2-21-2023

Sea Level Rise Vulnerability and Capital Improvement Project (CIP) Adaptation Plan

Brian Vivyan
GHD

Aaron Holloway
GHD

Technical Memorandum

21 February 2023

To	Jesse Willor, PE and Brian Gerving (City of Eureka Public Works)
From	Brett Vivyan, PE and Aaron Holloway, PE (GHD)
Reviewed	Jeremy Svehla, PE (GHD)
GHD Ref No.	11221286
Subject	Sea Level Rise Vulnerability and Capital Improvement Project (CIP) Adaptation Plan

1. Introduction

The City of Eureka's shoreline and landward areas will become increasingly vulnerable to sea level rise (SLR) and other climate-related processes. Previous SLR studies of the City's infrastructure by ESA (2019) and GHD (2020) focused on long-term SLR projections and vulnerabilities, which are significant. However, there is time to plan, fund, and implement adaptation strategies in response to these processes, beginning with efforts to improve the resilience of the City's infrastructure. The following technical memorandum was developed to support the City's need to develop a phased climate adaptation plan, tailored to planning for coordinated implementation of projects for the City's roads, trails, water, sewer and drainage infrastructure within the Coastal Zone.

1.1 Overview and Purpose

The City's Capital Improvement Program (CIP) is updated on an annual basis to reflect the anticipated investments needed over the next 5 years to maintain and enhance the City's infrastructure. Many CIP projects are focused on repair, maintenance, and upgrade of existing infrastructure to maintain or improve function, reliability and/or prolong service life. Incorporating the anticipated future sea levels and changes to coastal processes into the CIP planning process will be an effective way to ensure public investments are accounting for future conditions.

CIP projects present opportunities to increase infrastructure resilience and leverage local investments toward building adaptive capacity for other coastal resources in alignment with longer-term goals and objectives of the Strategic Plan and adopted General Plan. This memorandum provides a summary of the vulnerabilities to existing infrastructure, focused on SLR projections for the 2050 time horizon (Section 4). Adaptation concepts intended to mitigate existing and anticipated impacts described in Section 5.

1.2 Study Area

This study developed a hydrodynamic model to evaluate affected infrastructure along the six-mile shoreline of Humboldt Bay, between Elk River Slough and Eureka Slough and recommend adaptation projects. Model results and findings from other studies along Martin Slough, Jacobs Avenue, and Ryan Slough at Myrtle

Avenue have been incorporated into this technical memorandum for a complete assessment of the City's infrastructure that may be affected by coastal processes. The study reach was organized into seven shoreline planning areas, described below and illustrated in Figure 1 with shoreline cover from the Humboldt Bay Shoreline Inventory, Mapping and Sea Level Rise Vulnerability Assessment (Laird et al, 2013).

- **Martin Slough Drainage Area:** The shoreline in this planning area begins near Fairway Drive and F Street, within the Martin Slough watershed and encompasses the lower watershed elevations along Martin Slough and the Elk River to Highway 101. The shoreline is typically vegetated dikes or levees along the Elk River and Swain Slough, of which Martin Slough is a tributary. Tidal flow into Martin Slough is muted by a tide gate structure that allows a portion of the tidal range to propagate up Martin Slough. Tides above elevation 11 feet overtop the structure and the surrounding dikes. Martin Slough was not included in the hydraulic model domains prepared for this study. Engineering judgement is used in the evaluation of infrastructure located along Martin Slough.
- **Elk River Slough to Truesdale Street:** The shoreline along this planning area begins at the Highway 101 corridor and fronts the Elk River WWTP and consists of mostly earth/vegetated (un-armored) shoreline. McCullens Avenue Pump Station and Pound Road Lift Station are also located in this area.
- **Truesdale Street to Del Norte Street:** This shoreline is mostly armored with un-engineered rock that generally follows the railroad alignment fronting the Bayshore Mall and Palco Marsh.
- **Del Norte Street to L Street:** This shoreline area is completely armored and developed including a variety of industrial uses, the Eureka Boat Basin and other waterfront development. This planning area includes a sprawling network of utility and transportation infrastructure including the Washington Street Pump Station, Commercial Street Lift Station and the Hwy 101 corridor.
- **L Street to Hill Street:** This shoreline area consists of open space armored by rock revetment along Humboldt Bay and natural (earth/vegetated) shoreline along Eureka Slough fronting commercial/retail development and Shoreline RV Park. Infrastructure in this planning area includes the Hwy 101 corridor, Hill Street Pump Station, Waterfront Lift Station and Y Street Lift Station.
- **Jacobs Avenue:** The southern shoreline along Eureka Slough is largely armored and leveed while the northern shoreline, along Highway 101 is vegetated. This area is protected from tidal flooding by a system of levees along the shoreline. A small network of utility and transportation infrastructure including multiple pump stations are within the perimeter levees. This area was assessed in the Sea Level Rise Adaptation Plan for Transportation Infrastructure in the Eureka Slough Hydrographic Area (GHD, Caltrans, County of Humboldt, City of Eureka and HCAOG, March 2021), a summary of those findings and relevant figures are provided as a part of this technical memorandum.
- **Ryan Slough at Myrtle Avenue:** This vegetated shoreline is located outside of city limits and extends from Myrtle Avenue, north along an access road to the City's Ryan Slough pump station. A pipeline delivers drinking water from Humboldt Bay Municipal Water District to the pump station and is located under the diked former tidelands and slough channels to the north. This area was assessed in the Sea Level Rise Adaptation Plan for Transportation Infrastructure in the Eureka Slough Hydrographic Area (GHD, Caltrans, County of Humboldt, City of Eureka and HCAOG, March 2021), a summary of those findings and relevant figures are provided as a part of this technical memorandum.

