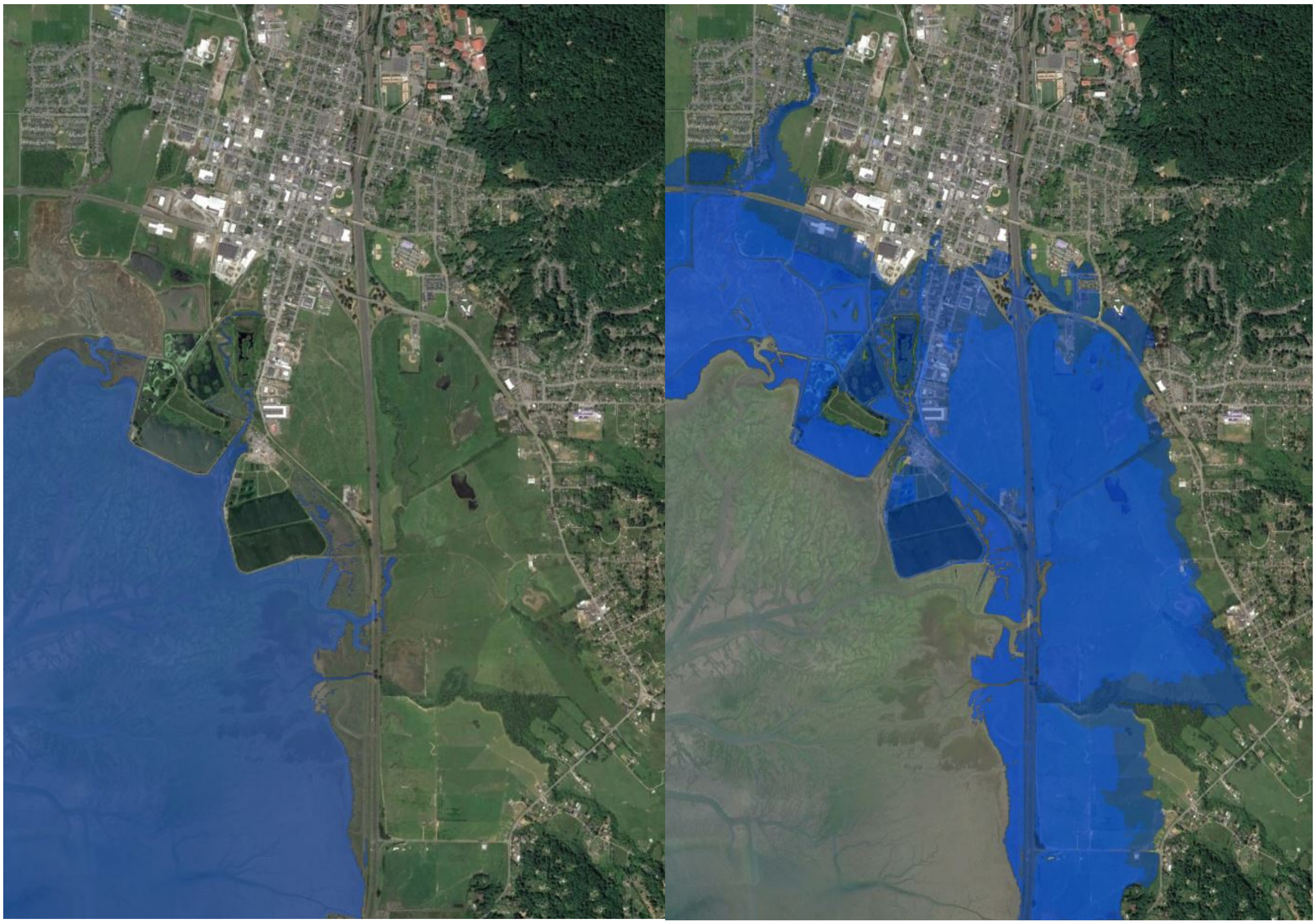
2-2018

City of Arcata Sea Level Rise Vulnerability Assessment

Aldaron Laird

City of Arcata



Current Tidal Inundation Areas versus Potential Tidal Inundation Areas (Stillwater)
with 4.6 feet (1.5 meters) of Sea Level Rise

Sea Level Rise
Vulnerability Assessment

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CITY OF ARCATA

Local Coastal Program

Sea Level Rise
Vulnerability Assessment

Prepared By

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Acknowledgements

Sea level rise vulnerability assessments and adaptation planning on Humboldt Bay have been greatly enabled by the research and engineering of Jeff Anderson of Northern Hydrology and Engineers. Combined with the equally valuable research by geologist at Cascadia Geosciences, planners now have the tools to educate the public, agencies, and decision-makers about sea level rise on Humboldt Bay.

