mph), as reported by FEMA (2014) for the coastal flood study.

Figure 27 shows the results of the wave runup analysis for each of the four cases under existing conditions (i.e. no sea level rise). Typical high tide conditions without wave action do not overtop the railroad berm along the shore. Wave runup associated with the 50-year wind wave and typical high tides (approximately a 2-year return period) overtops portions of the railroad berm, particularly along the low-lying segment north of Brainard. Storm events where coastal storm surge and wave action is combined overtop several thousand feet of the shore along the study area for existing conditions. A major flood elevation threshold of approximately 9 to 9.5 feet, which represents several thousand feet of shore, is exceeded during as low as a water level with annual recurrence plus an extreme wind wave event. As the coastal storm surge increases, the exposed shore is subject to increased combined surge and wave overtopping. With sea level rise, the flooding becomes more frequent as the high tide exceeds the height of the railroad berm, both in the absence and presence of waves.

5.5 Summary

The results of the hydraulic and wind wave analyses described above were used to assess vulnerability of critical resources within the study area through the development of Hazard Scenarios which are discussed in the following section.

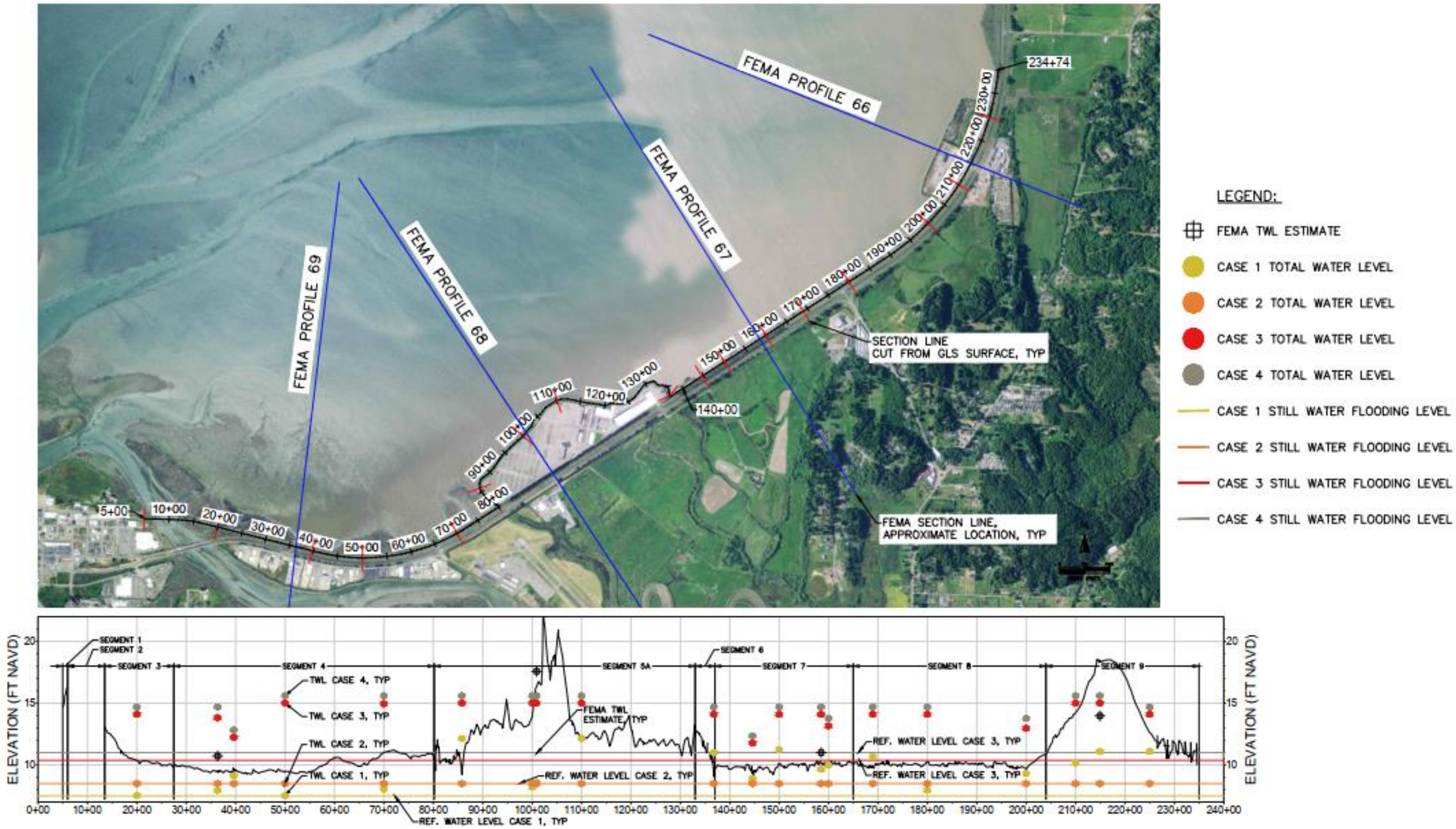


Figure 27. Total water level along Arcata Bay shore of Study Area (from ESA 2018)

6. HAZARD SCENARIOS

6.1 Overview

The scenario-based planning approach (introduced in Section 1.9) was used to describe the anticipated range of potential outcomes associated with existing and future tidal water levels, fluvial flows and modifications to the shoreline within the study area. Objectives of the scenario-based planning approach include:

- Improve understanding of the dynamics of flood events including the timing and location of flooding, depth of flooding, and potential flood pathways.
- Explore the water levels and locations where thresholds and tipping points of resources are met to better understand site-specific vulnerabilities.
- Clarify the role of external drivers and identify where management action may be possible.
- Inform the design objectives for adaptation projects to maximize effectiveness.
- Interpret sea level rise projections, modeling results, and geomorphic assessment to better characterize and understand risk.
- Increase the robustness of decision making.

For this study, hazard scenarios were developed to evaluate hypotheses about the potential cause-and-effect linkages between hydrologic and geomorphic processes and physical changes to the landscape. Each scenario is intended to tell a detailed story about a possible chain of events, documented as a case study with a narrative description, with example photos and graphics, and supporting exhibits. Hazard scenarios and accompanying tables and graphics are presented in Appendix D.

An infinite number of potential scenarios exist. The project team applied an iterative approach with the goal of capturing a representative range of conditions and trying to pinpoint key thresholds for critical resources and vulnerable areas. More scenarios could be developed in the future. In addition, scenarios could be refined based on new information or different interpretations, perspectives, or assumptions.

The hazard scenarios represent a range of astronomical tides, meteorological conditions and future sea level rise conditions. Annual, extreme spring tides typically occur in the months from November through January due to astronomical effects. Meteorological conditions increase water levels with storm surge and winds. Sea level rise increases water levels with or without astronomical and meteorological effects, resulting in equivalent extreme water levels occurring more frequently, while also increasing low tide water levels.

A summary of hazard scenarios is provided in Table D-1 and Table D-2 (Appendix D). Table D-1 summarizes scenarios with increasing tidal water levels and Table D-2 summarizes increasing fluvial flows. Each hazard scenario is described by the overall hydraulics, consisting of a tidal still water level which represents the maximum water level due to astronomical tides and storm surge; local meteorological effects resulting in wind set-up and wind waves; and the resulting wave run-up range based on the wave height and shoreline geometry. The combination of these three processes results in a total water level, representing the peak water level of the simulation. Peak water levels for astronomical tides and storm surge may occur over multiple days, while wind set-up may last hours and wave run-up may last seconds. The tidal still water level and wind set-up for each scenario are used to identify approximate equivalent still water events with sea level rise. For example, the Scenario 3 combined still water level of 9.3 feet and wind set-up of 1-foot results in a combined water level of 10.3 feet (NAVD). This water level currently has a recurrence probability of approximately 50-years (2% annual chance). With 2 feet of sea level rise, the Mean Monthly Maximum Water level would increase from 8.3 feet to 10.3 feet. Therefore, with 2 feet of sea level rise, a water level that currently has a 2% annual chance of occurrence will likely occur 5 to 6 times per year.

Scenarios 5a and 6a incorporate increased shoreline elevations along Arcata Bay associated with the proposed Humboldt Bay Trail South project (60% design). Hydraulic conditions remain the same in Scenarios 5a and 6a compared to Scenarios 5 and 6, respectively. The increased shoreline elevations reflect proposed potential future conditions as a way of assessing the changes to flooding with implementation projects.

For the critical resources within the study area, impact thresholds were assigned based on exposed flood depth and duration to each resource. Impact thresholds mark the hydraulic conditions that result in significant changes to the magnitude of impacts to a critical resource. For this study, impact thresholds are characterized by changes described as “initiation,” “increasing,” and “most severe.” “Initiation” marks the change between typical observed conditions (typically dry and accessible) and conditions that begin to disrupt functionality and or access. For example, a roadway that is flooded with less than 3 inches of tidal water for one hour is categorized as “initiation” as an observable difference in hydraulic conditions is present, motorists are able to use the roadway at reduced speed, and damage to the roadway is not expected. “most severe” represents hydraulic conditions for which failure, loss, or permanent changes to the critical resource is expected. “Increasing” spans the hydraulic conditions and impacts between “initiation” and “most severe.” Thresholds were assigned based on published literature and/or professional judgement. The thresholds are presented in Table D-3 (Appendix D).

The resource response and impact summary in Tables D-1 and D-2, highlights the extent of overtopping along the study area shorelines, including Arcata Bay and the slough network; screening level erosion potential of shoreline structures; impacts to transportation and other critical resources; and the key findings and conclusions associated with each hazard scenario.

Each hazard scenario case study is accompanied by a(n) exhibit(s) showing the location, depth and duration of shoreline structure overtopping; depth of flooding on roadways; flood depth of developed and undeveloped lands; and cells subject to daily tidal inundation due to a high potential for shoreline structure failure (Appendix D).

A detailed summary of overtopping, typical flood depth and maximum flood elevations with each cell is tabulated at the end of each hazard scenario case study, followed by an evaluation of the impacts and critical resource responses. The flood depth, duration and extent are compared to the thresholds identified (Table D-3) and color coded based on the level of impact (initiation of impacts, increasing impacts, and most severe impacts) as it relates to the resource.

6.2 Key Findings

Key findings from development of the hazard scenarios are presented below.

Finding #1 - Threshold for Significant Overtopping

Tidal water levels below elevation 10 feet (NAVD) generally result in conditions that resemble typical winter conditions in the study area, with areas of shallow flooding and restricted access to underground facilities and low-lying lands. Water levels between 10 to 10.5 feet (NAVD) mark the initiation of overtopping of shoreline structures resulting in widespread flooding. Water levels between 10.6 and 11.6 feet (NAVD) mark a significant increase in the extent of overtopping and conditions that have a high potential to create a breach.

Finding #2 - Salt Marsh Reduction of Wave Runup

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.

Finding #3 - Highway 101 Flooding

The highway is the highest elevation barrier to Cell A between Eureka Slough and Brainard. Overtopping of the rail prism in this area does not overtop the roadway until tidal water levels are between 10.6 and 11.6 feet (NAVD). The highway is typically lower elevation than the rail prism from Brainard to Indianola Cutoff. Overtopping of the rail prism begins at tidal water levels as low as 9.1 feet (NAVD) in this area, exposing the highway and motorists to a direct flooding pathway at a relatively low water level compared to the rest of the study area.

The drainage channel between Highway 101 southbound and the rail prism is able to store and convey a relatively small volume (approximately 100 acre-feet) of tidal floodwaters. Overtopping events up to elevation 10 feet (NAVD) are not expected to cause flooding of the southbound travel lanes. At higher water levels, the drainage channel is overwhelmed and tidal waters 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 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.

Finding #4 - Inundation Pathways

The rail prism is typically lower elevation than the rest of the shoreline structures protecting Cell A. Due to the lower elevation, the volume of flooding from overtopping of the rail prism is an order of magnitude larger than the volume of overtopping from the rest 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 rest of the Cell A shoreline structures (Hazard Scenario 6).

Finding #5 - Flooding Impact Reduction Associated with Humboldt Bay Trail South Project

With current shoreline elevations, the 100-year tidal flood event would cause 940 acre-feet of floodwaters to inundate Cell A, causing temporary closure of Highway 101 southbound and water depths of up to 1.5 to 2.5 feet (Scenario 5). The proposed Humboldt Bay Trail South project would increase the elevation of the rail prism to 11.5 feet (NAVD) and eliminate tidal flooding of Cell A for this flood event (Scenario 5a). With current shoreline elevations and one foot of sea level rise, the 100-year tidal flood event would 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 (Jacobs Avenue) and nearby agricultural land (Scenario 6). The increased railroad elevation proposed by the Humboldt Bay Trail South project would reduce the volume of tidal floodwaters associated with this flood event to 10 acre-feet, with water depths of up to 1 to 2 feet (Scenario 6a).

Finding #6 - Jacobs Avenue Flooding

The Jacobs Avenue is a low-lying, developed area protected from tidal flooding by a levee along Eureka Slough and Highway 101 along Arcata Bay. The area is hydraulically connected to the rest of Cell A, which is also protected by levees along Fay Slough and the rail prism along Arcata Bay. Flooding of the commercial, industrial and residential areas of Jacobs Avenue begins with overtopping of the rail prism north of Brainard at a water level of 10.3 feet (NAVD) and along Fay Slough. While not directly exposed to this overtopping, Jacobs Avenue is exposed to backwater effects from the Caltrans maintain drainage channel that outlets to Eureka Slough between Jacobs Avenue and Murray Field. When the drainage channel is overwhelmed during high tides when the gates are closed, flood water will occupy the low-lying areas and existing drainage channels along Jacobs Avenue. Overtopping of the levee along Eureka Slough is initiated at a water level of 10.6 feet (NAVD) but shallow and of short duration. Widespread overtopping of the levee along Eureka Slough and the highway occurs between 10.6 and 11.6 feet (NAVD). Three to six feet of flooding occurs quickly, and all ingress and egress roadways are flooded as well.

Finding #7 - Extreme Tidal Flood Events with Sea Level Rise

The extreme events presented in hazard scenarios 6, 7 and 8 include a sea level rise component that adds 1, 2 and 3 feet of sea level rise, respectively. Sea level rise not only increases the peak tide water level, but also the low tide water level and all other levels throughout the tidal cycle. Extreme tidal events are typically associated with spring tides, which result in extreme high and low tides. The extreme low tides provide an increased duration of favorable hydraulic conditions for drainage after a flood event in protected lands. Increased the low tide water levels due to sea level rise, reduce and potentially eliminate this window of favorable conditions, resulting in extended or permanently flooded lands.

Finding #8 - Spatial Extent of Tidal and Fluvial Effects

Extreme fluvial events primarily affect Cells B through G and Myrtle Avenue with flooding due to levee overtopping and limited conveyance from drainage infrastructure. Little to no effect of extreme fluvial events were noted in Cells A, H and I, where the majority of developed lands in the study area are located. Fluvial events in the study area do not result in flooding of Highway 101. If extreme tidal and fluvial flood events were to occur concurrently, there would be limited compounding effects within the study area.

Finding #9 - Duration of Extreme Tidal Events

Extreme tides due to astronomic and atmospheric effects can be present over multiple days, resulting in multiple flooding events as the tide floods and ebbs. Sea level rise increases the frequency of similar water levels under less extreme astronomic and atmospheric effects in addition to increasing the elevation of low tide.

Finding #10 - Ebb and Flood of Flooding

The rising tide generally increases by 0.25 to 2 feet per hour. In areas along the slough and bay that are protected by a natural elevation gradient or open to tidal inundation, observed flooding is relatively slow, affording the ability to seek higher ground as tidal waters rise. In contrast, flooding of low-lying lands protected by levees or other shoreline infrastructure is generally between 1.5 and 3.5 feet per hour and would increase significantly in the event of a breach. Due to the topography of levees separating the low-lying land from the rising tide waters, imminent overtopping and flooding are not likely observable from the lower elevation perspective and evacuation from the area may not be feasible after the onset of flooding.

The falling tide generally decreases at a similar rate that it rises, 0.25 to 2 feet per hour, affording temporary relief from flooding to areas exposed to the unobstructed tide. In areas protected by levees and other shoreline structures, the rate that flood waters recede is diminished as stormdrain infrastructure is required to convey flood waters back to the sloughs, only when slough water levels are below flood water levels inboard. This may result in multiple days or weeks of continuous flooding.

Finding #11 - Alternate Travel Detours

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 elevation 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. The risk of full closure of the transportation network would be reduced after the proposed Humboldt Bay Trail South project is constructed. Myrtle Avenue and Old Arcata will continue to be an essential alternative travel route.

Finding #12 - Utility Impacts

Given the topography of the study area, underground utilities and structures holding overhead utilities are likely located in saturated soils much of the year. Increases in groundwater levels and saltwater intrusion due to sea level rise and intermittent inundation of tidal waters are expected to result in temporary delays to access and challenges with the long-term maintenance plans, however loss of service due to episodic events appears unlikely.

Sanitary sewer manholes and pump stations, as well as the water booster pump station are more sensitive to flooding and could result in damage, loss of service and public health risks. Water levels of 11.6 feet (NAVD) mark a significant increase in flooding to sanitary sewer and water pump stations.