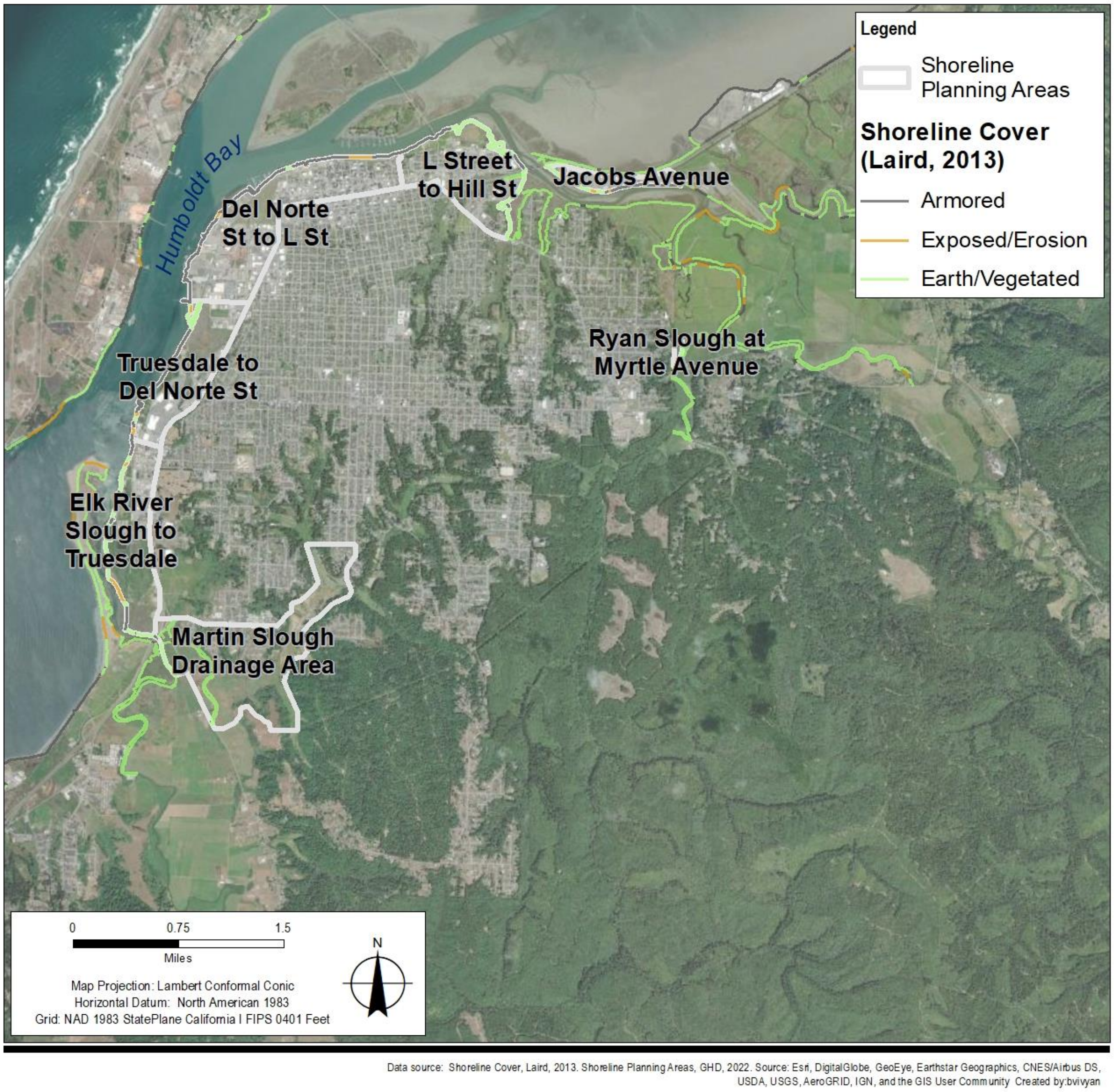

Figure 1 Shoreline planning areas within the City of Eureka.

1.3 Utility & Transportation Infrastructure

City-owned assets and infrastructure were the focus of the vulnerability assessment and adaptation concepts described in this memo. These include sewer, storm drain and water supply infrastructure. Transportation infrastructure included the network of roads in each shoreline planning area and the Eureka Waterfront Trail. Existing utility and transportation infrastructure within the study area were evaluated using the City’s GIS database and recent studies listed below.

– Elk River WWTP Climate Change Assessment and Adaptation Plan (ESA, 2019) and the Climate Readiness Plan: Adaptation Control Measures & Schedule (GHD, 2020)
– Eureka Area Watersheds Storm Water Resources Plan (GHD, 2019)
– Sea Level Rise Adaptation Plan for Transportation Infrastructure in the Eureka Slough Hydrographic Area (GHD, Caltrans, County of Humboldt, City of Eureka and HCAOG, March 2021)

– Natural Shoreline Infrastructure in Humboldt Bay for Intertidal Coastal Marsh Restoration and Transportation Corridor Protection Between Brainard and Bracut (GHD, County of Humboldt, In Current Draft)

2. Sea Level Rise

Sea level rise (SLR) is the primary issue of concern when considering how impacts from a changing climate could affect infrastructure along the Eureka waterfront. Sea level rise is unique among other natural processes and episodic events because it will develop over the span of decades. Initially, SLR may be difficult to distinguish among the variable water levels of Humboldt Bay, but even small amounts of SLR may increase the risk of coastal flooding during extreme events, posing a threat to a variety of coastal resources.

Global mean sea level is rising, with acceleration in recent decades due to increasing rates of ice loss from Greenland and Antarctic ice sheets, as well as continued glacier mass loss and ocean thermal expansion (IPCC, 2019). The rate of global SLR for 2006-2016 of 3.6 mm/yr is unprecedented over the last century and 2.5 times higher than the rate for 1901-1990 of 1.4 mm/yr (IPCC, 2019).

SLR projections along the west coast of California are provided in the 2018 State of California Sea Level Rise Guidance document (OPC, 2018) for 12 active tide gauges. The California Coastal Commission Sea Level Rise Policy Guidance, updated in 2018 to reflect the latest projections, refers to these as the "best available science" on SLR projections in California. SLR projections for North Spit (Station ID: 9418767), the nearest tide gauge to Eureka, are appropriate for this plan. These projections are shown in Figure 2 for a range of probabilistic scenarios and time horizons through 2070.

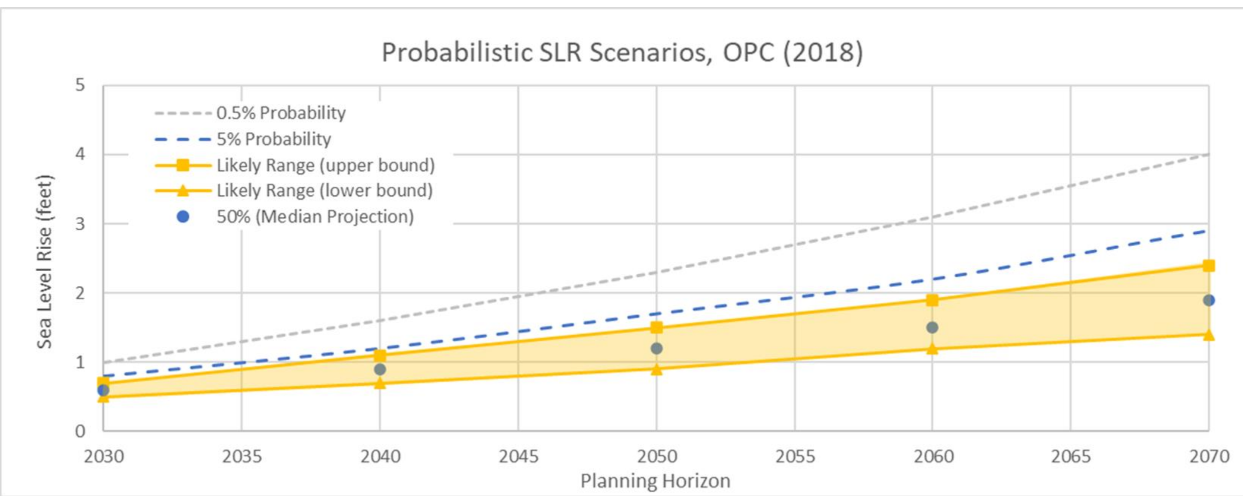

Figure 2 Sea Level Rise Projections at North Spit (OPC, 2018)

Risk tolerance and service life are important factors to consider when evaluating SLR projections and their effect on coastal processes and existing infrastructure. Specific risk tolerances vary for different assets and infrastructure throughout the study area.