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Glossary

Numerous technical terms are defined upfront for the reader, to enable a greater understanding of the material presented in this report. This report relies in part on terms and definitions that were derived from the California Coastal Commission (Commission) Sea Level Rise Policy Guidance (2015).

Adaptation: Adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which minimizes harm or takes advantage of beneficial opportunities.

Adaptive capacity: The ability of a system to respond to climate change (including climate variability and extremes), moderate potential damages, take advantage of opportunities, and cope with the consequences.

Backwater or Backwater flooding: Upstream flooding caused by downstream conditions such as channel restriction or high tide blocking high river flows from entering estuaries.

Coastal-dependent development or use: Any development or use which requires a site on, or adjacent to, the sea to be able to function at all.

Coastal resources: A general term used throughout the Guidance to refer to those resources addressed in Chapter 3 of the California Coastal Act, including beaches, wetlands, agricultural lands, and other coastal habitats; coastal development; public access and recreation opportunities; cultural, archaeological, and paleontological resources; and scenic and visual qualities.

Development: On land, in or under water, the placement or erection of any solid material or structure; discharge or disposal of any dredged material or of any gaseous, liquid, solid, or thermal waste; grading, removing, dredging, mining, or extraction of any materials; change in the density or intensity of use of land, including, but not limited to, subdivision pursuant to the Subdivision Map Act (commencing with Section 66410 of the Government Code), and any other division of land, including lot splits, except where the land division is brought about in connection with the purchase of such land by a public agency for public recreational use; change in the intensity of use of water, or of access thereto; construction, reconstruction, demolition, or alteration of the size of any structure, including any facility of any private, public, or municipal utility; and the removal or harvesting of major vegetation other than for agricultural purposes, kelp harvesting, and timber operations which are in accordance with a timber harvesting plan submitted pursuant to the provisions of the Z'berg-Nejedly Forest Practice of 1973 (commencing with Section 4511).

Environmentally Sensitive Habitat Area (ESHA): Any area in which plant or animal life or their habitats are either rare or especially valuable because of their special nature or role in an ecosystem and which could be easily disturbed or degraded by human activities and developments.

Erosion: The wearing away of land and removal of shoreline, beach or sand dune sediments by wave action, high tides, tidal currents, and overtopping shoreline structures such as dikes.

Flood (or Flooding): Refers to normally dry land becoming temporarily covered in water, either episodically (*e.g.*, storm or tsunami flooding) or periodically (*e.g.*, tidal flooding). Annual king tides are an example of tidal flooding of lands normally not covered by daily or monthly high tides. Coastal Hazard planning generally addresses episodic 100-year floods that have 1% probability of occurring in any year but like all floods are unpredictable as to when they might occur. Floods do recede, and flooded lands generally do dry out again.

Inundation: Inundation as used in this report is a form of tidal flooding. Inter-tidal areas are those lands above the lowest tide and below the highest tide elevations that periodically experience tidal inundation. Areas that are below the lowest tide elevation are submerged lands, and thus are permanently inundated. Tidal inundation datums are generally described as to their frequency of occurrence and elevation, such as daily mean low or high water (MLW and MHW); mean monthly and mean annual maximum high water are additional tidal datums (MMMW and MAMW). Tidal inundation is very predictable. Tide charts are published each year that identify when, and how low or high, the tides are expected reach common daily tidal datums: mean lower low water (MLLW), MLW, MHW, and mean higher high water (MHHW). Inundation maps used in this report depict areas that could be inundated by MMMW under various sea level rise scenarios, absent storm surge or wind wave conditions.

Mean sea level: The average relative sea level over a period, such as a month or a year, long enough to average out transients such as waves and tides.

Relative sea level: Combination of regional sea level measured by a tide gauge and vertical land motion trends of the land upon which the gauge is situated.