PART III – ADAPTATION PROJECT PLANNING

7. QUALITATIVE RISK ASSESSMENT

7.1 Overview

The concept of flood risk encompasses both the likelihood of hazardous flood events and the magnitude of the consequences from those events. Areas which are subject to frequent flooding but suffer limited consequences would be characterized as having relatively low risk. Conversely, areas which are rarely subject to flooding but would suffer significant consequences if a low-probability event occurs would be characterized as having relatively high risk. This section synthesizes information about the study area with the results of the hazard scenarios described in Section 6 to identify the locations with the highest overall risks. This study applies a qualitative risk assessment approach which relies on subjective judgment to synthesize a variety of factors, including site characteristics, land use, and population; the mechanisms that cause flooding; the vulnerability of protective structures; and the dynamics of water movement as floodwaters overtop or pass-through shoreline structures and flow across the landscape. This approach is appropriate for identifying priorities for scoping potential adaptation projects.

Much of the study area is located at elevations below mean high tide and relies on shoreline structures such as levees and rail and roadway prisms for flood protection. As water levels increase, the rate, extent, and duration of flooding varies throughout the study area. These flooding characteristics result in variable impacts to critical resources resulting in a spectrum of consequences to public health and safety and economic productivity. A qualitative risk assessment, taking into account the character of flooding and consequences in the study area, identifies the relative risk to the community and provides decision-support information to inform the prioritization of adaptation needs.

7.2 Flooding

As described in the Hazard Scenarios, flooding may occur due to tidal or fluvial sources. The primary focus of the qualitative risk assessment is on tidal flooding, as fluvial flooding affects cells with limited development and infrastructure and historically has not affected long term land use within the cells. Low elevation lands protected by shoreline structures are vulnerable to tidal flooding from overtopping or other modes of failure of the structures. Cells A through H exhibit these characteristics. Cell I and the inland areas adjacent to cells B through H are protected by a natural elevation gradient. Assessment of failure risk due to seepage or slope instability requires detailed soil information which is only available for the Jacobs Avenue levee (CGI, 2016). Due to the limited sub-surface soil information available for other levee segments, shoreline structure overtopping is assumed to be the primary mode of potential structural failure for this risk assessment. Flooding depths presented in the following sections are based on maximum modeled depths of tidal inundation, assuming shoreline structures remain stable throughout the flooding and overtopping event. However, the extent of potential structural failure caused by overtopping is noted in an effort to characterize differences in severity of events.

7.3 Impacts to Critical Resources

Flood impacts to critical resources vary throughout the study area based on exposure to tidal and/or fluvial flooding. A general overview of the magnitude of potential impacts, from initial to most severe, for tidal water levels ranging from 9.9 to 11.6 feet (NAVD) are shown in Exhibits 7-1 – 7-3. More detailed impacts to critical resources are provided in the tables at the end of each Hazard Scenario.

As flooding is initiated with water levels of 9.9 feet (Exhibit 7-1), the initial flooding impacts are limited to the Eureka Slough shoreline (Cell I) where critical resources are located at relatively low elevations along the natural shoreline; in Cell G and E where one to three residential structures are affected; and at roadway access points to Brainard and Murray Field within Cell A. Potential levee failure due to overtopping is limited to short sections protecting Cells B, C, G and E.

As water levels increase from 9.9 to 10.6 feet, the extent and magnitude of impacts increases in all cells (Exhibit 7-2). Shallow flooding occurs in Cell A, in the vicinity of Jacobs Avenue, and more severe flooding affects Highway 101, Murray Field and other developed areas. Development along the Eureka Slough shoreline in Cell I continue to be affected with deeper flood depths. Cells B through G see increased flood depths but are sparsely populated, with agricultural lands exhibiting shallow to multiple feet of tidal flooding. Overtopping and potential levee failure is more widespread and affects all cells.

Further elevated water levels, from 10.6 to 11.6 feet, results in widespread flooding of multiple feet on roadways, developed areas, agricultural areas, and transportation routes, resulting in the most severe impacts due to flooding. The potential for levee failure also increases significantly, with multiple locations of potential failure in each cell.

7.4 Consequences and Risk

For the purpose of this qualitative risk assessment, public health and safety and economic consequences resulting from flooding and impacts to critical resources in the study area were evaluated. A detailed analysis is provided in Appendix E. A summary of criteria evaluated and key findings is provided below.

7.4.1 Public Health and Safety

Four consequence criteria and associated thresholds were developed for public health and safety, including: the potential for death or injury due to flooding of residences and business; potential for death or injury due to flooding of ingress, egress, and travel ways; potential exposure to sewage or hazardous sites that expose populations to vectors for illness; and the affected population’s access to resources during and following a flood event. Consequence criteria and associated thresholds are presented in Table 9.

Table 9. Consequence Criteria and Thresholds of Public Health and Safety Risk

Consequence Criteria		Thresholds		
		Initiation	**Increasing**	**Most Severe**
Health & Safety	**Death or Injury** Due to Flooding of Residence or Business	<u>Potential Nuisance</u> < 1 foot flooding, Development at Higher Elevation, Few Residences/ Businesses	<u>Potential Injury</u> 1-4 feet Flooding, Development at Higher Elevation, Many Residences/ Businesses	<u>Potential Death</u> > 4 feet Flooding, Rapid Flooding, Development at Lower Elevation, Many Residences/ Businesses
Health & Safety	**Death or Injury** Due to Disrupted Ingress, Egress, Hazardous Conditions	<u>Potential Nuisance</u> Multiple Evacuation Routes Upgradient, Shallow Roadway Flooding < 3 inches	<u>Potential Injury</u> Limited Routes, 3-12 inches roadway flooding, Dangerous Conditions	Potential Death No Routes due to Road Closure and Dangerous Conditions, > 1 -2 feet roadway flooding
Health & Safety	**Potential for Illness** Due to Exposure to Sewage, Hazardous Sites, Disruption of Utility Service	<u>Potential Unknown Exposure</u> No Known Exposure Source, Continuous Utility Service	<u>Potential Illness</u> Exposure to Single Known Source, Temporary Disruption of Utility Service, many residences/business	Likely Illness Exposure to Multiple Known Sources, Long-term Inaccessibility of Utility Services, many residences/business
Health & Safety	**Potential for Displacement/ Homelessness** Due to Lack of Resources Following Event	<u>Likely Recovery</u> Disadvantaged/Low Income, < 1 foot flooding	<u>Temporary Displacement</u> 1-4 feet Flooding, Disadvantaged/Low Income Community	Long Term Displacement/ Homelessness > 4 feet Flooding, Disadvantaged/Low Income Community

7.4.2 Economy

Economic risk due to flood events was evaluated based on three consequence criteria and the associated thresholds of impact, including: potential loss of economic services and deliveries; loss of commercial structures, goods, services and jobs; and loss of agricultural lands, goods, services and jobs. Consequence criteria and associated thresholds are presented in Table 10.

Table 10. Consequence Criteria and Thresholds of Economic Risk

Consequence Criteria		Thresholds		
		Initiation	**Increasing**	**Most Severe**
Economy	Loss of Economic Services & Deliveries	Disruption of Local Services Local Road Flooding	Disruption of Community Services Arterial and Collector Road Flooding	Disruption of Regional Services Interstate, Freeway/Expressway Flooding
	Loss of Structures, Goods, Services & Jobs	Disruption of Services < 1 foot flooding, Gradual Flooding, Few Structures	Temporary Closure 1-4 feet Flooding Gradual to Rapid Flooding, Many Structures	Long Term Closure > 4 feet Flooding Rapid Flooding, Many Structures
	Loss of Agricultural Lands, Goods, Services & Jobs	Brief Disruption of Land Use < 1-day tidal flooding, No to Minor Loss	Temporary Disruption to Land Use 1 day to 1-week tidal flooding, Potential Longer-term Recovery of Lands	Permanent Change to Land Use > 1-week tidal flooding/High Potential for Breach, Loss of Land Use

7.5 Key Findings

The qualitative assessment of the likelihood of hazardous flood events and the magnitude of the consequences presented above and in Appendix E provides decision-support information to assess risk and identify locations for further investigation and investment in developing adaptation strategies. Key findings from the qualitative risk assessment with regards to public health and safety and the economy are outlined below and shown in Exhibit 7-4.

Finding #1 - Most Severe Consequences

The likelihood of flooding to Cell A is generally less than some other cells, but the magnitude of consequences are consistently much greater than other cells. Cell A consistently exhibits the most severe potential consequences to public health and safety and the economy. These consequences are typically associated with flood events considered to have moderate to low likelihood. The primary contributing factors to the evaluation of most severe consequences is 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; the 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. Populated areas of Cell A, including the Jacobs Avenue area, and Highway 101 are considered to exhibit the greatest risk in the study area, due to the number of people, structures, and transportation facilities impacted by flooding.

Similar to Cell A, Cell I contains higher density development and infrastructure, but at higher elevations. However, initial impacts begin at higher likelihood events compared to Cell A due to the natural shoreline elevation along Cell I, which is not protected by levees. The result is that consequences are typically less severe than in Cell A.

Finding #2 - Utility Disruption

The water supply pipeline for the City of Eureka and other major utilities such as PG&E's natural gas pipeline and overhead electrical power lines are protected by levees in Cells C and G. In the event of a levee breach, which may occur during a moderate likelihood event, access to these utilities would be severely limited. In the event of a failure of a utility line without rapid reconstruction of the levee, maintenance on the utilities may not be feasible without substantial additional cost, leaving large populations vulnerable to the loss of utility services. Based on the moderate likelihood and severe consequence of losing these facilities, the risk to these facilities is high.

Finding #3 - Flooding with Fewer Impacts

Cells B through H are primarily managed for agriculture, with sparse development and at higher elevations compared to Cells A and I. While flooding is initiated during more likely events, the consequences are not as severe as in Cells A and I, as agricultural lands may be temporarily inundated with tidal water and can recover overtime with rainfall infiltration and few residences, businesses, and transportation routes are impacted.

8. CONCEPTUAL ADAPTATION PROJECT DEVELOPMENT

8.1 Introduction

This chapter discusses project concepts and technical studies that could help increase sea level rise resiliency within the study area. Project concepts must be consistent with the vision statement, key assumptions, and guiding principles (Section 1.5 and 1.6) that comprise the foundation of the planning framework for sea level rise adaptation in this study. This study assumed that the Highway 101 corridor will be adapted in its present location over a long-term planning horizon. Starting construction in 2022, the Indianola Interchange project will elevate a portion of Highway 101 above the Indianola intersection. The Eureka Slough Bridge replacement project is currently scheduled to start construction in 2028. Further planning will be needed to assess the appropriate adaptation approach for the sections of at-grade roadways within other areas of the Highway 101 corridor. This topic is expected to be further addressed in Caltrans' Phased Adaptation Plan to be prepared by 2025.

8.2 Adaptation Project Considerations

The following sections provide more detailed discussion of how two guiding principles can inform project planning and design.

8.2.1 Multi-benefit Projects and Nature-Based Solutions

Guiding principle no. 6 specifies the intent to maximize multi-benefit projects and nature-based solutions. Multi-benefit projects have the potential to address multiple problems with a single, integrated solution. With respect to increasing sea level rise resiliency, a multi-benefit project might concurrently protect critical infrastructure, reduce current and future flood risk, improve roadway safety, and enhance natural ecosystem processes, among other potential benefits. Multi-benefit projects could combine or singularly apply nature-based (green) approaches and conventional physical (gray) infrastructure approaches (e.g., sea walls, rock riprap, etc.).

Nature-based approaches emphasize physical landscape features and environmental processes that provide coastal protection. Nature-based approaches can be naturally occurring or designed to mimic natural processes. Examples include salt marsh and wetland restoration and creation, geomorphic processes that promote sediment management, and dune expansion. Nature-based approaches to coastal resiliency can require a longer-term timeline (decades) to produce measurable outcomes and typically require larger project footprints.

Comparatively, gray infrastructure is constructed for coastal protection with minimal consideration of natural processes. In a coastal environment, the footprint of gray infrastructure can result in permanent environmental impacts, such as the fill of wetlands, but typically require a smaller footprint than nature-based approaches. Construction and repair of gray infrastructure can result in immediate benefits to coastal resiliency, such as flood risk reduction or infrastructure protection.

Both nature-based approaches and gray infrastructure have spatial footprints. These footprints typically change the character of environmental resources by either reducing habitat or changing habitat type. Even a nature-based measure such as a horizontal levee with salt marsh habitat has unavoidable tradeoffs by changing the character of the land it's constructed on. While this may confer certain environmental benefits, this conversion has to be addressed and determined to be appropriate. Gray infrastructure tends to have a smaller project footprint but typically results in a permanent loss of natural habitat.

Nature-based and gray infrastructure concepts can often be combined as a hybrid solution to most-effectively address sea level rise and related concerns. As a common example, a living shoreline can include an engineered interior composed of large rock armoring or compacted earthen material with exterior designed to support salt marsh and other natural habitats. Concepts that combine nature-based and gray infrastructure concepts have the potential to offset and balance potential environmental impacts and achieve results on a shorter-term timeline.

Multi-benefit projects and nature-based solutions are most likely to broaden the ecosystem services associated with or provided by an adaptation project. Ecosystem services are benefits that people obtain from natural ecosystems. Ecosystem services are broad and range from primary production and biodiversity to supporting the products people consume, such as seafood (AECOM and SFEI 2020). Key regulating ecosystem services include fundamental processes such as carbon sequestration, wave attenuation, stormwater retention, flood regulation, groundwater recharge, coastal protection, erosion control, sediment-related processes, water filtration, and nutrient removal (AECOM and SFEI 2020). Table 11 provides a summary of ecosystem services that can be considered in adaptation project development.

Table 11. Ecosystem Services Considered in Adaptation Project Development[1]

Ecosystem Service	Key Considerations and Examples
Coastal Protection	Marshes, terrestrial-estuarine transition zones, and oyster reefs can provide coastal protection by reducing wave height and energy during storm surges, dissipate and store flood waters, and reduce erosion by stabilizing shorelines.
Habitat	Increasing habitat connectivity by expanding tidal marshes and tidal channels increases climate change resiliency for native plant communities and wildlife.
High Tide Refugia and Transition Zones	Transition zones and high tide refugia allow habitats to slowly migrate. For example, living shorelines or horizontal levees can provide a transition zone for tidal marsh migration over time to avoid mudflat conversion.

Ecosystem Service	Key Considerations and Examples
Stormwater Retention	Wetlands increase flood storage capacity to reduce flooding and reduce peak flows during storms. Within the Humboldt Bay watershed, naturally occurring wetlands have been significantly reduced over time due to development.
Water Filtration and Water Quality	Tidal marshes remediate contaminants from terrestrial runoff and pollutants. Some salt marsh plants can uptake nutrients and pollutants in their plant tissues to reduce pollutants that would other enter bays and estuaries.
Carbon Sequestration	Tidal marshes are net carbon sinks and remove greenhouse gases. Maintaining existing tidal marshes will maintain carbon stores and prevent future release of sequestered carbon.
Socio-Cultural Services	Recreation and nature study occur on shorelines around Humboldt Bay. Culturally sensitive resources are also scatted around the Humboldt Bay shoreline.
[1] Adapted from Dumbarton Bridge Resilience Study (AECOM and SFEI 2020)	

8.2.2 Prudent Short-term Actions with Adaptive Capacity

Guiding principle no. 7 specifies the need for prudent short-term actions with adaptive capacity to improve resiliency. Adaptation projects have been developed under an incremental approach that combines short-term actions to reduce immediate risk along with long-term actions to address future conditions, which cannot be accomplished with one project alone. Tidal flooding and extreme wind and wave events in Humboldt Bay along with fluvial flooding are expected to increase in the decades and centuries to come, both in magnitude and duration. As such, these challenging conditions will continue to evolve throughout and beyond the useful life of adaptation projects. The useful life of gray infrastructure can vary significantly from <20 years to >100 years depending upon the design criteria. This assumed period for project life affects design decisions such as maximum elevation, maximum drainage capacity, environmental impacts, cost, and construction techniques.

Episodic physical changes can result from extreme storm events, such as substantial sediment deposition or severe erosion of shorelines and shoreline protection infrastructure. To help account for these significant yet difficult to predict changes of conditions, development of resiliency projects during the planning phase should consider the project’s adaptive capacity, which relates to the capacity of the proposed project to accommodate or adjust to potential damages from extreme events. Additionally, adaptive management plans could be developed for projects that provide a framework for long-term monitoring and maintenance following project implementation. A critical challenge with adaptive management is that ongoing funding will be needed and funding sources for this work may be limited. Projects that include longer-term monitoring and maintenance provisions as well as consideration of initial over-design (e.g., designing in excess of anticipated contemporary maximum flood requirements) of drainage capacity and flood protection during initial project development and construction could ease challenges to future project repairs or modifications, including regulatory approvals that would be required for future project modifications, expansion, or repair. Project cost and future savings must also be considered when evaluating adaptive capacity and application of adaptive management plan.

8.3 Adaptation Project Needs

In Section 6 (Hazard Scenarios), the highest at-risk critical resources were identified, including Highway 101, Jacobs Avenue, existing levees, private property, and critical utilities. These resources were evaluated with respect to inundation pathways and the potential duration, magnitude, and spatial extent of flooding and erosion related to tidal and fluvial flooding. Under each evaluated hazard scenario, numerous critical at-risk resources in Cell A were identified. Cell A, which includes Eureka Slough to Bracut along the Highway 101 corridor, has the highest potential for high magnitude consequences resulting from sea level rise. Cell A includes the Jacobs Avenue higher density development, Highway 101, and critical utilities. Thus, potential adaptation project development focused on efforts that would have the greatest flood risk reduction benefit to Cell A.