– Repair and maintenance projects focused on existing infrastructure with a low consequence of damage from coastal processes may have a higher risk tolerance for SLR. In these applications consideration of the likely range of SLR projections may be appropriate because there is a low risk of damage or service disruption if these projections are exceeded.
– Critical infrastructure projects with a high consequence of damage from coastal processes would have a lower risk tolerance for SLR. Critical infrastructure projects would require consideration of higher ranges of SLR projections over the expected design life to inform a risk-based decision-making process.

The City's Capital Improvement Program (CIP) is updated on an annual basis to reflect the anticipated investments needed over the next 5 years to maintain and enhance the City's infrastructure. Many CIP projects are focused on repair, maintenance, and upgrade of existing infrastructure to improve function, reliability and/or prolong service life. Incorporating the probability of SLR and coastal processes into the CIP planning process will be an effective way to ensure public investments are accounting for future conditions. CIP projects present opportunities to increase infrastructure resilience and leverage local investments toward building adaptive capacity for other coastal resources in alignment with the goals and objectives of the Strategic Plan and adopted General Plan.

This study evaluates the vulnerability of existing assets and infrastructure to SLR over the next 20-30 years to identify areas where CIP projects and planning efforts may warrant consideration of future coastal conditions and processes. The vulnerability assessment (Section 4) considers an extreme water level in combination with probabilistic SLR projections in 2050 which range from 0.9 to 2.3 feet:

- Likely range of SLR is between 0.9 **- 1.5 feet**. There is a 17% chance SLR exceeds 1.5 feet by 2050.
- 5% probability that SLR exceeds **1.7 feet**.
- 0.5% probability that SLR exceeds **2.3 feet**.

This assessment is largely geared toward CIP projects focused on improvements and upgrades to existing infrastructure with a remaining service life of 30 years or less. For major utility or transportation investments with a longer design life (e.g. 50 years or more), a project-specific risk assessment, based on this assessment, but focused on higher SLR scenarios, may be warranted to understand how these significant investments could be impacted by low probability but consequential SLR scenarios.

3. Coastal Processes

Several previous studies have identified coastal flooding, exacerbated by SLR, as a primary process of concern along the Eureka waterfront. This assessment focuses on flooding resulting from an extreme water level in combination with SLR. Wave conditions were also evaluated along the study reach to better understand the potential for shoreline erosion and additional flooding due to wave action.

3.1 Extreme Water Levels

Astronomical tides significantly influence water levels within Humboldt Bay. Typical daily tides range from mean lower low water (MLLW) to mean higher high water (MHHW), a range of about 6.85 feet (NOAA Station 9418767). During spring tides, which occur twice per lunar month, the tide range increases due to the additive gravitational forces caused by alignment of the sun and moon. The largest spring tides of the year, which occur in the winter and summer, are sometimes referred to as "King" tides and result in water levels that exceed 8 feet (NAVD).

Ocean water levels typically vary within predictable astronomical tide ranges; however, sea level anomalies caused by El Niño Southern Oscillation or storm surge events can increase the water levels above the predicted astronomical tide. These events in combination with high astronomical tides can result in extreme water levels that result in flooding of low-lying areas along the Eureka shoreline. The highest water level on record at the North Spit tidal station occurred on December 31, 2005 when a water level of 9.6 feet (NAVD88) was observed, which was roughly 1.5 feet higher than the predicted tide, as illustrated in Figure 3.

Note, this extreme water level was observed at the peak of the tide cycle, lasting a relatively short duration (e.g. several minutes), followed by the ebbing limb of the tide cycle and subsequent low tide. While topography and elevation are good indicators of flood potential, flood duration is also a key factor influencing the extent of coastal flooding, particularly where hydraulic connectivity is limited by a levee, berm or storm drain.

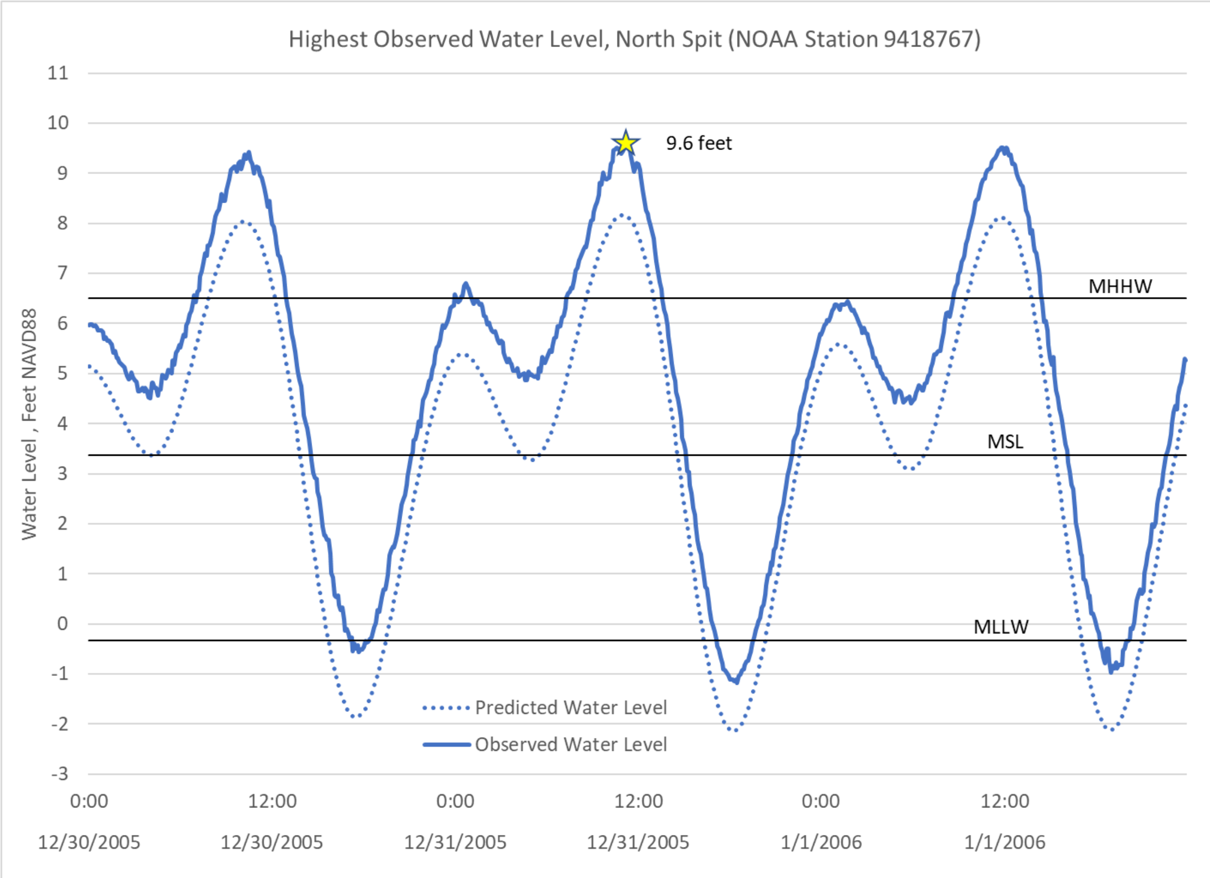

Figure 3 Highest Observed Water Level at North Spit (NOAA Sta 9418767)

A SWMM hydrodynamic model was used to simulate tidal flooding from the extreme water level time series shown in Figure 3. In addition to topography of the study area, the model also included the City's storm drain network to capture the potential for ocean water levels to cause urban flooding via reverse flow through the storm drain system. This model was used to estimate potential flood extents and depths for two water level scenarios of 9.6 and 10.6 feet.