Risk: Commonly considered to be the combination of the likelihood of an event and its consequences – *i.e.*, risk equals the probability of climate hazard occurring multiplied by the consequences a given system may experience.

Sea level: The height of the ocean relative to land; tides, wind, atmospheric pressure changes, heating, cooling, and other factors cause sea level changes.

Sea level change/sea level rise: Sea level can change, both globally and locally, due to (a) changes in the shape of the ocean basins, (b) changes in the total mass of water and (c) changes in water density. Factors leading to sea level rise under global warming include both increases in the total mass of water from the melting of land-based snow and ice, and changes in water density from an increase in ocean water temperatures and salinity changes. Relative sea level rise occurs where there is a local increase in the level of the ocean relative to the land, which might be due to ocean rise and/or land level subsidence.

Sea level rise impact: An effect of sea level rise on the structure or function of a system.

Sensitivity: The degree to which a system is affected, either adversely or beneficially, by climate-related stimuli. The effect may be direct (*e.g.*, a change in crop yield in response to a change in the mean, range, or variability of temperature) or indirect (*e.g.*, climatic or non-climatic stressors may cause people to be more sensitive to additional extreme conditions from climate change than they would be in the absence of these stressors).

Shore protection: Structures or sand placed at or on the shore to reduce or eliminate upland damage from wave action or flooding during storms.

Shoreline protective devices: A broad term for constructed features such as seawalls, revetments, riprap, earthen berms, cave fills, and bulkheads that block the landward retreat of the shoreline and are used to protect structures or other features from erosion and other hazards.

Shoreline vulnerability rating: A quantitative measure of vulnerability that uses combinations of shoreline attributes (cover type and relative elevation to modeled MMMW) to rank shoreline segment's vulnerability to erosion and/or overtopping due to extreme tides, storm surges, and sea level rise. (Laird and Powell 2013).

Still water level: The elevation that the surface of the water would assume if all wave action was absent.

Storm surge: A rise above normal water level on the open coast due to the action of wind stress on the water surface. Storm surge resulting from a hurricane also includes the rise in water level due to atmospheric pressure reduction as well as that due to wind stress.

Subsidence: Sinking or down-warping of a part of the earth's surface; can result from seismic activity, changes in loadings on the earth's surface, fluid extraction, or soil settlement.

Tectonic: Of or relating to the structure of the earth's crust and the large-scale processes that take place within it.

Tidelands: Lands which are located between the lines of mean high tide and mean low tide.

Vulnerability: The extent to which a species, habitat, ecosystem, or human system is susceptible to harm from sea level rise impacts. More specifically, the degree to which a system is exposed to, susceptible to, and unable to cope with, the adverse effects of sea level rise, and tidal extremes.

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Sea Level Rise Vulnerability Assessment Methods

The City of Arcata’s approach to assessing vulnerability to sea level rise in its planning jurisdiction is to identify the effects of specific water elevations, such as the mean monthly maximum water (MMMW) tidal datum. Because the uncertainty of sea level rise projections for any planning horizon generates an ever-increasing range of water levels over time, more confidence is provided to the public by the City’s focus on the effects of specific water level increases, rather than when those increased levels may occur. This is a departure from the California Coastal Commission’s (Commission) 2015 Sea Level Rise Policy Guidance and the January 2017 Memorandum summarizing steps for conducting sea level rise vulnerability assessments. The Commission recommends that sea level rise exposure scenarios associated with specific planning horizons based on high sea level rise projections should be considered for vulnerability assessments and adaptation planning. Projections based on low or high greenhouse gas emissions and contributions from melting ice are constantly being revised, ever upward. While the Commission does encourage utilizing specific water elevations in addition to planning horizons to reduce concerns over uncertainty of sea level rise projections, particularly for planning horizons after 2050. The City believes that it is more prudent to focus its sea level rise vulnerability assessment and adaptation planning based on the best available science and engineering and rely on specific increases in water elevations, and not a range of sea level rise projections.

All surface elevations in this report are North American vertical datum of 1988 (NAVD 88) and measured at the North Spit tide gauge (National Oceanic and Atmospheric Agency (NOAA) Station 9418767). California planners, and engineers, and scientists often use different units of measure. Sea level rise planning documents generally refer to sea level rise in feet (ft.), while engineers/scientists who create sea level rise models and maps are likely to use meters (m). To facilitate the public’s use of information presented in this report, it relies on English units of measure (feet) and offers metric conversions.