Within Cell A, an adaptation project would need to increase resiliency for transportation infrastructure, the Jacobs Avenue area, and critical utilities. Such adaptation measures would need to consider different scales – spatial and temporal – and integrate multiple layers of project planning, jurisdictional coordination, and multi-jurisdictional approvals. Opportunities within Cell A include existing landforms and infrastructure that currently serve as shoreline protection features, including but not limited to rip rap along the Humboldt Bay shoreline, the NCRA railroad prism, Highway 101 road prism, mudflats and wetlands, storm drainage infrastructure, and network of levees. These existing shoreline protections could be augmented, expanded, and redesigned to provide increased coastal resiliency in the future, as part of adaptation projects.

8.4 Adaptation Project Development

This section describes the process applied in developing the adaptation projects which included both stakeholder input and an evaluation of planning horizons and tipping points.

8.4.1 Stakeholder Input

Hazard Scenarios were presented to the stakeholders at the March 12, 2020 workshop. Stakeholder input following the March 12, 2020 presentation emphasized key needs and priority high risk areas, such as Cell A. The City of Eureka, County, and Caltrans provided initial feedback, emphasizing the need for specific adaptation project concepts and studies. These projects and studies are summarized in subsequent sections of this plan. Following the March 12, 2020 stakeholder meeting, the COVID-19 pandemic curtailed additional private landowner outreach and slowed stakeholder collaboration. A summary of the Stakeholder outreach associated with the development of this plan is provided in Section 10.

8.4.2 Planning Horizons

Following the March 12, 2020 stakeholder workshop, potential projects and studies identified by the stakeholders were grouped into two planning horizons, 1) current- through mid-century, and 2) mid- through late-century and beyond. Notably, long-range sea level rise planning comes with high uncertainty (DeAngelis et al. 2019, Stephens et al. 2018). Within the long-range planning horizon, adaptation thresholds, also known as adaptation tipping points, can be used in sea level rise planning. As described in DeAngelis et al. (2019), an adaptation tipping point occurs when the present pathway is no longer effective in meeting objectives and a new action or pathway is necessary.

Near-term Opportunities and Measures. Given the protective barrier function the railroad and Highway 101 provide to critical resources and mixed land uses with overlapping jurisdictions, adaptation planning is challenging. For example, elevating Highway 101 onto a viaduct would increase flood and/or wind-wave erosion risk throughout properties within and adjacent to Cell A, amplifying impacts from sea level rise. While this will remain a potentially viable option in a late century and beyond planning horizon, there are multiple short-term measures that Caltrans and other resource managers can take to incrementally reduce flood risk and extend serviceability of Highway 101 while minimizing impacts to adjacent properties. These measures have been identified as either projects or studies that should be completed in the near-term planning horizon.

Long-range Opportunities and Measures. Landscape transitions could create future opportunities for long-range adaptation projects. Several feet of sea level rise will likely impact agricultural productivity due to elevated groundwater levels, saltwater intrusion, and reduction in drainage efficiency. This is already occurring in low elevation diked former tidelands north of Indianola Cutoff where Caltrans recently acquired an inundation easement. While levees can be elevated to prevent overtopping in the short-term, by the mid/late century, vegetation composition within flood cells is anticipated to transform to less productive wetland species unless improved drainage and pumping systems are implemented in combination with levee improvements. Agricultural wetlands will also convert to brackish wetlands through increased occurrence of saltwater intrusion, which will also be incompatible with agricultural production. Drainage and pumping systems pose long-term cost and maintenance implications that may render the current land uses infeasible. With projected increases in sea levels, a tipping point may be reached that results in decreased value of these lands for agricultural purposes over time. However, as a result of this anticipated tipping point, these properties may be more compatible with restoration or mitigation needs in the future than they are at present. This may provide opportunities for Caltrans and others to collaborate with Cell A landowners and develop adaptive measures and pathways focusing on short-term drainage and flood storage improvements that remain compatible with current land uses, while initiating longer range planning for land use transitions.

8.4.3 Integration with the Caltrans Sea Level Rise Planning Process

This plan does not explicitly focus on Highway 101, although it does aim to be compatible with ongoing sea level rise planning associated with the corridor as well as adaptation projects that would involve Highway 101 and related Caltrans facilities (e.g., tide gates and drainage infrastructure). The Caltrans District 1 sea level rise planning process is underway, with an adaptation plan due to the California Coastal Commission in 2025. This report is intended to be a resource that can be utilized by Caltrans as they develop their plan. Short-term projects identified in this plan are intended to be compatible with a range of future adaptation planning scenarios Caltrans may ultimately develop for the Highway 101 corridor and other land uses within Cell A. These short-term projects can be referenced in or integrated with the Caltrans District 1 sea level rise plan currently under preparation.

8.5 Recommended Studies and Project Concepts

This plan focuses on two planning horizons: a near-term horizon that includes current conditions through mid-century and a long-term range horizon that includes mid- to late-century. Near-term strategies include technical studies required to develop the foundation for future sea level rise adaptation efforts and specific project concepts that increase resiliency of existing infrastructure and reduce flood risk, such as improvements to existing levees, lines of defense, and drainage infrastructure. The long-range planning horizon includes more substantial projects, such as elevating critical roadways and relocating essential public services infrastructure and utilities.

The following sections describe strategies developed for each planning horizon and define potential project concepts for each horizon that would achieve these strategies. Suggested studies to advance understanding of vulnerabilities are also identified. Identified studies would help fill data gaps and advance understanding of physical processes and landscape response to sea level rise. Many project concepts warrant further study, data collection, and synthesis to assess feasibility. Note this plan should be considered a living document and can inform future capital improvement plans and related planning processes. Project concepts considered in the following sections should not be viewed as an exhaustive or static list.

8.5.1 Near-Term Planning Horizon: Current- to Mid-Century

Within the near-term planning horizon, predicted sea level rise rates are bound within a relatively narrow range. Studies identified below to support the near-term planning horizon should be completed to fill current data gaps and help advance informed decision making to support both short- and long-range project planning. Identified near-term projects include flood protection actions that provide protection for more frequent events and address sea level rise through mid-century. Most of the identified near-term project concepts warrant more focused study prior to implementation. The overall strategy for this planning horizon is described below.

Near-Term Planning Strategy

Based on the guiding principles identified in this report, two strategies were developed and applied to the near-term planning horizon: (1) maintaining serviceability and extending resource service life and (2) completing technical studies to develop the scientific foundation for long-range planning and adaptation.

The first part of the near-term strategy focuses on maintaining the serviceability of critical resources and implementing projects that reduce flood risk, extend resource service life and can demonstrate flexibility and adaptive capacity to sea level rise in the long-range planning horizon. This strategy focuses on extending the life of existing infrastructure through increased resiliency to reduce risk, minimize maintenance and repair cost, and reduce the potential for environmental impact. Project concepts may include repair, modification, or expansion of existing lines of defense and drainage infrastructure.

The second part of the near-term strategy focuses on advancing science and studies to inform decision making and investment in future projects benefiting near- and long-range planning horizons. Recommended technical studies are summarized in the following section.

Recommended Studies and Plans

The following studies and plans are suggested to inform adaptation planning and better define project concepts in both near- and long-range horizons.

1. **Develop a sea level rise adaptation plan for the Jacoby Creek hydrographic area** between Bracut and Arcata. The intent of this plan would be to evaluate the northern portion of the Highway 101 Corridor and use predictive and analytical methods similar to those applied and described in the current study. The scope of the Jacoby Creek plan could be adjusted based on lessons learned from the current plan. Combined, these two plans could provide supporting information to the Caltrans led final adaptation plan due to the California Coastal Commission by 2025.
2. **Develop a sea level rise adaptation strategy for salt marshes near Eureka Slough**. As described in this study the ecosystem service benefits of flood risk reduction that salt marsh provides by attenuating wave energy and reduction erosion, especially when the marsh plain is high and wide. Salt marshes are vulnerable to sea level rise because elevations are dependent on sediment deposition, plant productivity, and subsidence. Salt marshes can keep up with sea level rise to a point with accretion of mineral and organic material, but their resilience will depend on geomorphic context and site-specific factors. If salt marshes are converted to mudflat, then the biodiversity, carbon sequestration, water quality benefits, and other ecosystem services will be lost. Strategies could be developed to preserve salt marshes and consider methods for increasing their resilience.
3. **Complete the required Highway 101 Corridor Phased Adaptation Plan - Caltrans** (Eureka Slough to Arcata). This plan is due to the California Coastal Commission in 2025 and could

utilize the information compiled in this report and any future or ongoing studies currently being led by Caltrans.

4. **Prepare an emergency response and preparedness plan for the Jacobs Avenue area**. This plan is intended to provide guidance on emergency response to an extreme flood event.

5. **Develop a guidebook for considering managed retreat as a sea level rise adaptation strategy.** This guidebook would identify practices and financial models being implemented in other coastal areas with a focus on tools, resources, and approaches that are most relevant for the Humboldt Bay region.

6. **Develop a feasibility study to assess Cell A flood and habitat management opportunities and constraints.** The purpose of this study would be to advance understanding of interior drainage interconnectedness, flood storage availability relative to Caltrans facilities, and CDFW's current freshwater management to inform future tidal marsh restoration/levee retreat and redundant tide gate opportunities. This study would provide the planning basis for near-term potential project concepts (5 and 6) below.

7. **Develop a feasibility study for the City of Eureka's water transmission lines and water mains**. The purpose of this study would be to provide an evaluation of measures to protect the parallel water mains in-place during the short-term verse rerouting in long-term. Options to evaluate could include improving Cell C perimeter levees, elevating water mains to a trestle system or into a new elevated earthen levee, or relocating along Myrtle Avenue or Highway 101 corridor.

8. **Expand the Greater Eureka Area Traffic Model to include the Eureka-Arcata Highway 101 corridor, Highway 255, and Myrtle Avenue/Old Arcata Road and run flooding scenarios.** The purpose of expanding the traffic model is to enable simulations that identify how traffic would be routed under various flooding scenarios. These results could be used to inform road improvement planning and contingency planning.

9. **Advance scientific and engineering studies** that improve understanding of landscape response to physical drivers and processes described in this plan. The following studies would help fill existing data gaps, improve areas of limited understanding, and inform decision making:

    a. Develop a two-dimensional (2D) hydrodynamic model of study area to evaluate geomorphic response (erosion) of slough channels associated with planned and un-planned levee breaches within the study area. The model would be used to evaluate breaches to flood basins, which can create adverse impacts to adjacent levees and critical resources, amplifying impacts to sea level rise.

    b. Advance a tidal sediment dynamics and sediment flux budget for the North Bay. This study is intended advance existing qualitative conceptual models to better quantify and understand erosion/sedimentation processes related to marsh plain/mudflat accretion and sea level rise. Re-connecting tidal exchange to subsided diked former tidelands will create sediment sinks, so understanding sediment supply and long-term accretion rates to achieve desired habitat types will be an important decision-making tool.

c. Continue salt marsh accretion monitoring along the east shore of North Bay to better predict future ecosystem services provided such as wave attenuation and opportunities for beneficial reuse of dredge spoils.

d. Implement levee and water control structure inspection program to monitor shoreline indicators of changed as described in this plan. Establish baseline conditions as basis for prioritizing future feasibility studies to assess locations to improve, retreat or remove levees.

e. Implement groundwater monitoring program in diked former tidelands and use collected data to advance a surface-groundwater coupled model to predict elevations and gradients associated with sea level rise.

f. Implement local vertical ground motion monitoring program to refine rates of relative sea level rise.

g. Implement and maintain long-term water level monitoring program to improve understanding of water level differences between North Spit and study area.

h. Implement wind-wave monitoring program to advance understanding of wave height and marsh plain attenuation.

Near-term Potential Project Concepts

The following project concepts are aligned with the overall near-term planning horizon strategy. Most project concepts will require additional studies to better define. During the planning phase of each project concept, resource manager(s) will need to determine design criteria based on acceptable level of risk, desired adaptability to adjacent future projects, service life, and cost.

1. **Natural Shoreline Infrastructure from Bracut to Brainard** (see Section 8.9)
2. **Jacobs Avenue Flood Resiliency** (see Section 8.10)
3. **Jacobs Avenue Levee Resiliency** (see Section 8.11)
4. **Implement Highway 101 safety, maintenance, and drainage improvement measures** by developing vegetation management and maintenance program to maximize stormwater storage and conveyance in Caltrans' existing drainage channels. Implement redundant cross-drains under Highway 101 between Brainard and Bracut to increase collection and conveyance of over-topping and stormwater to Cell A storage. Incorporate notification and traffic safety measures for overtopping events such as Changeable Message Signs (CMS) and moveable median barriers to allow 2-way traffic in the existing northbound lanes.
5. **Develop and implement habitat and flood management projects within Cell A based on outcome of feasibility studies**. The projects would align with the planning horizon strategy

and achieve common goals between CDFW, Caltrans, County of Humboldt, City of Eureka and other property owners and resource managers. These projects could include adding additional tide gates to Cell A to increase drain-off efficiency at low tides, thereby maximizing storage capacity for overtopping/impounded stormwater during high tides. New tide gates could be equipped with muted-tide gate regulators and/or habitat doors that improve fish passage and habitat connectivity while not diminishing flood storage capacity. The projects could also include elevating or stabilizing the CDFW Fay Slough Wildlife levees to maintain storage capacity or retreating levees to restore salt marsh habitat compatible with Cell A flood storage needs.

6. **Implement managed retreat** where such a transition makes sense and is supported by property owners. Managed retreat could include relocating development and facilities to higher ground, removing levees, rebuilding "setback" levees as appropriate, and converting the property to a more sustainable land use. Diked former tidelands have the potential for restoration back to intertidal habitat. One consideration for restoring diked former tidelands is the potential impact on erosion processes from expanding the tidal prism. The timeframe for implementing a managed retreat approach may extend into the long-range planning horizon.

7. **Increase flood resiliency of City of Eureka and Humboldt Community Services Districts vulnerable sewer collection and water distribution facilities.** Incorporate recommendations from City of Eureka Climate Readiness Plan (GHD 2020) into the Capital Improvement Program (CIP). The projects are anticipated to include:

    a. Construct a perimeter flood wall around Hoover Street Pump Station

    b. Relocate Ryan Creek Booster Pump Station up-slope

    c. Construct a perimeter flood wall around Y-Street and Jacobs Ave. sewer pump/lift stations

    d. Construct a protection berm around Tydd Street Sewer Lift Station consistent with Bay to Zoo Trail

    e. Reduce infiltration and inflow (I&I) potential to vulnerable gravity sewer collection lines by slip lining using trenchless technologies, elevate manholes and re-direct the collection system as needed.

8.5.2 Long-range Planning Horizon: Mid- to Late-Century and beyond

Uncertainties increase within the long-range planning horizon, which includes more than three feet of sea level rise. Potential impacts and future conditions are described below and are more speculative than the near-term horizon. Based on the hydrodynamic model results and evaluated hazard scenarios (see Section 6 - Hazard Scenarios), it is anticipated that approximately 3 feet of sea level rise will result in widespread overtopping of existing levees unless the levees are elevated and maintained during the near-term planning horizon. Modeling results also indicate that cells with maintain perimeter levees are anticipated to experience impeded interior drainage as favorable hydraulic conditions to drain-off during low tides will diminish and pump stations will be needed. Furthermore, model results predict that cells reliant on agricultural land uses will likely experience diminished drainage and elevated groundwater that could alter the species composition and viable agricultural practices.

The following questions and uncertainties make planning for this horizon difficult:

- The rate of relative sea level rise and landscape response is highly variable and site-specific (i.e., mudflat/marsh accretion rates and groundwater gradients).
- The landscape response to physical processes described in this report from extreme storm events are estimates. How will extreme event(s) alter the shoreline and were emergency response interventions made that alter various adaptation pathways?
- How will the dependency on current land uses and the demand for critical resources change over time?
- Will critical resource managers risk tolerance increase or decrease overtime based on changes in landscape response and land uses?

The following section describes potential long-range projects which are difficult to define given the above uncertainties.

Long-range Planning Strategy

The long-range planning strategy will build upon the outcomes of current- to mid-century studies to inform adaptation project prioritization and implementation. These studies will include their own conclusions and recommended next steps based on current conditions at the time, updated projections for increases in sea level rise, and the future environmental and regulatory settings.

The long-range strategy will also include projects that extend the service life of critical resources to the extent practical and transition land uses that accommodate sea level rise through a strategic and managed retreat approach compatible with adjacent and interconnected landscapes. Long-range projects are more likely to involve more substantive infrastructure projects, such as elevating portions of Highway 101 and Myrtle Avenue and relocating critical utility infrastructure that can no longer be protected in place through adaptive measures.

Long-range Potential Project Concepts

The following project concepts are aligned with the overall long-range planning horizon strategy. Most projects will require substantial studies to better define and further clarify the uncertainties and questions identified above.