– 9.6 feet, representative of the highest observed water level, or a king tide + ~1.5 ft SLR

– 10.6 feet, representative of the highest observed water level + 1 ft SLR, or a king tide + ~2.5 ft SLR

The hydrodynamic model was used to identify flood pathways from overtopping of the shoreline and surcharging of the stormdrain system; the extent, depth and duration of flooding; and the resulting effect on transportation and utility infrastructure. The depth and duration of flooding, in association with the frequency of events, supports a more accurate evaluation of flood risk. Shallow, brief tidal flooding of roadways and trails can be similar to rainfall events with no damage. However, frequent deep flooding may impact the long-term usability and function of transportation facilities and utilities.

Beyond an elevation of 10.6 widespread flooding would be expected throughout the Eureka waterfront. A third water level scenario of 11.6 feet was evaluated using elevation-based mapping and a GIS analysis to determine hydraulic connectivity and extent of flooding.

The three water level scenarios are depicted in Figure 4 along with the range of SLR projections in the 2050 time horizon. The extreme water level return periods are based on the NHE (2015) model results near the North Spit tidal station (ESA, 2019). This figure demonstrates that the water levels considered are representative of the range of future water levels in 2050 and capture all but the most extreme combinations of SLR and ocean water levels.

The following figure sets in Attachment 1 show the extent and pathways of flooding for the three water levels:

– Figures 1.1 to 1.7, water level 9.6 feet
– Figures 4.1 to 4.7, water level 10.6 feet
– Figures 7.1 to 7.7, water level 11.6 feet

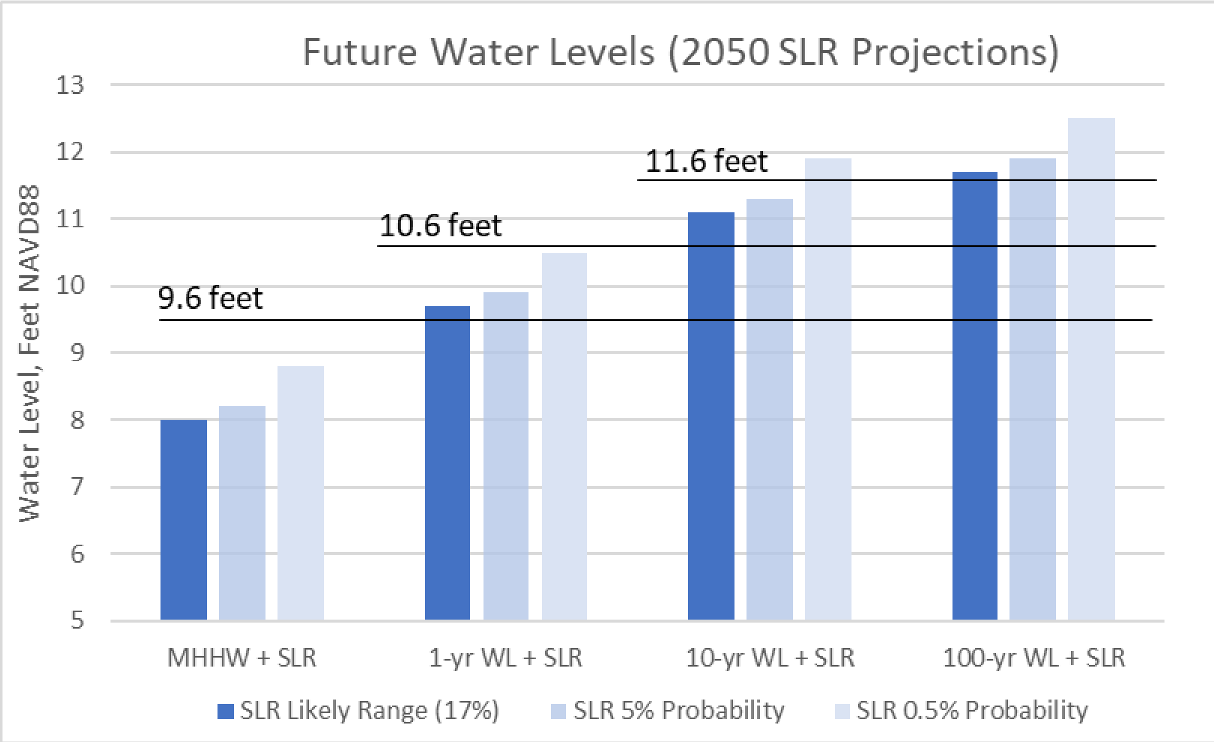

Figure 4 Future Extreme Water levels + SLR at the 2050 time horizon

3.2 Wave Conditions

GHD evaluated wave conditions using previous studies and anecdotal reports of wave related runup and shoreline erosion along the study area. The purpose of this task was to understand the exposure of the study area to different sources of wave energy and the potential for wave induced shoreline erosion or increased flooding. An investigation into the sources and magnitudes of the waves within Humboldt Bay that interact with the shoreline is presented in Attachment 2. Wave sources considered along the study reach included:

– **Wind waves:** FEMA (2014) evaluated wind waves within Humboldt Bay as part of the Coast of California Analysis and Mapping Project. Intermediate Data Submittal (IDS) #3 – Nearshore Hydraulics summarizes their approach to quantifying wind waves along the Eureka shoreline. A 50-year return period wind speed of 45 mph was used to estimate fetch-limited wave heights in the study area. The results indicate wave heights range from 0.5 – 1.5 feet with wave periods of approximately 2 seconds along most of the study area. The northern most segment of the study area, which is exposed to fetch across Arcata Bay, could experience wind generated waves of 2-3 feet at 3 seconds.

– **Swell propagation:** Propagation of long-period swell through the Humboldt Bay entrance has been observed along the study area but has not been measured or modeled in any of the previous reports reviewed. ESA (2019) reports observations made by SHN Engineers & Geologists of five-foot breaking waves along the seaward side of the Elk River spit during a significant long-period swell event. However, the amount of swell energy propagating over or around the spit and along the Eureka shoreline is significantly less. Anecdotal observations of 0.5-1 foot high "surges" have been observed by the GHD team in the vicinity of the McCullens Avenue pump station with similar observations made by City and Harbor Patrol staff.

– **Vessel wakes:** The magnitude of vessel wakes is dependent on the type, size and speed of the vessel. Passing vessels generate a series of waves that quickly decrease in height as they travel from their source. The potential for passing vessels' waves to result in erosion depends on the water depth and distance from shore. Based on anecdotal information about typical vessels transiting Humboldt Bay we are assuming the typical waves are on the order of 0.5-1 feet in height and are unlikely to be a significant contributor to shoreline erosion or flooding along most of the study reach.