This report uses two approaches to address sea level rise on Humboldt Bay:

1) shoreline elevation profile, and
2) inundation modeling and mapping.

A shoreline elevation profile, utilizing the baseline MMMW elevation of 7.7 ft., was used to identify shoreline segments that are vulnerable to sea level rise, in one-foot increments (Laird and Powell 2013). Sea level rise vulnerability assessment efforts on Humboldt Bay have selected the MMMW as a baseline because it correlates well with the current upper boundary of tidal vegetation on the shoreline.

Hydrodynamic modeling and inundation vulnerability mapping prepared for Humboldt Bay by Northern Hydrology and Engineering (NHE) depicts and quantifies areas that are potentially vulnerable to being inundated, with the assumption that shoreline structures (dikes) are absent or not functioning, by specific water elevations, including:

- MMMW (7.7 ft.),
- mean annual maximum water (MAMW) (8.8 ft.),
- MMMW+0.5-meter (M) (9.3 ft.),
- MMMW+1.0 M (11.0 ft.), and
- MMMW+1.5 M (12.6 ft.) (NHE 2015).

The inundation maps depict still water conditions, with no wave run-up or storm surge incorporated.

NHE's inundation maps of Humboldt Bay are the best maps available and are used as the basis for identifying areas that are potentially vulnerable to sea level rise and quantifying impacts for purposes of this report. For example, they are used to visually depict the extent of tidal inundation from sea level rise absent the effects of protective barrier-like structures such as dikes and road grades, commonly referred to as a "bathtub model". The integrity of the entire protective shoreline in a common hydrologic unit needs to be maintained to prevent inundation of the low-lying areas behind the shoreline, not just the shoreline in front of an asset. A single breach would cause the inundation of the entire hydrologic unit and all assets residing behind that common shoreline. With six feet of sea level rise, 92% of the current artificial shoreline would be overtopped; the low-lying land behind artificial shorelines would be inundated.

Executive Summary

With three feet of sea level rise, the most critical and vulnerable asset in the City of Arcata is its wastewater collection system and treatment facility, including the Arcata Marsh. The City is not sustainable if its wastewater infrastructure is compromised. The risk to wastewater infrastructure is ongoing. Based on existing conditions, exposure of wastewater infrastructure will become critical due to the combination of two feet of sea level rise and king tides that could result in three feet of sea level rise for several days a year.

Humboldt Bay will expand in response to three feet of sea level rise while the available footprint for urban development and open space areas used for agriculture and wildlife will decrease. The majority of the City is not directly vulnerable to sea level rise. However, vulnerable areas include the former tidelands south of Samoa Boulevard and west of Old Arcata Road that were isolated from Humboldt Bay in 1890, including associated infrastructure and land uses.

Other assets located in these vulnerable areas include Highways 101 and 255, industrial and residential property, Pacific Gas and Electric's gas lines and electrical transmission structures, optical fiber lines, the Humboldt Bay Trail, and the Bayside Wildlife reserve. Likewise, the City of Eureka's municipal water transmission line, which traverses vulnerable former tidelands within the City of Arcata, and is also a critical, at-risk asset.

Today, there are approximately 52 miles of shoreline on Humboldt Bay that form a barrier protecting nearly 10,000 low-lying acres from tidal inundation. A New Year's Eve 2005 king tide and storm surge caused sea levels to rise 1.8 feet, the highest water level ever recorded on Humboldt Bay. The Governor responded by declaring a State of Disaster (Figure 1). King tides could reach 2005 levels on an annual basis with just one foot of sea level rise. With three feet of sea level rise, roughly 35 miles of barrier shoreline (58% of the artificial shoreline) could be overtopped. Approximately 10,000 acres of agricultural land, Highways 101 and 255, municipal water and wastewater lines, electrical distribution infrastructure, gas lines, and optical fiber communications lines could all become tidally inundated if tidal waters on Humboldt Bay rise three feet. The current mean annual maximum tide (MAMW) of 8.8 ft.—king tides— would become equivalent to daily mean high tide (MHW) with three feet of sea level rise.