1. **Elevate southbound Highway 101** and the proposed Humboldt Bay South Trail between new Eureka Slough Bridge and Brainard shoreline (minimum elevation 15 feet). Also elevate southbound Highway 101 between Brainard and Bracut compatible with the planned Indianola Interchange. The elevated height will depend on the outcomes of the proposed studies.

2. **Reduce dependency on Cell A flood storage capacity** and elevate northbound Highway 101 as needed. Given the interconnected interior drainage system of Cell A, during overtopping events the flood storage capacity is essentially shared across multiple low-lying property owners within the Cell. Elevating Highway 101 can reduce the risk of roadway flooding from flood/overtopping sources on adjacent properties within Cell A.
3. **Adapt or add horizontal levee(s)** (salt marsh transitions) in areas absent of bayward marsh along Highway 101 to reduce wind-wave exposure and maintain pace with sea level rise.
4. **Install pump stations** as needed along Highway 101 to manage excess wave overtopping.
5. **Elevate Myrtle Avenue** to maintain redundant transportation/utility corridor. The timing and design criteria would need to consider future dependance on other transportation corridors (Highway 101 and Highway 255) and utility corridors. Subsequently, evaluate relocation of PG&E, fiber optic utilities, and the City of Eureka's water main to Highway 101 or Myrtle Avenue.
6. **Develop fluvial flood/sediment management strategies** for agricultural cells with fluvial sediment sources such as Cell C1 to passively accept sediment to elevate ground to extend use and prepare for long-term agricultural-estuarine conversion. These concepts should be considered during the development of the proposed City of Eureka water transmission line feasibility study during the near-term planning horizon.
7. **Implement managed retreat** as described in Section 8.5.1.

8.6 Project Concepts Screening and Selection of Four Adaptation Projects for Detailed Evaluation

The scope of work for this study included the selection of at least four project concepts for more detailed evaluation of flood reduction benefits and to test the benefit-cost assessment methodology. Through the adaptation project planning process, Cell A was identified as having the greatest need for increased sea level rise resiliency. Thus, potential near-term project concepts in Section 8.5.1 were narrowed to those located in or benefiting Cell A. Subsequently, the list of near-term project concepts in Cell A were narrowed to those that best met the screening criteria listed below and were selected for further development in this plan. Screening criteria included prioritizing project concepts that:

1. Reduce flood potential to high-risk Cell A critical resources including transportation infrastructure
2. Demonstrate compatibility with a range of future adaptation planning scenarios for the Highway 101 corridor and other land uses within Cell A
3. Show cost viability and regulatorily feasibility
4. Address near-term planning horizon and can be implemented within approximately 5-20 years

5. Increase resiliency for the 66% chance sea level rise projections over the estimated project life and can be adaptable to 0.5% chance projections
6. Provide a basis for future supporting studies and preliminary design phases.

The Humboldt Bay Trail South project (“Project 1”) was selected for detailed evaluation because it was already in progress and the hazard scenario information from this study was used to inform the design. In addition, three project concepts were selected for more detailed evaluation based on the screening criteria presented above:

Project 2: Natural Shoreline Infrastructure (Bracut to Brainard)

Project 3: Jacobs Avenue Flood Resiliency

Project 4: Jacobs Avenue Levee Resiliency

Conceptual designs were developed for Projects 2, 3, and 4. These conceptual designs were developed for evaluation purposes only to gain useful information and do not imply a commitment to implement the projects. The four projects are shown in Figure 28 and are further described below.

8.7 Opinion of Probable Construction Cost Estimating Methodology

Opinion of probable construction costs were developed for each of the four projects. For Project 1, the project cost was obtained from the Project Study Report and included right-of-way acquisition, engineering, environmental compliance and construction management. For Projects 2, 3 and 4, an order of magnitude opinion of probable construction cost estimate was developed for the conceptual designs including a 30% estimating contingency. An additional 25% for engineering design, environmental review, permitting and construction management was added to the construction cost. The expected accuracy for an order of magnitude cost estimate is +70% to -40%.

Construction costs associated with coastal adaptation projects are subject to variable site conditions such as a high groundwater, low strength soils, limited work periods and the presence of sensitive species. The risks associated with working in these environments are high and can influence bid prices. Project construction costs are also 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 makes no warranty, express or implied, that actual project costs will not vary from the provided cost. As the design and regulatory approval processes evolves for projects 2, 3 and 4, the costs will be better understood. For the purpose of this plan, a cost range was provided representing the project cost with and without the 30% contingency.

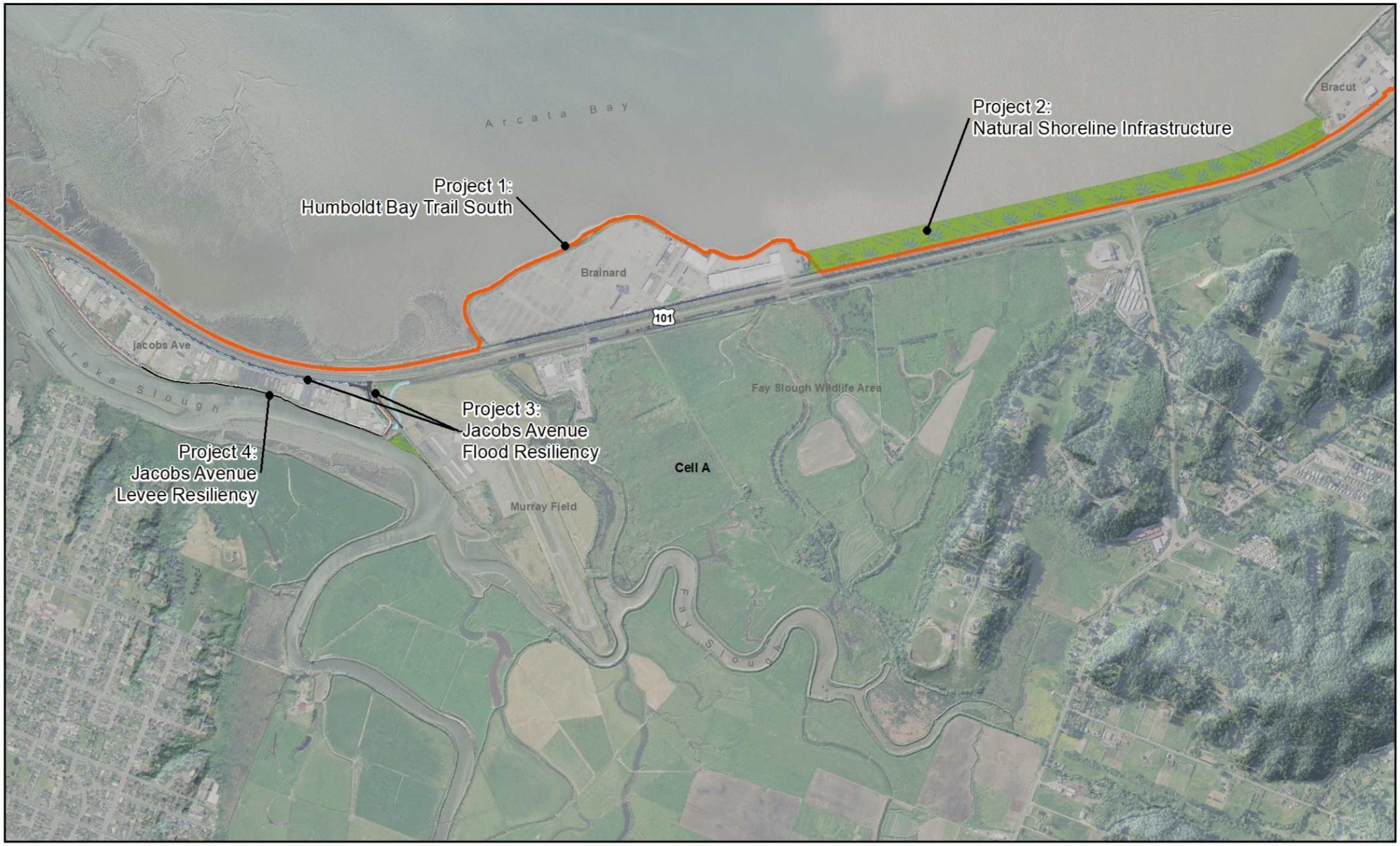


Figure 28. Project Concept Location

8.8 Project 1: Humboldt Bay Trail South

8.8.1 Description

Project 1 is currently in the final design and permitting phase. The project would construct approximately 4.25 miles of Class I multi-use trail to provide non-motorized transportation and recreational access along the Eureka-Arcata Highway 101 transportation corridor and connect the City of Eureka's Waterfront Trail with the southern terminus of the City of Arcata's Humboldt Bay Trail North. The trail would be paved to accommodate pedestrians, bicyclists, wheelchairs, strollers, and mobility devices. The majority of the trail would be ten feet wide (two five-foot bi-directional lanes) with two-foot gravel shoulders. The trail will include drainage facilities and measures for erosion control.

For a total length of approximately three miles, Project 1 would be constructed by widening the railroad prism and constructing the trail parallel to, and offset from, the rails. For the segments of railroad that have been damaged by flooding and erosion, Project 1 would repair and maintain the shoreline revetment, remove the rails, and raise the elevation of the rail prism to provide resiliency to flood hazards and sea level rise.

Approximately one mile of trail is proposed to be located on the perimeter levee around the Brainard mill site, with two new bridges providing connectivity between the railroad and levee trail sections.

8.8.2 Key Features

The trail design within the study area can be described by three typical cross sections, along three segments of shoreline: Eureka Slough to the Brainard mill site, the Brainard mill site, and the Brainard mill site to the southern end of Bracut (Figure 29).

The typical design from Eureka Slough to the Brainard mill site preserves the existing railroad prism with the trail constructed between the rail prism and highway on an imported fill embankment with a 10-foot-wide paved trail and 2-foot-wide gravel shoulders. The finished grade elevation of the trail is designed to be elevation 10.5 ft. The finished trail elevation is typically higher than the existing railroad prism and lower than the adjacent highway. The drainage system is located between the trail and the highway.

The typical design along the Brainard mill site utilizes the existing shoreline levee that typically ranges in elevation between 12 and 14 feet. The top of the levee will be graded with a continuous cross slope and import aggregate base placed to achieve a 4-foot gravel shoulder along the bay side of the levee with 8-foot wide paved trail and 1-foot gravel shoulders.

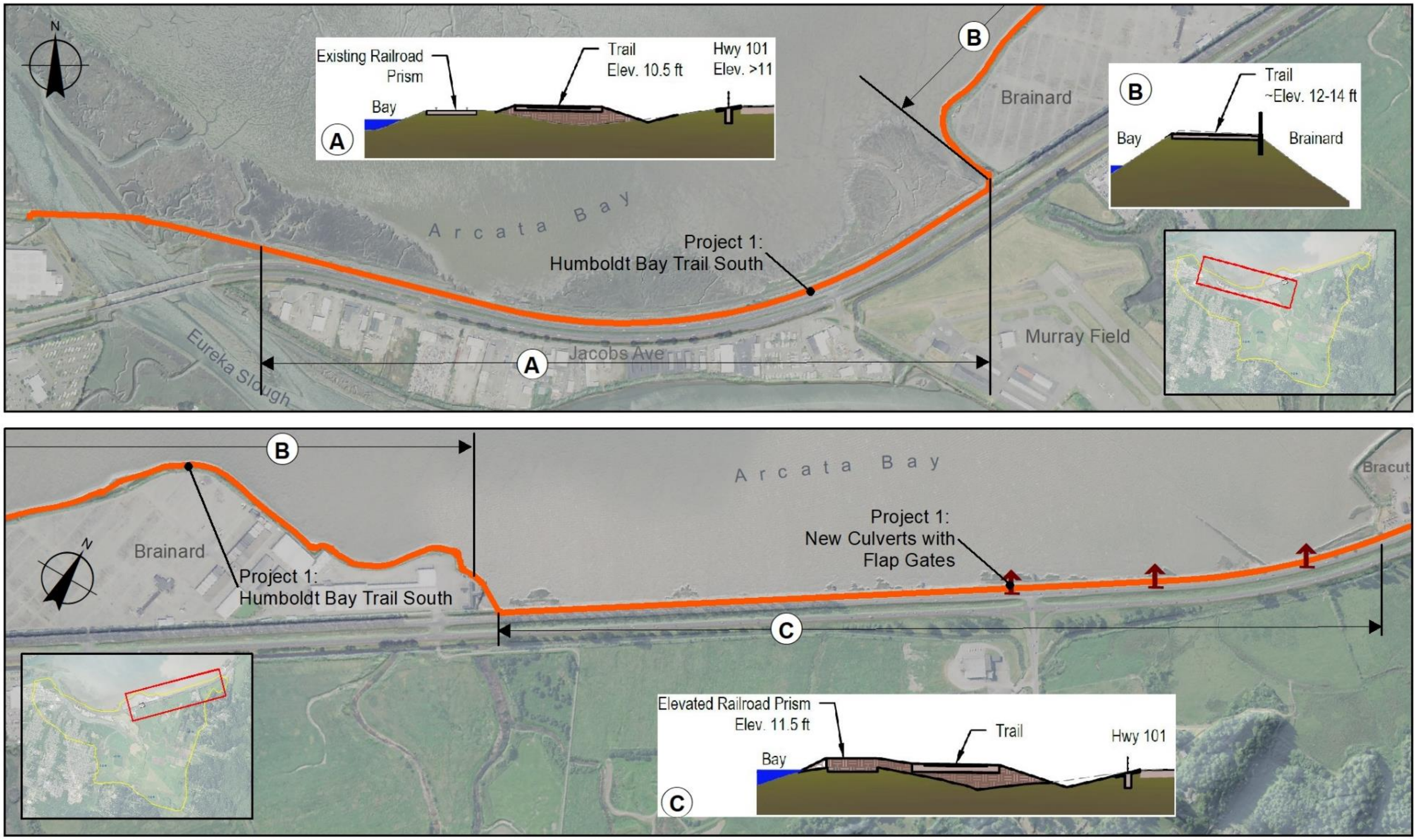


Figure 29. Project 1 Concept: Humboldt Bay Trail South

The typical design along the Brainard to Bracut segment uses imported fill for the trail embankment and to elevate the railroad prism. The trail is constructed between the rail prism and highway with a 10-foot-wide paved trail and 2-foot-wide gravel shoulders. The rail prism is elevated to elevation 11.5 feet and the bay-facing slope receives shoreline revetment in select locations where existing erosion is present. The drainage system is located between the trail and the highway and culverts with flap gates will be installed to convey flow from the drainage ditch to the bay, through the trail and rail embankment.

8.8.3 Benefits

Project 1 benefits are expected to include a significant increase in the number of non-motorized trips, improve safety, enhance public health, and promote community vitality in addition to flood reduction benefits. Project 1 would result in a continuous non-motorized trail from central Arcata to the southern end of Eureka, for a total length of nearly 14 miles. Completion of the link between the two largest cities in Humboldt County would provide a major step toward regional trail connectivity around Humboldt Bay. In recent years the Project has been Humboldt County's top priority for investing in active transportation and represents the greatest opportunity to enable a major mode shift in transportation within the county.

The existing bay shoreline, south and north of the Brainard mill site, exhibits some of the lowest shoreline elevations in the study area. From Eureka Slough to Brainard, the highway serves as the primary flood protection barrier, with minimum crest elevation of approximately 11 feet. With a proposed trail elevation of 10.5 feet in this segment, the highway will continue to serve as the primary flood protection barrier. The rail prism and trail will serve as the primary features to dissipate wave energy, reducing flooding of the roadway caused by wave overtopping.

The existing shoreline segment from Brainard mill site to Bracut serves as the primary flood protection barrier for Highway and Cell A, but is overtopped with still water events as low as 8.7 feet. ESA 2018 assessed wave runup, overtopping, and tidal flooding of multiple trail and rail elevations. Significant flood benefits are realized with the implementation of this project up to still water levels exceeding 11.5 feet, as the volume of still water overtopping affecting the Highway and interior lands of Cell A is significantly reduced. Most notably, at still water levels of 11.6 feet, flooding of Cell A is reduced from several feet to less than 0.25 feet in developed areas and the closure of all Highway 101 lanes is prevented. The primary source of still water flooding following implementation of this project is along Fay Slough.

Flood benefits of the project diminish with still water levels greater than 11.5 feet. At a water level of 12.6 feet, the volume of overtopping along other shorelines of Cell A and the rail prism result in several feet of flooding in Cell A, including Highway 101 and alternate routes around the bay.

The assessment of wave overtopping by ESA 2018 shows that the trail and rail embankments are subject to wind and wave exposure that results in wave overtopping during the 5- 10-year event. Average wave overtopping rates were calculated to be up to 1.1 cfs/lft at rail elevations of 11.5

feet. Assuming a duration of two hours, this overtopping rate would result in significant flooding to the interior of Cell A and closure of Highway 101 southbound lanes.

8.8.4 Opinion of Probable Cost

Planning for the Humboldt Bay Trail South project began in 2013 (County of Humboldt, 2020). This project is currently in the final design and permitting phase and a detailed opinion of probable construction has been developed. The total project cost is currently estimated to be $26 million, including pre-construction work (engineering and permitting) ($4 million), wetland mitigation ($5.6 million), and construction ($16.6 million).