Wind waves and swell propagation represent the most significant wave energy sources along the study reach. However, these events are relatively infrequent, and are unlikely to be the primary drivers of coastal flooding or erosion. Continuous erosion of the shoreline may be attributed to more routine events, such as boat wakes and currents. In consideration of SLR and the extreme water levels evaluated in Section 3.1, the wave energy sources considered here would not significantly affect the estimated flood extents. However, when coupled with a high-water level event, the added wave action could increase the potential for erosion and flood damage along the shoreline. Any future adaptation strategies such as berms or floodwalls located along the shoreline should consider the potential for wave exposure when determining an appropriate geometry, crest elevation, freeboard allowance, and surfacing.

4. Vulnerability Assessment

Vulnerability is the degree to which natural, built, and human systems are susceptible to harm as defined in the Adaptation Planning Guide[1] which was recently updated by the State of California Office of Planning and Research. Assessing vulnerability is one of the key steps in understanding existing and future conditions and their potential impacts to City assets and infrastructure. Vulnerability was evaluated based on three factors:

- **Exposure** is the degree to which a resource is exposed to sea level rise (SLR) and associated processes. Exposure was evaluated in terms of the spatial extent, duration and frequency of flooding using the extreme water level scenarios described in Section 3.
- **Sensitivity** is the degree an asset would be impaired by the impacts of SLR. Systems that are greatly impaired by the exposure to SLR conditions have a high sensitivity, while systems that are minimally impaired by this same exposure have a low sensitivity.
- **Adaptive capacity** is the ability of an asset to respond to SLR, to moderate potential damages, to take advantage of opportunities, and to cope with the consequences. This does not mean that the system must look the same as before the impact, but it must provide comparable services and functions with minimum disruption or additional cost.

This section describes the vulnerability of existing utility infrastructure and transportation assets owned, operated and maintained by the City of Eureka. The estimated flood pathway, depth, and duration at key locations are illustrated in the maps provided in Attachment 1.

Identifying impact thresholds, or tipping points, at which the potential consequences associated with a given scenario increase significantly are a key outcome of this assessment. The impact thresholds can be correlated to a SLR projection to quantify the probability of occurrence at a given time horizon. This provides valuable information for prioritizing adaptation strategies and understanding how these strategies may need to evolve over longer planning horizons.

4.1 Transportation Infrastructure

Transportation infrastructure is exposed to similar flooding as utility infrastructure described in previous sections. Under the 9.6-ft water level, the Eureka Waterfront Trail experiences flooding along the Hikshari Trail and at the Eureka Slough. Pound Road and a segment of Waterfront Drive near the Eureka Boat Basin are also exposed to flooding in this scenario. Transportation infrastructure would experience localized vulnerabilities during a 9.6-ft water level, resulting in temporary disruptions to access while flooded and potentially requiring road/trail repairs and debris cleanup after flooding subsides.

[1] https://resilientca.org/apg/

Transportation infrastructure vulnerability increases significantly under a 10.6-ft water level. The number of roads, length of roads impacted, depth and duration of flooding would result in widespread disruptions in transportation patterns and likely result in significant infrastructure damage. Table 1 provides a list of transportation infrastructure that experiences flooding greater than 6 inches in depth at both 9.6-ft and 10.6-ft water level scenarios. Refer to the maps in Attachment 1 for a detailed depiction of all potential flooding for each water level scenario, including a depiction of potential flooding under an 11.6-ft water level.

The following figure sets in Attachment 1 show the extent, depth and duration of flooding of roadways and trails for the three water levels:

- Figures 2.1 to 2.7, water level 9.6 feet
- Figures 5.1 to 5.7, water level 10.6 feet
- Figures 8.1 to 8.7, water level 11.6 feet

Table 1 Transportation Infrastructure – Exposure to Flooding at 9.6 and 10.6 ft Water Levels

	Transportation Asset	Flooded Length (ft)	Max Depth (inches)	Duration (Hours)
9.6-ft	Eureka Waterfront Trail	2,000’	Varies	Varies
	Pound Road	700’	9”	2.5 hrs
	Waterfront Drive (Eureka Boat Basin)	600’	9”	0.5 hrs
10.6-ft	Eureka Waterfront Trail	20,000’	Varies	Varies
	Pound Road	700’	21”	3.5 hrs
	Hwy 101 (SB Off Ramp – Herrick Ave)	800’	24”	2.3 hrs
	Hilfiker Lane	250’	16”	2.1 hrs
	A Street	300’	10”	3 hrs
	McCullens Court	200’	24”	3 hrs
	Truesdale, Howell & Christie Streets	1,400’	8”	2.5 hrs
	Bayshore Mall & Bayshore Way	3,500’	24”	3.2 hrs
	Hawthorne, Felt, Del Norte Streets	1,200’	26”	2.3 hrs
	15th Street	600’	9”	8 hrs
	Waterfront Drive	3,000’	20”	4.2 hrs
	Broadway, Commercial St, A St	2,500’	16”	11 hrs
	2nd, 3rd, 4th, 5th Streets	4,500’	20”	10.2 hrs
	Jacobs Avenue	4,000’	12”	1 hr
	Ryan Slough Access Rd.	300’	6”	2.25 hrs

4.2 Utility Infrastructure

City of Eureka utility infrastructure includes sewer, water, and stormwater. City sewer and water infrastructure may be vulnerable to SLR based on the proximity to the shoreline for existing and future erosion conditions, flooding of pump or lift stations, and flood inflow to sewer manholes. The stormdrain system may increase vulnerabilities due to inflow from ungated outfalls and surcharge of drain inlets.

The following figure sets in Attachment 1 show the extent of flooding, pump and lift stations affected by flooding, proximity of utilities to the shoreline, and shoreline cover (armored, exposed/eroded, and vegetated) for the three water levels:

– Figures 3.1 to 3.7, water level 9.6 feet
– Figures 6.1 to 6.7, water level 10.6 feet
– Figures 9.1 to 9.7, water level 11.6 feet

4.2.1 Sewer Infrastructure

Sewer infrastructure in the City of Eureka generally consists of a collection system of pressure and gravity flow pipes that conveys sewage from each user to a network of pump/lift stations which then convey sewage to the Elk River Wastewater Treatment Plant (WWTP). This assessment focuses on vulnerabilities to the collection system and network of pump/lift stations due to SLR and coastal processes. A detailed vulnerability assessment of the WWTP was performed by ESA (2019) which informed the Climate Readiness Plan: Adaptation Control Measures & Schedule memorandum (CRP) prepared by GHD (2020).

4.2.1.1 Pump/Lift Stations

Several City-owned pump/lift stations are exposed to coastal flooding for the water level scenarios described in Section 3. These assets are essential to the functional performance of the sewer infrastructure and play a vital role in collecting sewage from a vast pipeline network and conveying untreated sewage to the centralized WWTP. The facilities are listed below in order of their exposure to water level scenarios. Vulnerability of the exposed facilities largely depends on the sensitivity to flooding which is discussed further below.

