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

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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.