8.8.5 Considerations for Next Steps

Project 1 was selected for this analysis based on the multiple benefits provided and adaptability and compatibility with future potential projects within and along the Highway 101 corridor. Project 1 is proposed to be constructed in 2022/2023, which provides the physical foundation for the construction of Project 2.

8.9 Project 2: Natural Shoreline Infrastructure (NSI)

8.9.1 Description

Project 2 consists of a horizontal levee that provides an ecotone slope extending bayward from the rail prism to the mudflat along the 1.25-mile segment between Brainard and Bracut. The purpose of the project is to reduce flood and erosion hazards by dissipating waves generated in Arcata Bay, while providing ecological benefits with a nature-based design that restores salt marsh. The project will protect the proposed Humboldt Bay Trail South (HBTS, Project 1), and also reduce wave exposure to Highway 101 located slightly landward. The project builds upon Project 1 that forms the landward boundary. A detailed memorandum of the conceptual design is provided in Appendix F and conceptual layout in Figure 30. A summary of the project is provided below.

8.9.2 Key Features

The conceptual design is intended to restore the historic salt marsh and provide for habitat transgression with sea level rise. The design will create three marsh zones: low, mid and high. The low-marsh is a 75-foot-wide slope that transitions from the existing mudflat elevation to the mid-marsh elevations, at a 20H:1V slope. Coarse sediment, marsh sill or shellfish reefs could be included in this reach to mitigate wave action. The mid marsh begins at MHW elevation and transitions to MHHW over approximately 100 feet. The mid-marsh dissipates locally generated wind waves and runup during most tides. Channels and ponds would likely develop throughout the mid-marsh over time. Elevations may be adjusted to compensate for relative sea-level rise and settlement. The high-marsh is a vegetated earthen slope connecting the mid-marsh at MHHW to the Project 1 grade of 11.5 feet at the railroad prism, over a 100-foot width. This flat slope is expected to dissipate wind waves during extreme high water levels and more frequent events with future sea level rise. A mix of native mid- and high-marsh and upland vegetation would be planted

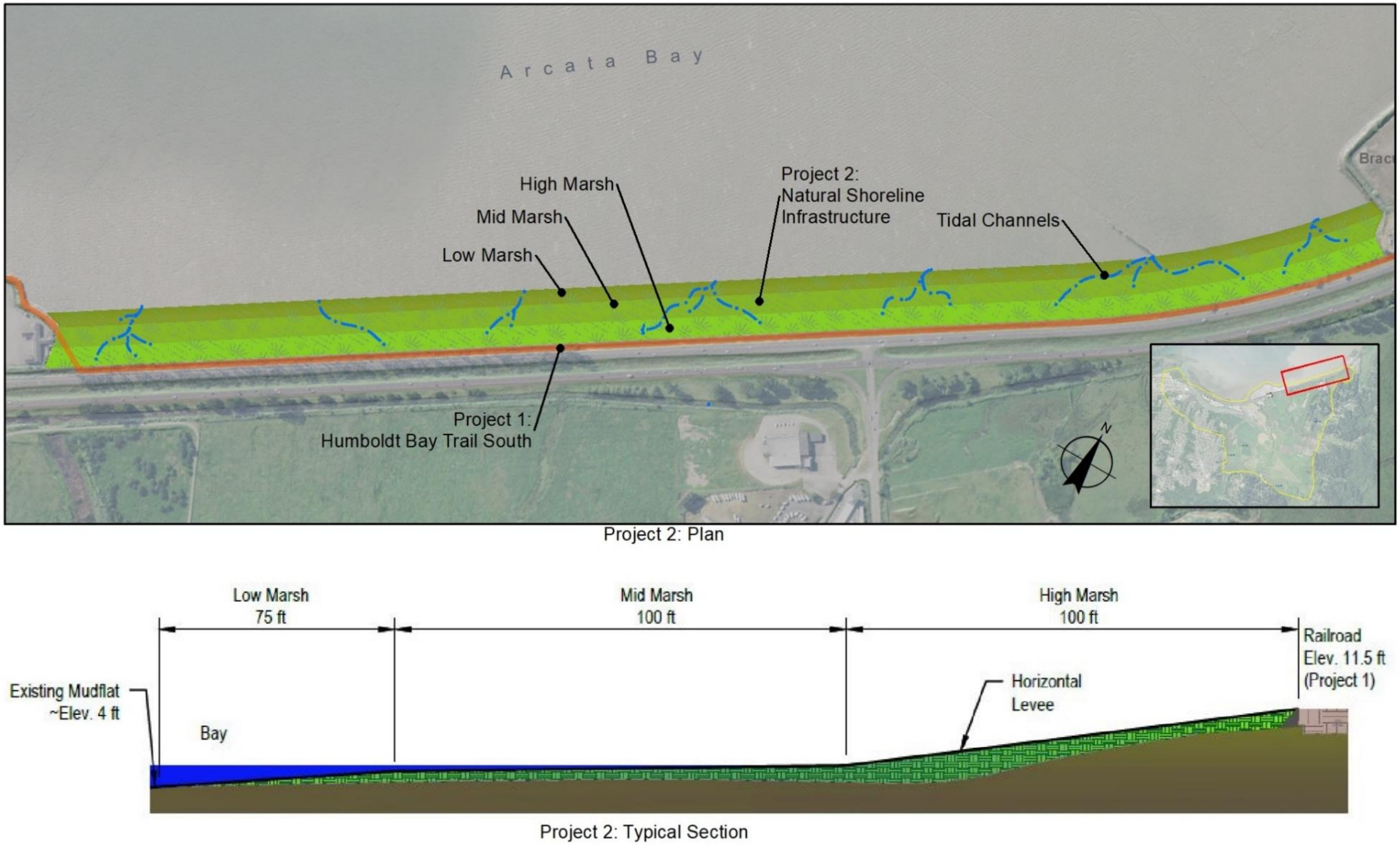


Figure 30. Project 2 Concept: Natural Shoreline Infrastructure

on the slope. With sea-level rise, mid-marsh would migrate into this zone. The long, gentle slope provided by the project will 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.

8.9.3 Benefits

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.

Project 2 improves wave dissipation and reduces wave runup and overtopping, thereby preventing wave erosion damages to the Project 1 embankment and flooding due to wave overtopping. Project 1 includes sufficient vertical fill to withstand static tidal water levels with up to 11.5 feet, but shoreline protection improvements proposed in Project 1 have an expected service life of 20 years, at which time, reconstruction or other adaptive measures will be required. Project 2 extends the service life of shoreline protection 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.

8.9.4 Opinion of Probable Cost

The current cost estimate range based on the conceptual design presented in Appendix F is $20-$29 million. The estimate includes preliminary construction cost with 30% contingency and 25% for planning, engineering, environmental compliance, and construction management. The ongoing separate study for this project will develop other alternatives and scaling options that are anticipated to achieve project goals at a likely lower cost.

8.9.5 Considerations for Next Steps

The County is currently leading a project assessing the feasibility of natural shoreline infrastructure between Brainard and Bracut with funding from the National Fish and Wildlife Foundation and Ocean Protection Council. The initial concept included in this plan will be one of multiple concepts considered. The study will be completed by the end of 2021 and is intended to identify feasible options and next steps in advancing the project.

8.10 Project 3: Jacobs Avenue Flood Resiliency

8.10.1 Description

Given the density of critical resources along Jacobs Avenue, Projects 3 and 4 were developed to provide incremental flood reduction benefit to the residences and businesses of Jacobs Avenue, beyond that provided in Projects 1 and 2. Projects 3 and 4 would increase flood resiliency for the Jacobs Avenue area in the short term and are intended to accommodate a range of future adaptation planning scenarios for the Highway 101 corridor and other resource lands within Cell A.

Project 1 would reduce overtopping potential along the bay shoreline of Cell A up to a still water elevation of 11.5 ft. Project 2 would reduce wind-wave energy and erosion potential along the bay shoreline between Brainard and Bracut, further reducing flood risk to critical resources within Cell A. While Projects 1 and 2 would reduce flood risk to the commercial and residential properties along Jacobs Avenue, levee overtopping along Eureka and Fay Slough levees remain as a flood pathway and exhibit conditions for potential levee failure above a still water elevation of approximately 10.6 feet. Because of the interconnected interior drainage system within Cell A, critical resources such as Highway 101, Murray Field Airport and Jacobs Avenue, are all at risk of flooding due to a levee overtopping and/or failure from the slough levees. Under current conditions, the crest elevations of the Fay Slough levee are generally lower relative to Eureka Slough levee backing Jacobs Avenue. Note, the hydraulic modeling conducted for the study area assessed both tidal and fluvial flood events. The results indicate that tidal events generate higher water levels relative to fluvial events for the same frequency (i.e., 100-year recurrence) within Eureka and Fay Sloughs. As such, flood risk was assessed in developing Projects 3 and 4 using the dominating tidal still water events.

Project 3 proposes to protect the densely populated Jacobs Avenue area from the flood risk associated with levee overtopping and more significant flooding due to levee failure along Fay Slough by creating an elevation barrier. The elevation barrier consists elevating Airport Road, increasing crest elevation of the historical rail prism/levee, and constructing a short section of new levee. The project would also improve the current stormwater drainage deficiencies and associated nuisance flooding along Jacobs Avenue in addition to stabilizing known eroded sections of the levee adjacent to Murray Field.

8.10.2 Key Features

Elevating Airport Road, modifying the crest elevation of the historical rail prism/levee and implementing a short section of new levee would connect the northbound Highway 101 fill prism to Jacobs Ave levee while maintaining access to all facilities. This action would also include realigning the existing Caltrans drainage system adjacent to Airport Road while maintaining the existing tide gate structure in place (Figure 31).

A section of the historical rail prism/levee adjacent to Murray Field is showing signs of active erosion, with over-steepened slopes and exposed soils. Repairs/stabilization measures are proposed along this section, consisting of rock slope protection within the original rail prism/levee

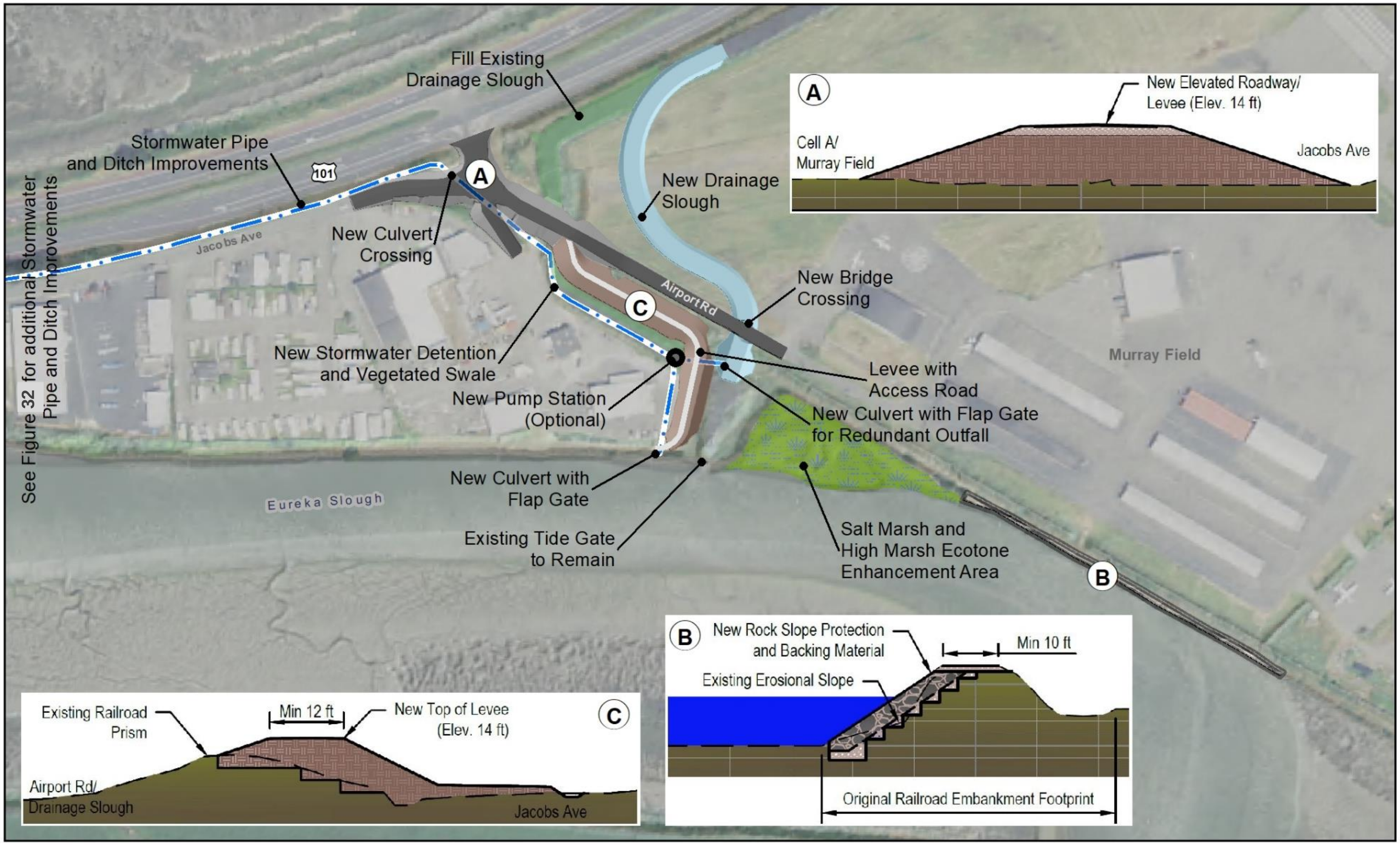


Figure 31. Project 3 Concept: Jacobs Avenue Flood Resiliency

footprint. Implementing stormwater drainage improvements (drainage inlets, pipes/ditches) along the Jacobs Avenue shoulder to collect and convey stormwater would also provide co-benefit of capturing Highway 101 median drainage during future overtopping of the roadway between Eureka Slough and the Brainard mill site. This action could also include stormwater pump station(s) to improve drainage efficiency during coincident rainfall and high tidal events depending on the design storm and timing of implementation. Salt Marsh enhancement is proposed in the depositional area where Jacobs Ave levee joins the historical rail prism/levee adjacent to Murray Field. Extending the creation of a salt marsh fringe along the Murray Field rail prism and Jacobs Avenue levee was considered however it is likely infeasible given the observed shoreline erosion, adjacent deep slough channel and high velocities.

8.10.3 Benefits

As stated above, the primary intent of Project 3 is to provide the Jacobs Avenue area protection from flooding due to overtopping and the potential failure of levee sections along Fay Slough. Failure of a levee section along Fay Slough would result in several feet of flooding throughout Cell A until repairs or temporary measures could be implemented. Project 3 improves ingress and egress availability for Jacobs Avenue, which would be limited for residents and businesses during flooding on Cell A. Project 3 provides flood protection for the Jacobs Avenue area up to a water level of 11.6 feet.

The disconnecting the hydraulic connection between the Jacobs Avenue area and the rest of Cell A provides expanded adaptation options for the rest of Cell A. Adaptation projects for Murray Field, the auto dealership, Fay Slough Wildlife Area, and Highway 101 are afforded more flexibility with the Jacobs Avenue area protected changes in drainage and flood patterns to the rest of Cell A.

Drainage improvements along Jacobs Avenue would reduce the depth and duration of flooding from rainfall runoff and minor overtopping, as this area is a continual issue for the residences, business owners, City of Eureka and Caltrans.

Repair of the existing historical rail prism/Murray Field levee would increase flood resiliency for this section of levee. The existing depositional area adjacent to the levee would be enhanced to create salt marsh, improving ecological benefit.

8.10.4 Opinion of Probable Cost

The current cost estimate, based on the conceptual design described above, is $9-$12 million. The estimate includes preliminary construction cost with 30% contingency and 25% for planning, engineering, environmental compliance, and construction management. Additional feasibility studies would improve the accuracy of this estimate.

8.10.5 Considerations for Next Steps

In the short term, preparation of an emergency preparedness plan for Jacobs Avenue is recommended. Identification of funding for a feasibility study that includes preliminary engineering studies is also needed to advance the project planning. The feasibility study would define design criteria based on levee owner risk tolerance, conduct hydrologic/hydraulic analyses of the stormwater system and perform additional sub-surface investigation to support levee improvements. Implementation of Project 3 would require coordination between Caltrans, City of Eureka, Humboldt County, and private landowners.

8.11 Project 4: Jacobs Avenue Levee Resiliency

8.11.1 Description

The purpose of this project is to increase the service life of the levee along Eureka Slough, that provides the primary flood protection of Jacobs Avenue residences and business. A preliminary needs assessment was completed that assessed four geotechnical modes of levee failure that include erosion, overtopping, seepage, and slope instability at various water levels and developed recommendations to improve resiliency (Appendix G).

Overtopping of the levees is considered to be the most likely risk, followed by underseepage, slope instability and lastly, erosion. Overtopping resulting in temporary flooding is initiated at water levels between 9.9 and 10.6 feet. Conditions for overtopping failure occur at a peak water level between 11.6 and 12.6 feet. Project 4 proposes levee improvements along Eureka Slough (Figure 32). The need for improved observation, inspection, and reporting of failure indicators (seepage, slope stability, overtopping, and erosion), supplemented with additional subsurface exploration are needed to further advance the existing conditions assessment and inform conceptual levee improvements.