– **Martin Slough Pump Station** is partially protected from tidal flooding due to the lower tidal range created by the muted tide gate at the downstream extent. However, access to the pump station would likely be impeded at tidal water levels that exceed 11 feet, due to overtopping of the tide gate structure and surrounding area, with tidal flooding propagating up the slough flooding the access road to pump station from Fairway Drive, which is approximately elevation 8 feet (NAVD88).
– **Pound Road Lift Station** is exposed to flooding for the 9.6-ft (NAVD88) water level scenario for a duration of about 2.4 hours and maximum depth of 15 inches. This lift station is one of the lowest lying pump stations of the City's collection system and the frequency and duration of flood exposure will increase with SLR.
– **Hill Street Pump Station** is exposed to flooding in the 10.6-ft water level scenario with an estimated flood depth of about 1 foot. Given the existing ground surface elevations, the facility may be exposed to flooding at lower water levels. This facility is adjacent to Second Slough and several sewer mains and manholes that convey sewage to the facility are also within the flood extents, potentially increasing inflow and infiltration (I&I) during extreme water level events.
– **McCullens Avenue Pump Station** is exposed to minimal flooding at the 10.6-ft scenario, but this appears close to the impact threshold with water levels overtopping the shoreline in front of the facility and adjacent parking lot. The flood depth increases to about 1 foot in the 11.6-ft scenario, posing a greater risk of damage to this asset.
– **3rd and Y Lift Station** is exposed to minimal flooding adjacent to the lift station in the 10.6-ft scenario. This water level appears very close to the impact threshold for this lift station with flooding across Y Street via the ditch alongside Highway 101. The lift station would be exposed to about 1 foot of flood depth at the 11.6-ft water level scenario.
– **Waterfront Lift Station** is exposed to flooding in the 11.6-ft water level scenario with an estimated depth of about 1 foot. The ground surface elevation of this facility is lower than the 10.6-ft scenario but no flooding was predicted due to limited hydraulic connection via the storm drain system. It is possible flooding at this facility occurs before the 11.6-ft scenario depending on the surface elevations adjacent to the bay and the hydraulic connection via the storm drain system.

– **Commercial Street Lift Station** is exposed to minimal flooding adjacent to the lift station in the 11.6-ft scenario but there is widespread surface flooding in the vicinity in this scenario. While the lift station may be above this water level, access to the facility could be a challenge until adjacent flooding subsides.
– **Jacobs Avenue Lift Stations** were evaluated in the Sea Level Rise Adaptation Plan for Transportation Infrastructure in the Eureka Slough Hydrographic Area (GHD, Caltrans, County of Humboldt, City of Eureka and HCAOG, March 2021) and are not shown in this study's figure set. The sewer pump stations are protected up to a water level of 10.6-ft. A water level of 11.6-ft results in significant overtopping of the levees and Highway 101, resulting in multiple feet of flooding within the pump station footprints.

Sensitivity to flooding is a key to understanding the vulnerability of each facility listed above. Facilities which are sensitive to flooding, could lose power and functionality until flooding recedes and repairs are made, a significant downtime that could result in discharge of untreated sewage (sanitary sewer overflow), particularly for the larger pump stations.

Pump Station Vulnerability

Pump station facilities are partially enclosed in buildings with emergency backup generator equipment, above and below ground-level equipment, and exterior located wet wells. The electrical systems (transformers, switchgear, motor control centers, and control panels) are most sensitive to flooding. The vulnerability of electrical systems varies by facility depending on the location, elevation and exposure rating of the electrical components. Exterior wet wells exposed to overtopping could also pose a vulnerability in terms of pump capacity. The CRP (GHD, 2020) identified the pump stations as having a medium sensitivity to flooding under the assumption that if electrical damage occurred the backup generators would be able to maintain operations without significant damage or disruption.

Given the importance of these facilities in conveying sewage to the WWTP via the crosstown interceptor, the CRP proposed a 2.5-foot water level buffer above Mean Monthly Maximum Water Level (MMMW) as a trigger for implementation of adaptation measures. Based on the flood exposure and asset sensitivity, the Hill Street pump station has the highest vulnerability. The 2.5-ft trigger above MMMW (7.7 feet, NAVD88) has already been met, indicating this facility warrants consideration for CIP improvement to reduce the risk of flood damage.

The McCullens Avenue pump station is not exposed until the 10.6-ft water level and therefore has more lead time (i.e. 5-10 years) before the 2.5 foot MMMW trigger is met. Based on the latest SLR projections (CCC, 2018) there is a 66% probability this trigger will be met before 2030.

Lift Station Vulnerability

Lift stations consist of mostly below-grade infrastructure such as wet wells with submersible pumps and above ground equipment with control panels and connection to mobile backup generators. Lift stations could be sensitive to flooding if excessive overtopping exceeds the pumping capacity or if above ground equipment is damaged by flooding. Similar to pump stations, the electrical systems are typically most sensitive to flooding but this depends on the location and exposure rating of these systems.

Lift stations were identified as having a low sensitivity to flooding in the CRP and a suggested trigger of 0.5 feet water level buffer above MMMW. The Pound Road lift station is the most vulnerable to SLR and coastal flooding given its location and exposure to flooding from Elk River Slough. Based on the CRP criterion the trigger for implementing adaptation measures would likely be met in the next 5-10 years.

4.2.1.2 Sewer Collection System

Portions of the crosstown interceptor pipeline between the McCullens Avenue pump station and the Elk River WWTP are within 25 feet of the present-day shoreline. Although partially protected by a rock revetment, segments of this pipeline are exposed or unprotected and vulnerable to erosion damage from currents and/or wave energy at the mouth of the Elk River Slough. Undermining of the pipe bedding due to erosion could compromise the stability of the pipeline, increasing the risk of a sewage spill and disruption to the collection system. Vulnerability to shoreline erosion will increase under the 10.6-ft scenario because the overland flooding will likely exacerbate erosion of the shoreline during extreme water level events.

The Martin Slough Interceptor, located adjacent to Martin Slough and accessed by a gravel road off Fairway Drive. The access road exhibits an elevation of approximately 8 feet and the pump station finished floor elevation and immediate surrounding ground elevation of 12 feet. The Martin Slough tide gate reduces peak tidal elevations. The magnitude of muting was not modeled, however, annual monitoring reports indicate a peak tidal water in Martin Slough near the pump station (monitoring location near gold course hole 18) was elevation 5 feet, while the peak water surface elevation at the North Spit was 8 feet. Given the pump station elevation of 12 feet and the Martin Slough tide gate elevation of 11 feet, the area would not flood due to tides up to 11 feet. Tides greater than 11 feet would begin to overtop the tide gate structure. The muted tidal range would reserve capacity in the Martin Slough area to accommodate overtopping between 11 and 12 feet. While the pump station would not likely experience tidal flooding with Martina Slough water levels below those of the Elk River, the access road at elevation 8 would likely flood.

Increased I&I is another vulnerability for sewer infrastructure subject to widespread surface flooding for a prolonged duration. The number of sewer manholes exposed to flooding increases significantly at the 10.6-ft and 11.6-ft water level scenarios as indicated on the maps in Attachment 1. I&I typically increases during significant rainfall events due to surface flooding and elevated groundwater that infiltrates into the collection system. Although groundwater impacts due to SLR were not evaluated in this assessment, we expect I&I would increase proportionally to the flooded areas depicted for each water level scenario. The City of Eureka is already in the process of implementing an I&I reduction program to address existing issues and support future reductions.

4.2.2 Water Infrastructure

There are several water mains between the Elk River WWTP and West Del Norte Street which are located within 25-50 feet of the active shoreline. Water mains between West Del Norte and the Bayshore Mall are marginally protected by the railroad prism. Water mains in the vicinity of Truesdale Street are protected against erosion by a rock revetment. Near the WWTP, the water main is unprotected and vulnerable to erosion damage from currents and/or wave energy at the mouth of the Elk River Slough.

The Humboldt Community Service District water pump station is located at Truesdale Street and Howell Street. While this is not City infrastructure it is connected to the city system with valves in the closed position. It is possible for the City to take water if there were an emergency or planned need from this location. The station is at approximately 10 feet of elevation.

Several water mains are also located within the flood extents under the 10.6 and 11.6-ft water level scenarios. However, water supply lines have a low sensitivity to surface flooding since these are “closed” and pressurized systems that would be unlikely to experience damage or disruption from surface flooding.

The Ryan Slough Water Booster Station was evaluated in the Sea Level Rise Adaptation Plan for Transportation Infrastructure in the Eureka Slough Hydrographic Area (GHD, Caltrans, County of Humboldt, City of Eureka and HCAOG, March 2021) and is not shown in this study’s figure set. The water booster station is subject to shallow flooding of 0.3 feet at a water level of 10.6-ft. However, access to the facility is limited, as the access road experiences shallow flooding adjacent to Ryan Slough.

4.2.3 Storm Drain Infrastructure

City storm drain infrastructure provides hydraulic connection to Humboldt Bay at various locations along the shoreline as indicated on the maps in Attachment 1. As ocean water levels increase with SLR, these systems will be subject to higher backwater elevations. There are two main sensitivities to higher backwater elevations:

– Reduced capacity in gravity systems. Storm drains designed for historical water levels may experience a reduction in capacity due to the higher downstream boundary condition. This could result in more frequent surface flooding during future rainfall events and was evaluated in The Eureka Area Watersheds Storm Water Resource Plan (EAWSWRP)(GHD, 2018). The EAWSWRP included an evaluation of storm drain performance with consideration for SLR and higher ocean water level events and identified several adaptation measures and projects to improve storage & capacity of the storm drain system to better accommodate SLR.

– “Non-storm” flooding could occur during extreme ocean water level events in which tides flow through the storm drain system and result in surface flooding via drainage inlets whose elevations are below the Humboldt Bay water levels.

The Commercial Street storm drain system services a relatively large area of Eureka’s waterfront and is most vulnerable to the impacts described above. The 9.6-ft water level would result in minor surface flooding adjacent to drainage inlets along this storm drain line. The 10.6-ft scenario result in extensive flooding throughout the Commercial Street Area between Hwy 101 and the Eureka Boat Basin. This is also an indication the storm drain system capacity could be limited, especially when rainfall events coincide with high ocean water levels. Building on the findings of the EAWSWRP, the Eureka Flood Reduction & Sea Level Rise Resiliency Project, currently in progress, is intended to alleviate these potential impacts.

5. Adaptation Concepts

This memorandum presents several adaptation concepts to mitigate the vulnerabilities described in Section 4. The concepts are intended to provide a starting point for capital improvement planning efforts focused on maintaining and enhancing the City’s utility and transportation infrastructure. Incorporating the probability of future conditions into the CIP process with an understanding of remaining design life and risk tolerance provides an effective way to implement public works projects while accounting for uncertainties associated with climate change and SLR.

While some of the strategies described below could become stand-alone projects, many can be incorporated into upcoming CIP projects. These projects present opportunities to include site-specific adaptation strategies to increase resilience and build adaptive capacity into these systems.

The concepts listed below are focused on reducing near-term vulnerabilities of existing infrastructure with a remaining service life of 30 years or less. In other words, these concepts represent an initial step of a phased SLR adaptation process that would buy time to plan, fund and implement subsequent adaptation phases to address long-term SLR vulnerabilities. An illustration of how these concepts could be applied to the different vulnerabilities along Eureka’s shoreline are depicted on the maps in Figure 10.1 to 10.7 in Attachment 1. The location and extent of the concepts are preliminary and will be subject to further community and stakeholder outreach, planning, analysis, and design to determine feasibility.

5.1 Coastal Resilience Corridors

The potential for overland flooding depicted for water levels of 10.6 feet and higher poses a significant challenge for the sprawling network of utility and transportation infrastructure along the Eureka shoreline. One potential strategy to reduce flooding is to convert the existing rail corridor into a multi-benefit coastal resilience corridor. The rail corridor alignment generally follows the City’s shoreline and presents an opportunity to integrate flood protection with transportation infrastructure (e.g. trails & roads), a utility corridor, and nature-based strategies to promote ecosystem resilience. The Eureka Waterfront Trail, including the Hikshari Trail, are among the most vulnerable transportation assets to future coastal flooding. Relocating these features to a more landward and elevated location improves the adaptive capacity of these important access and recreation assets. The potential alignments of this corridor are depicted on the maps in Attachment 1 including elements of infrastructure relocation and nature-based adaptation strategies.

5.1.1 Infrastructure Relocation

Sewer and water lines along the Elk River Slough that could be vulnerable to erosion could be relocated to an alignment beneath the coastal resilience corridor to improve setbacks from coastal processes and provide more reliable access to these utilities for maintenance and repair. Vulnerable lift stations (i.e. Pound Road and Commercial Street) could also be relocated within or behind the corridor to achieve similar benefits.

5.1.2 Nature-based Strategies

Nature-based adaptation strategies such as ecotone slopes, horizontal levees, living shorelines, salt marsh sills, pocket beaches, and sediment augmentation to support habitat migration could also be applied along several segments of the Eureka shoreline. In addition to ecosystem resilience, these features can be designed to achieve multiple benefits including habitat diversity & connectivity, flood protection, wave dissipation, nature study and carbon sequestration. Recent studies have shown that watersheds tributary to Humboldt Bay have the potential to supply adequate fine sediment to mudflats and salt marshes to accrete (elevate) at pace with sea level rise (Curtis et al, 2021). Reducing wave exposure along the shoreline through use of living shorelines that trap and accrete sediment can reduce erosion potential and reduce future impacts from sea level rise. The efficacy of similar strategies is currently being evaluated along Humboldt Bay shoreline between Brainard and Bracut (Figure 5).