8.11.2 Key Features

Due to the potential for significant flooding and levee failure associated with overtopping under existing extreme events and increased likelihood of these water levels with sea level rise, failure due to overtopping is considered the highest priority. A determination of levee crest elevations would need to be made during a future feasibility study based on an acceptable level of risk and cost. For the purpose of this plan, a levee crest elevation of 14 feet was used, which raises the existing west reach between 1.5 and 3.5 feet above the existing crest elevation. Two designs were considered for the nearly one-mile segment of levee. Earthen fill and relocation of the inboard drainage ditch is proposed along the western 2,000 linear feet of levee, from Highway 101 embankment at the Eureka Slough bridge to the County Corp Yard property. A sheet pile cut-off wall is proposed for the remaining 3,200 feet from the County Corp Yard property to the existing Caltrans tide gate structure (Figure 32). Both designs provide functionally equivalent results for reducing overtopping, seepage and slope stability failure and were selected based on available space and the location of existing structures. As part of the recommended next steps, a feasibility study can further evaluate seepage and/or other project components added to reduce seepage vulnerabilities such as drains with relief wells and sump pumps or seepage berms. A maintenance access road extends along the entire one-mile segment of levee.

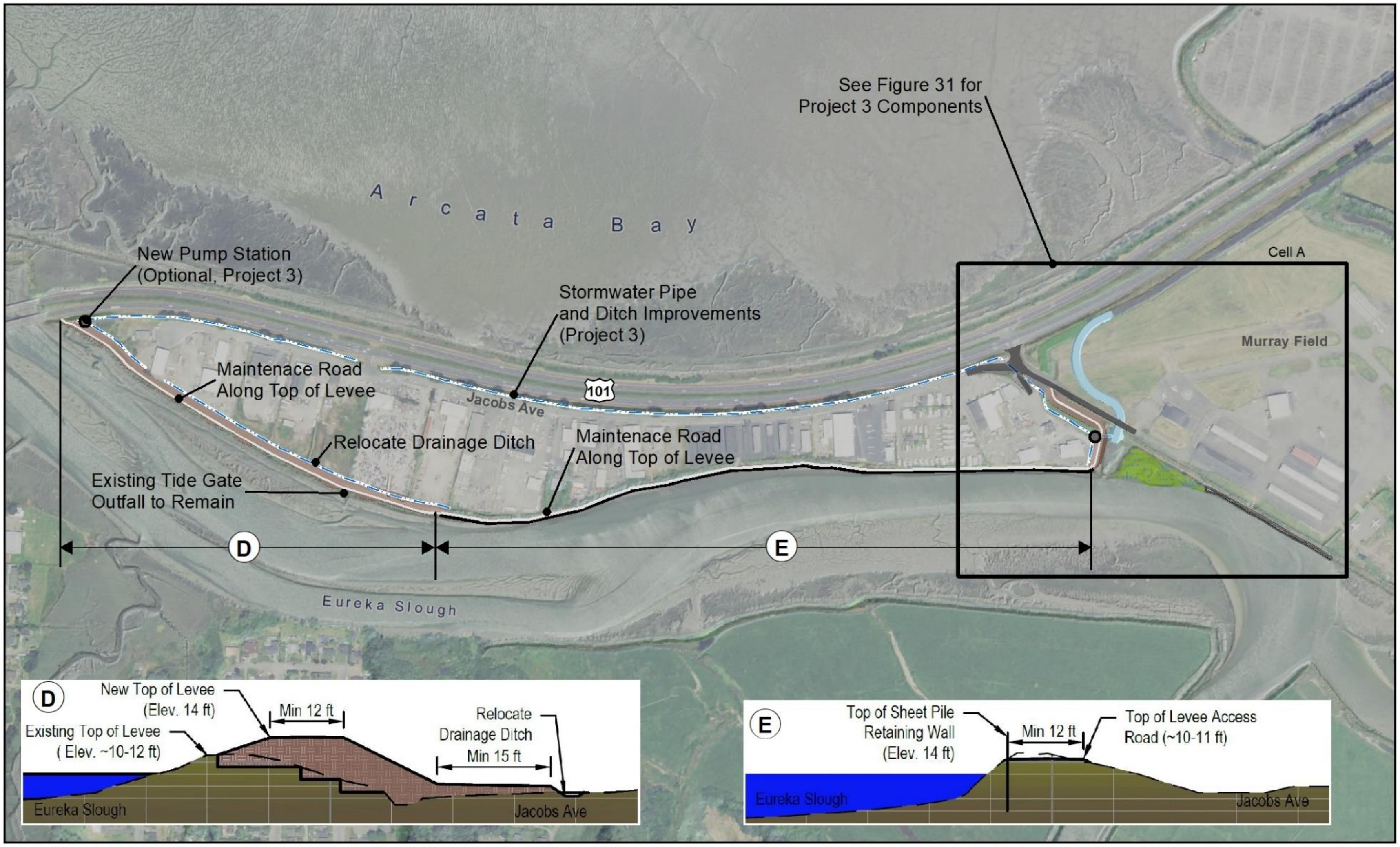


Figure 32. Project 4 Concept: Jacobs Avenue Levee Resiliency

8.11.3 Benefits

Project 4 improves flood resiliency of the Jacobs Avenue area up to elevation 14 feet while providing access along the entirety of the levee for inspection and maintenance. Based on the modeled overtopping volume of the existing levee, still water levels above 11.6 feet result in several feet of flood inundation in this area. Elevating the levee crest elevation and improving seepage and slope stability would provide flood resiliency for future water levels with sea level rise.

8.11.4 Opinion of Probable Cost

The current cost estimate, based on the conceptual design described above, is $7-$9 million. The estimate includes preliminary construction cost with 30% contingency and 25% for planning, engineering, environmental compliance, and construction management. Additional feasibility studies would improve the accuracy of this estimate.

8.11.5 Considerations for Next Steps

The existing levee along Eureka Slough crosses more than 25 parcels under separate ownership. Continued need for an organizational structure and challenges with multi-jurisdictions and multiple private landowners exists. An organizational structure is needed to not only develop and deliver the project, but also provide the necessary future monitoring and maintenance. Identification of funding for a feasibility study that includes preliminary engineering studies for Projects 3 and 4 is needed. The feasibility study would define design criteria based on levee owner risk tolerance, conduct hydrologic/hydraulic analyses of the drainage system and perform additional sub-surface investigation to support levee improvements.

8.12 Project Concept Summary and Regulatory Considerations

The four project concepts proposed above are sequenced to first address most vulnerable shorelines to overtopping that result in flood hazard exposures for transportation, residential and commercial resources. Project 1 increases flood resiliency to protect against several feet of sea level rise and low frequency events, while providing adaptive capacity to implement nature-based solutions, enhanced recreational opportunities and related benefits. Project 2 builds upon Project 1 to increase resiliency to wind and wave hazards that result in higher frequency and higher water levels, while providing habitat benefits as sea levels rise. Projects 3 and 4 focus on protecting the highest density of low-income residential and commercial properties that are also at greatest risk in the study area. The implementation of Projects 3 and 4 support more flexibility for other projects in Cell A by removing the hydraulic connection between areas. Figure 33 presents a summary of the flood reduction and ecosystem services provided by the four proposed projects.

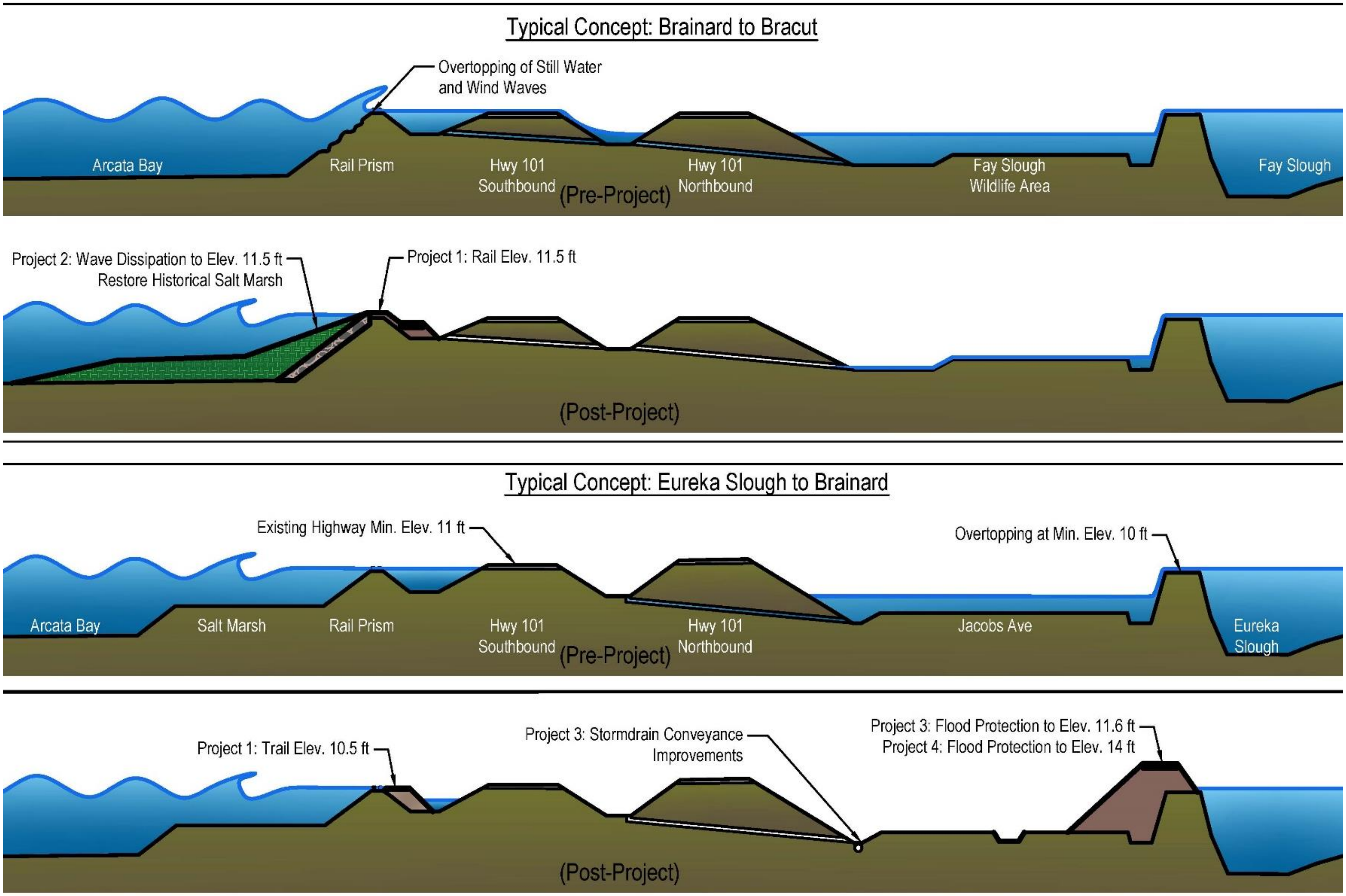


Figure 33. Cross-sections Showing Flood Reduction in Cell A and Highway 101 Corridor Pre- and Post-Project Concepts 1, 2, 3 and 4.

Project 1 is already in the planning and design stage, and mitigation has already been identified. The project is considered permittable, and required regulatory approvals are pending. Project 2 and any associated wetland impact is assumed to be allowable under Section 30233 of the Coastal Act, as it would support restoration purposes. Similarly, Project 3 and Project 4 and any associated wetland impact is assumed to be allowable under 30233, as the projects would support incidental public services, specifically:

- Protection of public health and safety,
- Protection of public infrastructure, including roads and critical sewer infrastructure; and
- Protection against environmental damage related to industrial and sewage spills along the Jacobs Avenue corridor.

Projects 2, 3 and 4 are thus anticipated to be feasible with regards to anticipated regulatory compliance and are intended to be “self-mitigating” for habitat conversion and wetland fill/creation. The feasibility studies proposed for each project will need to further evaluate potential impacts, right-of-way needs, confirm on-site mitigation is feasible, and conduct baseline surveys/studies to assess regulatory pathways. As discussed below, existing conflicts within the coastal zone may disallow some adaptation strategies if unallowable wetland fill, impacts to Environmentally Sensitive Habitat Areas (ESHA), or other land use inconsistencies are proposed.

Project regulatory considerations for adaptation projects 2, 3 and 4, as well as other future adaptation projects, are integrated with design and funding processes (see Figure 34 – Project development Overview), as any adaptation project must be both permittable and fundable, in addition to being physically feasible. Depending upon project complexity and mitigation requirements, the project planning phase can take multiple years, requiring significant advance planning. Adaptation projects must adhere to applicable policies and regulations (see Section 1.13 – Policies, Laws and Regulations). Every project will require a unique regulatory approval pathway. Implementation of adaptation projects will require compliance with CEQA and, pending federal funds, NEPA.

Projects in the coastal zone will require a Coastal Development Permit from the CCC or a Local Coastal Program (city or county government), depending on the project location. Projects involving waters or wetlands will also require permits from the North Coast Regional Water Quality Control Board (Regional Board) and U.S. Army Corps of Engineers under Sections 401 and 404 of the Clean Water Act and related federal consultation with the National Marine Fisheries Service and U.S. Fish and Wildlife Service under Section 7 of the Endangered Species Act and the State Historic Preservation Officer under Section 106 of the National Historic Preservation Act. Similarly, a Lake and Streambed Alteration Agreement and the California Endangered Species Act (CESA) compliance would be required by the California Department of Fish and Wildlife (CDFW). Depending on the project location, a Shoreline Development Permit from the Humboldt Bay Harbor, Recreation, and Conservation District could also be required. Similarly, a lease or permit from the State Lands Commission may also be required. Prior to construction, a grading permit from the local jurisdiction (city or county) would also be necessary.

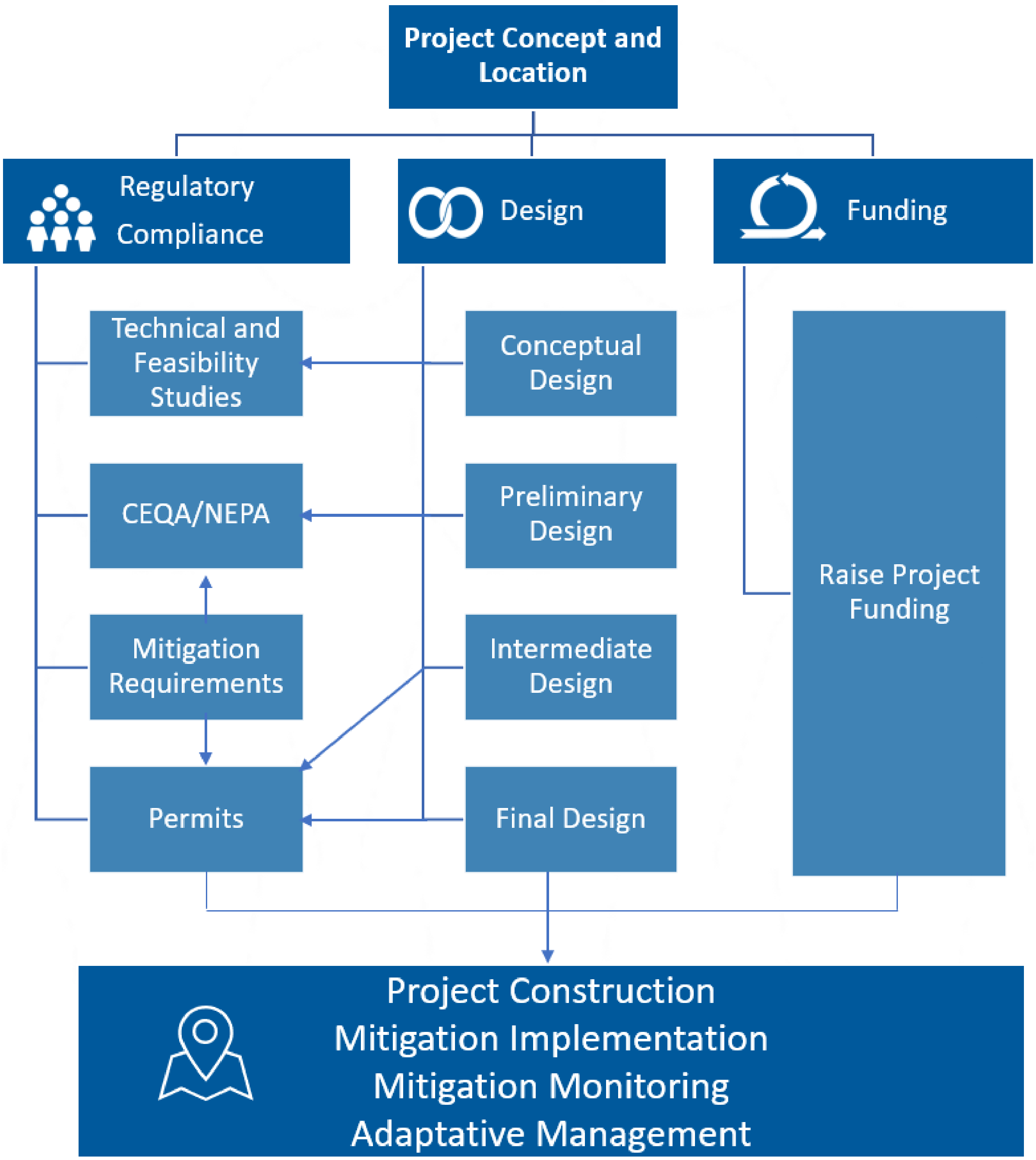


Figure 34. Project Development Overview

Regulatory challenges facing sea level rise adaptation project implementation are significant and can be a disincentive to pursing innovative projects. *Cutting the Green Tape* is a state-led initiative that seeks to streamline permitting processes for habitat restoration projects (CLSN 2020). This initiative provides a model for the type of regulatory reform that will likely be necessary to enable significant advances in sea level rise adaptation. While existing streamlined pathways exist in CEQA, CDFW, and the Regional Board for small-scale restoration projects under five acres, there are limited equivalents for Coastal Development Permits. *Cutting the Green Tape* recommends that the Coastal Commission utilize efficiencies within their authorities to advance restoration projects that are consistent with streamlined processes under CEQA as well as CDFW and Regional Board permitting, in addition to other recommendations to expand these streamlined pathways for larger-scale restoration projects and other policy initiatives to develop new regulatory efficiencies (CLSN 2020). Initiatives under consideration within *Cutting the Green Tape* specifically apply to restoration projects and would need to be more explicitly expanded to equally apply to sea level rise adaptation projects that included environmental benefits.