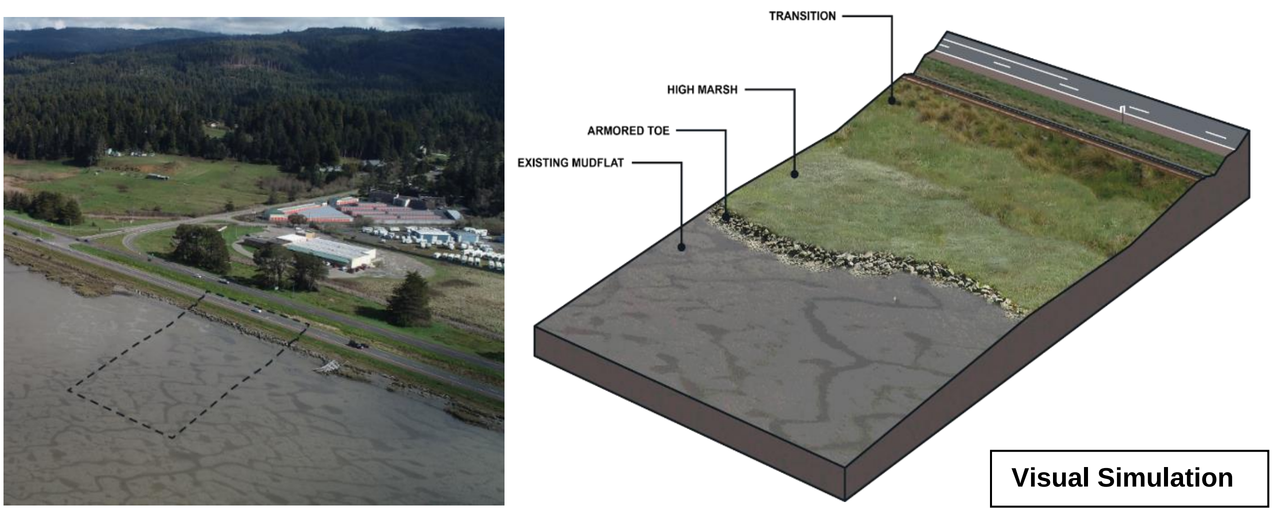

Figure 5. Visual Simulation of Living Shoreline (Restored Salt Marsh with Armored Toe) Concept Shown on Humboldt Bay Shoreline Between Brainard and Bracut (GHD and Humboldt County, 2022).

Additionally, existing freshwater and tidal marshes with diminished function, such as highly muted tidal hydraulics and sediment deposition potential, may be restored in conjunction with areas of proposed living shorelines and/or areas of shoreline retreat.

5.2 Site Specific Adaptation Concepts

Site specific adaptation strategies provide an opportunity to increase resilience to coastal flooding at the parcel scale. These measures can be tailored to a given site and coupled with other local and regional efforts such as the coastal resilience corridors previously described.

5.2.1 Sewer Pump/Lift Stations

Sewer pump stations and lift stations which are vulnerable to coastal flooding could benefit from a variety of site-specific adaptation strategies which may include a combination of the following strategies:

– Parcel-scale flood protection may include berms, floodwalls or deployable barriers installed around the perimeter of these facilities. These can be permanent features with deployable gates for access during non-storm conditions, or temporary features installed in advance of extreme water level events.

- Reduce sensitivity to flooding through dry-floodproofing or elevating sensitive equipment (i.e. electrical systems). Sensitivity to flooding can also be reduced through improved redundancy which may consist of backup generators (which are already installed at pump stations), or deployable generators and pumps for use at lift stations in the event of an emergency.

5.2.2 Tide Gates

Tide gates are an effective way to mitigate the potential for coastal flooding via storm drain networks such as Commercial Street. Tide gates are manufactured in a variety of types and sizes and most can be easily adapted to existing outfalls. These are a relatively low-cost feature that could provide a significant reduction in flooding during high ocean water level events. Regular inspection and maintenance are important to the proper performance of any tide gate installation.

5.3 Long-term Adaptation Planning

Long-term SLR scenarios (i.e. 2070-2100) pose a challenge for a wide variety of resources on both public and private lands along the Eureka shoreline. Adapting to these scenarios will involve difficult decision-making and trade-offs associated with the diverse land uses vulnerable to future flooding including waterfront industry, commercial and retail areas, residential areas, open space, and natural resources.

Where feasible, near-term adaptation strategies described above should be aligned with long-term adaptation planning efforts guided by the updated land use and zoning policies of the Local Coastal Program (LCP). Infrastructure planning will be an essential piece of both near-term and long-term adaptation planning efforts and will require a coordinated effort among private and public landowners, City staff, elected officials, regional stakeholders and State agencies.

6. Next Steps

- Perform a feasibility level analysis of the coastal resilience corridor including an evaluation of opportunities for nature-based strategies such as living shorelines
- Evaluate opportunities for site-specific adaptation strategies at pump stations and lift stations
- Develop a utility relocation plan for aging infrastructure vulnerable to future coastal processes
- Continue planning and outreach efforts to promote a regional and collaborative response to long-term vulnerabilities posed by high SLR scenarios

7. References

California Coastal Commission. 2018. California Coastal Commission Sea Level Rise Policy Guidance.

Curtis, et al. 2021. Amplified impacts of climate change on fine-sediment delivery from fluvial sources and implications for building ecosystem-based resiliency to sea-level rise, Humboldt Bay, California. Draft under peer review.

Environmental Science Associates (ESA). 2019. Elk River WWTP Climate Change Assessment and Adaptation Plan.

FEMA. 2014. Intermediate Data Submittal #3: Nearshore Hydraulics Humboldt County, Coast of California Analysis and Mapping Project (CCAMP).

GHD and Humboldt County Public Works. 2022. Natural Shoreline Infrastructure in Humboldt Bay for Intertidal Coastal Marsh Restoration and Transportation Corridor Protection Between Brainard and Bracut (In Current Draft)

GHD, Caltrans, County of Humboldt, City of Eureka and HCAOG. 2021. Sea Level Rise Adaptation Plan for Transportation Infrastructure in the Eureka Slough Hydrographic Area

GHD. 2020. Climate Readiness Plan: Adaptation Control Measures & Schedule.

GHD. 2018. Eureka Area Watersheds Storm Water Resource Plan (EAWSWRP).

IPCC. 2019. The Ocean and Cryosphere in a Changing Climate. Special report released by the Intergovernmental Panel on Climate Change. September 2019.

Laird, A., Powell, B., and Anderson, J., 2013. Humboldt Bay Shoreline Inventory, Mapping and Sea Level Rise Vulnerability Assessment, Humboldt Bay Sea Level Rise Adaptation Planning Project, Phase 1, prepared for the State Coastal Conservancy, January 2013.

Northern Hydrology & Engineering (NHE). 2015. Humboldt Bay: Sea Level Rise, Hydrodynamic Modeling, and Inundation Vulnerability Mapping, Final Report, Prepared for the State Coastal Conservancy and Coastal Ecosystems Institute of Northern California, April 2015.

Ocean Protection Council (OPC) (March 2018). State of California Sea-Level Rise Guidance 2018 Update, Prepared by the California Natural Resources Agency and the California Ocean Protection Council.

Attachment 1

Figures

Figure Number	Title	Still Water Level
1.1-1.7	Tidal Flooding Pathways	9.6 ft
2.1-2.7	Transportation Facilities Flooding	
3.1-3.7	Utilities Flooding and Shoreline Vulnerability	
4.1-4.7	Tidal Flooding Pathways	10.6 ft
5.1-5.7	Transportation Facilities Flooding	
6.1-6.7	Utilities Flooding and Shoreline Vulnerability	
7.1-7.7	Tidal Flooding Pathways	11.6 ft
8.4-8.7	Transportation Facilities Flooding	
9.1-9.7	Utilities Flooding and Shoreline Vulnerability	
10.1-10.7	Adaptation Concepts	10.6 ft

Attachment 2

Wave Analysis