Adaptation projects, by their very nature, are located in the coastal zone and require a Coastal Development Permit. Inherent conflicts within the Coastal Act can make obtaining a Coastal Development Permit from the CCC challenging. The Coastal Act does not currently allow impacts to ESHA for certain uses, even if mitigated, or diking, filling, or dredging of waters or wetlands for shoreline protection projects unless such projects can be primarily described as restoration projects, nature study, or other limited allowable uses listed in Section 30233. Prohibiting permanent fill of wetlands, even if mitigated, to repair, expand, or construct levees and other protective infrastructures renders some potential adaptation projects infeasible. Filling of wetlands for sea level rise-related shoreline protection via rip rap and other gray infrastructure, or even living shorelines, is currently disallowed. This conflicts with Section 30235 of the Coastal Act, which allows for revetments, retaining walls, and other structures to protect existing structures and public beaches in danger from erosion. The Coastal Act attempts to address these inherent conflicts under Section 30007.5, which requires balancing to prioritize the policy that would result in the most protection for significant coastal resources.

Allowable Diking, Filling, and Dredging in Coastal Waters, Wetlands, and Estuaries

Allowable fill under Section 30233 of the Coastal Act is permitted if there is no feasible less environmentally damaging activity for specific types of projects only:

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

Under the Coastal Act, conversion of one type of wetland to another type of wetland is allowable only if the wetland conversion results in a net environmental benefit. In Humboldt Bay, conversion of salt marsh to mudflat is typically discouraged, as salt marsh is viewed as having a higher value than mudflat. If the project is eligible under Section 30233 (allowable diking and filling), conversion of wetlands from mudflats to higher value wetlands such as salt marsh has been allowed.

Non-wetland ESHA is also common throughout the Coastal Zone, and complete avoidance of impacting ESHA is likely not possible. Under Section 30240, development that would impact ESHA is only allowable if the proposed uses are dependent on the site-specific resources. The Coastal Act's disallowance of mitigation for impacted upland ESHA that is found not to be resource dependent would further constrain sea level rise adaptation efforts.

In evaluating potential allowability for wetland fill under Section 30233, the CCC requires an analysis to demonstrate the proposed project is the least environmentally damaging alternative feasible. This includes evaluating whether the assets requiring protection can feasibly be relocated, as an alternative to protecting them in place. This leaves applicants with the burden of detailing how relocating existing assets further inland could be cost prohibitive, or infeasible for other reasons (e.g. land ownership or access control). Complex regulations and permits pose challenges for applicants. It can be difficult to interpret agency guidance and address competing objectives of different agency requirements and laws. Regulatory requirements can be a disincentive to pursuing innovative projects to address sea level rise. This disincentive can be a detriment when a project holds technical merit and a high likelihood of environmental benefit but may be infeasible or difficult to permit in the existing regulatory setting. Regulatory requirements apply equally to pilot projects addressing sea level rise, just as they would any other project. Guaranteed outcomes preferred by the Coastal Commission can be difficult to provide when designing dynamic projects based on natural processes.

Mitigation requirements for impacts to wetlands and other sensitive habitats 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

Sea level rise adaptation projects remain experimental by their very nature. Adaptation projects are reliant on dynamic natural processes, predicting guaranteed outcomes, even with complex (and costly) modeling and thus result in a high level of uncertainty. Nonetheless, the CCC has an implicit preference for the status quo and has set a high bar for describing guaranteed project outcomes with certainty, neither of which consistently apply to sea level rise adaptation pilot projects.

Implementation of the Coastal Act by the CCC could more directly support sea level rise adaptation by pursuing policy and administrative reforms. While the 2018 CCC Sea Level Rise Guidance requires applicants to consider sea level rise implications to proposed projects, the guidance fails to promote permitting pathways for projects that are seeking to implement adaptation projects by navigating the conflicting and often constraining Coastal Development

Permit process. In the San Francisco Bay, the San Francisco Bay Conservation and Development Commission (BCDC) operates similarly to the CCC. In 2011, BCDC unanimously approved an amendment to the San Francisco Bay Plan to address climate change. The amendment adopted policies to require projects to be resilient to rising sea level through at least mid-century and beyond, given the project's expected life. Just as important, the amendments directed that a regional adaptation strategy be developed by the Bay Area's regional agencies. Similar policy and administrative amendments within the CCC would benefit sea level rise adaptation efforts elsewhere in the state, including Humboldt Bay.

9. BENEFIT COST ANALYSIS

9.1 Overview of Economic (Benefit/Cost) Analysis

A valuation of flood damage to existing critical resources during extreme tidal events was conducted to complete the Economic (Benefit/Cost) Analysis for the proposed projects. A benefit/cost analysis (BCA) is a technique for monetizing select benefits and avoided costs with implementation of a project and weighing these benefits against the costs of a project. The primary monetized benefits of Eureka Slough hydrographic area consisted of avoided costs. In particular, the damages caused by flooding and delays or extended travel by motorists that are avoided by implementing adaptation projects.

The selected adaptation projects exhibit multiple benefits. Many of these benefits are difficult to monetize due to limited documentation and methods, available information, uncertain futures, regional factors, and inherent differences in defining the value of resources. When feasible, given the scope of this study and available information, other benefits were monetized. Otherwise, these benefits were recognized conceptually and not explicitly included in the benefit/cost monetization.

Damage costs were limited in scope and do not capture the full breadth of indirect and direct costs and economic impacts incurred by property owners, facility managers, and the local and regional community. Many damages are recognized conceptually and not explicitly included in the benefit/cost monetization.

The economic (benefit/cost) analysis in Appendix H provides the accounting framework for evaluating the benefits and avoided damages of adaptation projects for this study. A summary is provided below.

9.2 Estimating Flood Damage

Water levels and modeling results presented in the Hazard Scenarios provide a summary of anticipated impacts to critical resources within each cell during a range of extreme tidal and fluvial events. For the purpose of this economic assessment, a range of tidal still water levels were considered to assess flood damage with and without Projects 1, 3 and 4. Project 2 was analyzed based on total water levels and average overtopping rates presented in ESA 2018, that describes the combined effect and recurrence of tidal still water, wind and waves, following the implementation of Project 1 and prior to Project 2 implementation.

Flood damage to the following critical resources was evaluated either quantitatively or qualitatively based on available information, impacts, and significance.

- Land Use by Parcel
  - Structures (residential and commercial)
  - Open Space and Agricultural Land
- Road Use and Damage

- Shoreline Infrastructure (Levees or Rail Prism)
- Public Trail Usage and Damage
- Utility Use and Disruption
- Other Economic Impacts

9.3 Estimating Other Benefits

Projects can provide direct quantifiable benefits as well as indirect benefits that are not quantifiable. For example, Project 1 includes extension of an existing trail along the bay shoreline which connects Eureka and Arcata. Once the project is constructed it will become vulnerable to future extreme events and associated usage disruption and potential damages (ESA 2018).

Ecological benefits were not included due to a lack of sufficient methods and data to quantify this benefit and inherent differences in the value and monetization of functions and services they provide. The services of natural ecosystems are often undervalued and future analyses of adaptation may utilize improved accounting methods as more information becomes available.

Projects may have indirect or co-benefits that are difficult to quantity and monetize. For example, benefits to the local region, regarding the use of dredge spoils from Humboldt Bay were not monetized. Dredged sediment is currently disposed of at the expense of the Humboldt Bay Harbor, Recreation, and Conservation District and US Army Corps of Engineers. Use of these dredge spoils could result in the spoils becoming a resource, as opposed to a burden. Additionally, a project, such as Project 2, could provide not only use of a large volume of dredge spoils during construction, but an ongoing location for placement of dredge spoils to increase elevations and resiliency.

The value of implementing projects that decrease the cost of other future projects or provide flexibility to future projects is also difficult to quantify and monetize. For example, implementing a project that reduces or eliminates the hydraulic connectivity between areas of a single cell can provide opportunities for more nature-based adaptation measures or projects with reduced footprint and cost in other areas of the cell. The co-benefit of implementing a project that enhances opportunities or reduces separate project costs were not included in this study.

The City of Eureka, and the Redwood Coast Region in general, have significantly higher poverty rates than the State of California. Many of these vulnerable households are located in areas vulnerable to coastal flooding. Within the study area, mobile home park communities are located in low-elevation, levee-protected areas, surrounded by industrial and commercial areas. The projects proposed in this study would protect some of these vulnerable residences, such as the mobile home community on Jacobs Avenue, but the benefits to these communities were not monetized.

9.4 Benefit Cost Analysis

The benefit cost analysis focused on evaluating the proposed projects, which are all located within Cell A, which was determined to be the highest risk cell and contains the highest value of monetized critical resources. The BCA utilized the estimated avoided damage costs and monetized benefits to evaluate costs and benefits. Evaluation of these costs and benefits considered planning horizons of 20-years, 50-years, and through 2100, accounting for the time value of money, probability of flooding, and the 66% and 0.5% probability projections for sea level rise. Costs and benefits were compared to the cost of implementing each project to determine a net benefit valuation. The analysis also examined the net benefits from delaying project implementation.

9.5 Key Findings

The BCA examined the main property assets at risk and benefits of the proposed projects. Key findings from this analysis are presented below.

Finding #1 - Flood Reduction Benefit

The primary quantifiable benefits from these projects are flood reduction, resulting in reduced property damage and road closures. The most significant damage costs area associated with commercial structures on the Jacobs Avenue corridor. The other benefits evaluated from these projects are relatively small compared to commercial property damage.

Finding #2 - Project Sequencing

The most substantial, quantifiable flood reduction benefit is achieved with the implementation of Project 1. Significant flooding of Cell A occurs between water level 10.6 and 11.6 feet, under existing conditions. Implementation of Project 1 prevents flooding and closure of Highway 101 and reduces flooding from several feet to several inches in Cell A, up to water level 11.6 feet. Project 2 relies on the implementation of Project 1 and provides protection of Highway 101 and flooding in Cell A for combined wind and wave effects up to a water level of 11.6 feet. Projects 3 and 4 focus on providing flood protection of the Jacobs Avenue area businesses up to water levels 13.6 feet.

Finding #3 - Valuation of Ecosystem Services and Nature-Based Adaptation Measures

Ecosystem services are an important consideration for adaptation approaches and should be accounted for in a complete benefit-cost assessment. Methods can be developed to formulate economic valuations of ecosystem services; however, this type of assessment was beyond the scope of this study. Development of methods to account for the economic benefits of ecosystem services would benefit adaptation planning around Humboldt Bay.

Finding #4 - Valuation of Usage and Damage to Roadways

Standard cost estimating methods for roadways focus on loss of service and include additional vehicle mileage traveled and detour time. However, methods to evaluate damage to roadways and hazardous conditions resulting in accidents, stranding, and loss of life are not well documented. Damage to roadways in the study area, due to flooding, is not well documented and therefore difficult to monetize in a BCA.

Finding #5 - Flood Benefit Limitations

Projects 1 and 2 provide significant flood protection for combined still water, wind and waves effects up to elevation 11.6 feet. Water levels exceeding 11.6 feet result in wide-spread overtopping of shoreline infrastructure along Fay Slough and Eureka Slough, as well as the majority of the Bay shoreline. The flood benefit of Projects 1 and 2 rapidly diminish with water levels above 11.6 feet.

Finding #6 - Project Implementation Timing

Projects 1, 3, and 4 yield high benefits under both the likely (66% probability) and the 1-in-200 chance scenarios, particularly in relationship to the cost of the project. Project 2 also yields benefits under the 66% probability scenario, but negative net benefits under the more extreme 0.5% probability scenario, due to higher water levels occurring sooner and smaller, incremental flood reduction benefit compared to other projects. The data suggests that there is little to no benefit to delaying these projects.

10. STAKEHOLDER OUTREACH

The intended audience for this report encompasses the general public including citizens, students, landowners and specialists. Inclusion of community members is critical for support of adaptation projects. The primary purpose of community outreach was to inform stakeholders of the study need, objectives and guiding principles for which the study is based upon. The agendas from the planning meetings and workshops are located in Appendix H.

As part of the initial project phase, the County in close coordination with project partners (Caltrans, City of Eureka and Humboldt County Association of Governments) developed a list of project stakeholders. The list is comprised of private and public property owners, asset managers, public agencies, utility providers, public service providers and other entities. Community outreach for the Project began in spring and summer 2019 and was focused towards connecting with organizations representing transit-dependent community members and the Jacobs Avenue community.

10.1 Organizations Representing Transit-Dependent Community Members

The Project Team targeted stakeholder outreach to understand current transit use and ridership patterns within the project area and transportation vulnerabilities for transit-dependent populations living and working in the project area. The Redwood Community Action Agency (RCAA) reached out to Humboldt Transit Authority, CAE Transport, Tri-County Independent Living, Area 1 Agency on Aging, and the Humboldt Senior Resource Center while also serving as the point of contact with the Social Services Transportation Advisory Council (SSTAC) of HCAOG. The project team first met representatives of each of these organizations in spring 2019 to review the project and understand needs from transit-dependent populations and then presented the project to the SSTAC, which includes these same organizations, on August 14, 2019.

The HTA general manager was appreciative that the sea level rise study was considering impacts to transit service and was interested in understanding the results of the vulnerability study to consider for any future transit stop siting. He noted that ETS will soon be changing its routes to increase frequency of service, improve efficiency of transfers between ETS and RTS, while ensuring transit coverage for areas with high ridership throughout greater Eureka. A new ETS bus stop will soon be located in the project area at Humboldt Plaza which the bus will access from Tydd Street and then depart via 6th Street to V Street, which crosses First Slough. Potential sea level rise impacts along First Slough, Second Slough, and Third Slough could impact ETS transit service as these are the lowest lying areas that ETS services. Even if a transit stop is not located in a low-lying area, many people walk along Myrtle Avenue and V Street to access these transit stops. HTA is currently writing grants to upgrade its bus fleet to more electric buses to reduce the carbon footprint of transit operations. The first electric RTS bus joined the fleet in June 2019.

10.2 Jacobs Avenue Levee Information Meeting (Community Workshop #1)

A community meeting focused specifically on Jacobs Avenue within the project area was prioritized because of the concentration of businesses and properties, complex ownership and management issues of the Jacobs Avenue levee, and the need to report back to the Jacobs Avenue community following a past study. The community meeting was designed to inform about the current project, report back on results from the previous study, and invite further involvement from Jacobs Avenue property owners.

Outreach was conducted through the following means:

- A letter was sent to every landowner and business tenant on Jacobs Avenue inviting them to the meeting and providing information about the project.
- A visually appealing meeting flyer was created and distributed along with the landowner/business owner letter
- Flyers were delivered in person door-to-door to each business located on Jacobs Avenue. When contact was made with business owners and/or employees project staff discussed the project, invited questions and comments, and encouraged them to attend the meeting.
- A survey was developed both in paper and online format to ascertain the Jacobs Avenue community's understanding of flood risk and levee management, experiences with flooding, and interest in becoming involved in planning for flood preparedness and levee management.
- The Lazy J Mobile Home & RV Park owners did not invite distribution of the flyer to park tenants. Direct outreach to Lazy J tenants was postponed until later in summer 2019.

The meeting flyer, meeting photos, and survey can be found in Appendix I.

The Jacobs Avenue Levee Information Meeting was held on Thursday, May 30, 2019 between 5:30-6:30 p.m. at All Points Signs, a business located on Jacobs Avenue. The meeting started with an open house to talk with project staff, complete a survey or comment cards, and view project maps. Hank Seemann gave a brief presentation on the key topics and invited conversation and questions from attendees.

The key topics for the informational meeting were the following:

- Levee ownership and long-term management of flood risk
- FEMA flood hazard maps
- Results of an engineering study of the levee completed in 2016
- Introduction to the sea level rise planning project currently in progress
- Starting a conversation around ideas for improving preparedness for flood hazards and coordination among Jacobs Avenue community

Nine people from the Jacobs Avenue community attended the meeting including business and property owners, an employee of an organization located on Jacobs Avenue, and a real estate professional. Staff from the project team, the City of Eureka, the County, and Caltrans were also present.

Only six surveys were completed but they indicate that participants are concerned about flood hazards, not sure if they have enough information regarding flood risks and interested in attending follow-up meetings. There is small contingent of Jacobs Avenue community members who have been engaged for years around levee issues, but there has not been universal participation from all property/business owners that own and maintain a portion of the levee.

Several attendees noted that engaging other property and business owners on Jacobs Avenue has historically been difficult. It was suggested that in preparation for a follow-up meeting the project team should work together with engaged business owners to reach out to other businesses in the area to invite them to participate. A follow-up meeting was planned for late summer/early fall to garner additional involvement from the Jacobs Avenue community, report back on survey results and progress on the study, and discuss specific ideas to increase preparedness and response to potential flood hazards. Several years ago, the Jacobs Avenue property owners initiated an account at the Eureka Chamber of Commerce to serve as matching funds for potential projects to support the levee and preparedness. The follow-up meeting could include discussion of ideas of how this account could support next steps.

Following the Jacobs Avenue Levee Meeting the project team was able to share about the project and engage residents of the Lazy J Mobile Home & RV Park by mailing the community survey and a stamped return envelope to each of the 59 residential spaces. The project team received back eight completed surveys from Lazy J residents on Jacobs Avenue (14% survey return rate). The responses from Park residents were mixed, with some residents showing concerns about the ability of the levee to protect Jacobs Avenue and others not having concerns as well as some knowing there is no single entity responsible for levee maintenance and others who were not aware. Three residents noted they would be interested in attending the levee follow-up meeting planned for fall 2019. While the survey of Lazy J residents may only have had a 14% response rate, it was also an opportunity to share information about levee conditions with residents.

10.3 Stakeholder Workshop #1 (March 12, 2020)

The purpose of this workshop was to present the results of the vulnerability assessment to the stakeholder group which included Caltrans, City of Eureka, HCAOG, County of Humboldt, CDFW, USFWS, USGS, Humboldt Bay Harbor District, Humboldt Bay Keeper, City of Arcata, State Coastal Commission and State Coastal Conservancy. The draft vulnerability assessment portion of the report was provided in advance of the workshop. Comments on the report were provided by the State Coastal Commission following the presentation. The agenda and list of attendees is located in Appendix I.

10.4 COVID-19 Global Pandemic

On March 19, 2020, the Humboldt County Health Officer issued an Order directing Humboldt County residents to shelter at their place of residence in an effort to slow the spread of COVID-19. The order was in recognition of the imminent threat COVID-19 presented to the public’s health and a way to further broaden social distancing. The order was intended to ensure the maximum number of people self-isolate in their residence to the extent possible. The Order significantly limited continued outreach to private landowners and other non-government organizations.

10.5 Stakeholder Workshop #2 (March 17, 2021)

The purpose of this workshop was to present the adaptation projects to the stakeholder group and solicit feedback prior to finalizing the report. The agenda and list of attendees is located in Appendix I

11. CONCLUSIONS AND KEY FINDINGS

11.1 Summary

This plan presents a framework for developing sea level rise adaptation strategies within the Eureka Slough hydrographic area of Humboldt Bay. This plan developed a scenario-based planning approach to evaluate the range of possible consequences resulting from tidal and fluvial flood hazards under current conditions and with future sea level rise. The plan improves the collective understanding of specific flood vulnerabilities within the study area and offers adaptation project concepts for the most at-risk locations, which were determined to be located within Cell A. Cell A extends from Eureka Slough to Bracut along the Highway 101 corridor and includes higher density development as well as the Jacobs Avenue area, Highway 101, and critical utilities.

After completing stakeholder outreach, hydraulic modelling, and hazard scenarios analysis, the project team identified a range of project concepts and technical studies that could increase sea level rise resiliency in the study area. The Humboldt Bay Trail South project currently in development and three new project concepts were selected for more detailed evaluation of flood reduction benefits and to test a newly developed benefit-cost assessment methodology.

The Humboldt Bay Trail South project would construct approximately 4.25 miles of Class I multi-use trail along the Eureka-Arcata Highway 101 transportation corridor. The project includes repairing shoreline armoring and eroded railroad embankment and raising portions of the railroad prism one to two feet. The project would provide significant flood reduction to Cell A and Highway 101 by reducing still water flooding and dissipate wave energy.

The Natural Shoreline Infrastructure project concept would reduce shoreline erosion between Bracut and Brainard by restoring nearly 40 acres of salt marsh habitat and reducing wind-wave overtopping. The project would utilize a living shoreline approach that combines nature-based and gray adaptation strategies.

The Jacobs Avenue Flood Resilience project would isolate the densely populated Jacobs Avenue area from the flood risk associated with potential levee overtopping and failure along Fay Slough. The project would include a new levee segment connecting the northbound Highway 101 fill prism to Jacobs Avenue levee along an alignment adjacent to Airport Road. This project would also include realigning the existing Caltrans drainage system adjacent to Airport Road; implementing levee repairs and stabilization measures to address erosion adjacent to Murray Field; and stormwater drainage improvements along Jacobs Avenue, stormwater pump station(s), and salt marsh enhancements.

The Jacobs Avenue Levee Resiliency project would increase the service life of the levee by elevating low spots along the levee to approximately 14 feet in elevation, stabilizing isolated areas of surface erosion, and addressing seepage after additional investigations.

A summary of the projected flood reduction benefits of the Humboldt Bay Trail South project and the three additional project concepts is provided in Table 12.

Table 12. Flood Reduction Benefit Summary for Projects 1 Through 4.

Project Benefit Metric	Existing Conditions	Project 1: Humboldt Bay Trail South	Project 2: Natural Shoreline Infrastructure (Bracut to Brainard)	Project 3: Jacobs Avenue Flood Resiliency	Project 4: Jacobs Avenue Levee Resiliency
Still Water Overtopping at 11.5 ft					
Overtopping					
Arcata Bay	4,300 ac-ft	0 ac-ft			
Eureka Slough	80 ac-ft			0 ac-ft	
Fay Slough	210 ac-ft				
Flood Depth	3-6 ft	0-2 ft			
Hwy 101 Road Closure	Yes	No			
Wind Wave Overtopping at 11.5 ft					
Overtopping					
Arcata Bay	1,400 ac-ft		0 ac-ft		
Flood Depth	0-3.5 ft		0-1.5 ft		
Hwy 101 Road Closure	Yes		No		
Still Water Levels 11.5-14 ft or Levee Breach					
Jacobs Avenue Flood Depth	5-8 ft				0 ft
Construction Cost	$0	$22M	$20-29M	$9-12M	$7-9M
Avoided Damages (Likely Sea Level Rise Rate) Through 2100	N/A	$114M	$43.2M	$82.3M	$38.5M

Key

Flood Reduction Benefit (green shading)

11.2 Work in Progress

This plan has advanced methods to assess sea level rise vulnerability in the Eureka Slough hydrographic area of Humboldt Bay. The field of sea level rise adaptation planning is advancing rapidly and techniques and methods will continue to evolve. Studies related to sea level rise around Humboldt Bay that are currently in progress or planned for initiation include the following:

- **City of Eureka: Sea Level Rise vulnerability and capital improvement program adaptation plan (2021) –** This plan will characterize flood risks from shoreline overtopping during extreme tidal and precipitation events. The results will be used to identify infrastructure vulnerabilities and capital improvements throughout the City of Eureka.
- **City of Arcata: Living shoreline pilot project (2021)** – This ongoing pilot project is currently collaborating with Thriving Earth Exchange to advance the understanding and efficacies of potential living shoreline techniques especially around the Arcata Marsh and Wildlife Sanctuary.
- **Humboldt County: Pre-feasibility study for natural shoreline infrastructure along the Humboldt Bay shoreline between Brainard and Bracut (2021) –** This study will characterize physical processes (tidal currents, wind wave forces, and sediment exchange) and the anthropogenic interventions that have contributed to foreshore erosion to develop a range of nature-base techniques that could provide multiple benefits such as salt marsh restoration and wind wave dampening to increase resiliency of the vulnerable shoreline adjacent to Highway 101.
- **U.S. Geological Survey (USGS): Coastal Storm Modeling System applied to the North Coast (2021)** – The USGS is performing a technical study to apply their Coastal Storm Modeling System for the North Coast, with completion expected by the end of 2021.
- **Wiyot Tribe: Climate change adaptation plan (2022) –** The Wiyot Tribe will be initiating a planning effort to determine sea level rise vulnerability and adaptation approaches for culturally significant areas around Humboldt Bay.
- **Christina Bewley, HSU graduate thesis: Geologic hazards assessment of Highway 101 corridor (2022)** – This masters thesis is intended to fill data gaps that can further inform adaptation planning for Highway 101 corridor between Eureka and Arcata. The study will include geologic/geomorphic mapping with LiDAR differencing to assess geomorphic change along the Bay's eastern shoreline; assess vertical land motion rates by reconciling geodetic records from known benchmarks; and implement a groundwater monitoring program to assess sea level rise effects on groundwater gradients.
- **Humboldt County: Sea level rise regional planning feasibility study (2022)** – The Humboldt County Building and Planning Department received funding from the Coastal Commission to conduct a feasibility study of options for implementing a Humboldt Bay regional sea level rise adaptation planning effort to facilitate regional coordination and cooperation.

- **Humboldt County: Humboldt Bay Area Plan update (2022)** – The Humboldt County Building and Planning Department is currently updating the Humboldt Bay Area Plan (HBAP), a component of the County's Local Coastal Program. The primary objective of the HBAP update is to build on the coordinated sea level rise planning around Humboldt Bay and address potential impacts to coastal-dependent uses; critical public facilities such as roads, wastewater treatment plants and shoreline protection structures; communities, including some of the County's most vulnerable areas - the economically disadvantaged communities of King Salmon, Fields Landing, and Fairhaven/Finn Town; agricultural land; and environmentally sensitive habitat areas (ESHA).
- **Humboldt County: Airport system wide study (2023)** – This plan will include an assessment of the County's existing airport system and make recommendation for future capital investments and/or consolidation of airport facilities.
- **Jacoby Creek Land Trust: Jacoby Creek water sustainability and anadromous fish habitat enhancement feasibility study (2024) –** This study area covers lower Jacoby Creek from Brookwood Bridge to Humboldt Bay encompassing the delta plain and City of Arcata's Bayland property. The study will characterize historic and current conditions that have contributed to ongoing flood and habitat impacts, and through stakeholder engagement develop schematic designs that provide multiple benefits related to habitat enhancement, sea level rise resiliency, and flood reduction.
- **Caltrans: Highway 101 phased adaptation plan (2025)** – This plan is due to the California Coastal Commission in 2025 as a condition of approval to the Corridor Safety Improvement Project Coastal Development Permit. Caltrans is leading the development of this plan which will evaluate adaptation alternatives for the Highway 101 corridor between Eureka and Arcata.

11.3 Strategic Considerations

Strategic considerations for advancing sea level rise planning and adaptation include the following:

1. **Aim to maximize multi-benefit projects and nature-based solutions:** Multi-benefit projects are likely to be in the best position to secure funding, and projects that incorporate nature-based solutions are more likely to receive regulatory approvals. Projects with nature-based solutions should align with bay-wide restoration goals and be developed in consultation with resource agencies and managers.
2. **Consider how multiple lines of defense including natural features and built structures work together to provide flood protection and explore how they can be improved to optimize protection.** A robust shoreline adaptation strategy should consider how natural features and built structures work together to provide enhanced protection. Existing railroads, roads, levees, and natural features could be enhanced with targeted improvements to help defend critical areas from flood risks.

3. **Understand the vulnerability of the transportation network as a whole and work to ensure that alternate routes are accessible during flood events to avoid a complete system shutdown.** Planning for sea level rise and flood hazards should incorporate comprehensive transportation planning to address alternatives to main transportation routes that could be affected by potential flooding. This planning should include improvements to alternate routes as appropriate and public information so the community can plan for possible closures and be aware of alternative routes and restrictions.
4. **Incorporate sea level rise adaptation measures into capital improvement projects.** Sea level rise adaptation will be an ongoing process as climate change progresses. Therefore, adaptation will need to be incorporated into ongoing capital improvement planning. As an example, the City of Eureka is currently developing a Capital Improvement Plan for Sea Level Rise Adaptation Planning which may serve as a model transferable to other local municipalities.
5. **Make prudent investment of limited resources:** Funding for planning, studies, and project development will be limited. Therefore, priorities and opportunity costs should be considered when making funding decisions to ensure that the limited funding delivers optimal value. One recommendation is to prioritize investment in work that is most likely to lead to actions and improvements. Another recommendation is to invest in early studies that improve readiness and competitiveness for applying to larger funding sources. For example, feasibility and design studies are typically needed in order to define the scope and budget of a large capital project before applying for construction funding. Having a concept alone is typically not enough to be successful with competitive grant opportunities. In addition, innovative projects involving nature-based solutions may require demonstration projects or pilot projects to confirm the soundness of the approach before receiving funding or permits for full implementation. A final recommendation is to prioritize investment in work that has regional benefit.

   Potential funding sources for adaptation projects include the National Coast Resilience Fund administered by the National Fish and Wildlife Foundation (NFWF); Building Resilient Infrastructure and Communities (BRIC) and Hazard Mitigation Grant Program (HMGP) funding administered by FEMA; and Integrated Regional Water Management (IRWM) grants through the California Department of Water Resources (DWR). Other opportunities could stem from transportation-related funding, infrastructure protection funding, or natural resources enhancement and conservation grants.
6. **Look for cooperative funding opportunities where multiple beneficiaries contribute to flood risk reduction measures implemented at a landscape scale:** This plan identified high-risk areas, such as Cell A, that have a high density of critical resources and populations protected by vulnerable levees. Collaboration between property owners and land managers within this area to better define risk tolerances could help inform a long-range resiliency vision. Ideally this collaboration would result in effective actions based on a shared vision providing multiple benefits and thereby reducing overall adaptation costs on any single property owner.

7. **Expand and improve regional coordination on sea level rise planning and adaptation:** Local governments, agencies, and stakeholders will need to decide on a framework for coordination, collaboration, and decision making. Coordination could include one or more of the following goals:
   - Information exchange and shared learning
   - Consistent policies and decision-making frameworks
   - Coordination of studies, project development, monitoring
   - Joint implementation projects

   In the short-term there is a need for facilitated meetings among local agencies and land managers. One recommendation is for Caltrans to initiate stakeholder engagement for their development of the Phased Adaptation Plan for the Eureka-Arcata Highway 101 corridor. Understanding the structure and approach for stakeholder engagement on the Phased Adaptation Plan will help other agencies consider how this process can fit with other coordination options.
8. **Find ways for the public to participate in discussions about adaptation approaches and be involved in meaningful and effective actions:** Our community is increasingly aware of the social, economic, and environmental implications of climate change. Many citizens care strongly about climate change and seek opportunities to be involved. Finding opportunities for meaningful dialogue and effective action toward a positive vision of resilience would channel the public's concern and interest in a productive direction.
9. **Look at other coastal communities for models of success to emulate and learn from (and examples of failures and mistakes to avoid):** Communities along every coastline are in the shared position of being forced to address the unprecedented challenges of sea level rise. Approaches and practices are evolving rapidly as communities respond to the immense scale and complexity of these challenges. Inevitably some communities are further ahead than others, especially in urban areas with greater resources. For example, in 2016 the nine-county San Francisco Bay Area passed Measure AA which established a parcel tax that provides funding to the San Francisco Bay Restoration Authority for shoreline projects that protect, restore, and enhance the bay. In addition to dedicated funding, the San Francisco Bay Area benefits from years of research and monitoring of restoration projects, the establishment of bay-wide habitat goals and planning frameworks, progressive policies from the San Francisco Bay Conservation and Development Commission, and effective organizations such as the San Francisco Estuary Institute and the San Francisco Bay Area Planning and Urban Research Association. One ongoing challenge is figuring out how to apply the lessons and examples from other communities to the size and context of the rural Humboldt Bay region. In addition to identifying models of success it can be equally beneficial to understand the root causes from examples of unsuccessful outcomes.

10. **Work with interested property owners and land managers to explore managed retreat and identify opportunities where such a transition makes sense and could be feasible.** While many property owners may prefer a strategy for ongoing defense of their property from the growing effects of climate change, it may not be economically nor technically feasible to defend all properties indefinitely. In many cases, defending an asset may only be temporarily feasible and eventually an episodic event could breach defenses and result in catastrophic damage that is not economical to repair. To avoid these potential catastrophic losses, transitional land use and managed retreat strategies should be considered for areas subject to ongoing and increasing risks of flooding. Transitional land use strategies should be developed based on the specific circumstances for each situation including the willingness of property owners and land managers to consider longer term changes in land use that would be compatible with future water levels and flood risks. The Humboldt Bay region would benefit from the development of guidance and resources for developing transitional land use and managed retreat strategies.

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Appendix A Exhibits

Appendix B Indicators of Change – Observation Protocols and Logs

Appendix C Hydraulic Modeling Technical Memo

Appendix D Hazard Scenario Case Studies

Appendix E Qualitative Risk Assessment

Appendix F Natural Shoreline Infrastructure Project

Appendix G Jacobs Avenue Levee Assessment

Appendix H Benefit Cost Analysis

Appendix I Stakeholder Outreach Notes