Figure 1. New Year's Eve 2005 king tide with dikes filled to overtopping in Arcata.

The effects of three feet of sea level rise in the City's Local Coastal Program (LCP) planning area would be significant. Roughly 3.4 miles (49%) of the shoreline in the City would be overtopped. The shorelines on Butcher Slough and Gannon Slough would be overtopped and substantial tidal inundation of the City's Waste Water Treatment Facility (Treatment Plant) and Arcata Marsh and Wildlife Sanctuary (Arcata Marsh), as well as the residential, industrial properties, and agricultural lands south of Samoa Boulevard would occur.

With three feet (1.0 M) of sea level rise, nearly 684 acres (78%) of the agricultural lands, 249 acres (84%) of the natural resource lands, 29 acres (37%) of the public facilities, 63 acres (46%) of the industrial property, and 21 acres (15%) of the residential area in the City's LCP planning area would become tidally inundated.

Most of the City's streets south of Samoa Boulevard would become tidally inundated with three feet (1.0 M) of sea level rise, as would the Bayside Cutoff. Highway 101, as it traverses Arcata Bay and Highway 255 on the Mad River Bottom adjacent to the City, would be tidally inundated. Roughly 1.4 miles of railroad and the recently constructed Humboldt Bay Trail would become tidally inundated.

Approximately 2.6 miles of municipal water transmission lines and one pump station, 3.7 miles of sewer lines and one lift station, 2.8 miles of gas lines, and nine electrical transmission towers and 30 transmission poles would be tidally inundated.

There are 1,639 acres of environmentally sensitive habitat (ESHA) in the City's LCP planning area, including open water, eelgrass, mudflats, salt marsh and seasonal freshwater wetlands (pasture). With three feet (1.0 M) of sea level rise, tidal inundation would expand mud flats by 735 acres and salt marsh by 261 acres; seasonal freshwater wetlands would shrink by 393 acres. Eelgrass habitat, currently a valuable habitat on Humboldt Bay, could expand by 62 acres.

While it is necessary to locate and assess individual assets in areas vulnerable to sea level rise, to do so is not a complete vulnerability assessment by itself. Assets do not exist in a vacuum. Assets are intricately linked to and served by multiple regional assets, including municipal water, wastewater, electricity, natural gas, optical fibers, local streets and Highway 101. Focusing on just one asset or one location would omit the inter-connectedness of other related assets and their vulnerabilities. For example, even if all the residences in the vulnerable area south of Samoa Boulevard had livable floor elevations above the 100-year sea level rise projection, they would still be vulnerable and at risk when local streets and utilities become tidally inundated.

Unique to the north coast region of California, relative sea level rise (a combination of vertical land motion trends and regional sea levels) projections and potential inundation maps have been developed for Humboldt Bay. Both tools have informed the preparation of this vulnerability assessment report. The City's sea level rise planning work is building on previous regional vulnerability assessments and adaptation planning efforts as well as state guidance.

Based on available tidal inundation maps (NHE 2015), this report emphasizes impact assessment for specific water elevations [1.1 ft. (MAMW), 1.6 ft. (0.5 M), 3.3 ft. (1.0 M) and 4.9 ft. (1.5 M)] relative to various assets, rather than assessing a range of potential sea level rise projections for specific planning horizons (2030, 2050, and 2100). This report focuses on informing the public, agencies, and decision-makers about where, what, and how a particular level of sea level rise could have impacts, regardless of when that sea level rise level might occur.

Sea levels on Humboldt Bay currently vary by three feet: daily MHW is 5.8 ft. and MAMW is 8.8 ft. Sea levels on Humboldt Bay tend to be highest in the winter months when king tides provide real time examples of the impacts of one or more feet of sea level rise. Despite the conclusions of recent federal and state sea level rise reports (NRC 2012 and Griggs 2017), Humboldt Bay has the highest rate of sea level change on the west cost of the United States, rising 18 inches over the last century. Local geologists and engineers have studied regionally specific vertical land motion (Patton 2017) and tidal modeling (NHE 2015); these studies and models are the technical basis for this vulnerability assessment.

The primary near-term sea level rise impacts to the assets within the City's LCP planning area are shoreline erosion and the resultant tidal inundation due to extreme tidal events and storms. Long-term impacts include backwater flooding (a result of downstream blockage from higher tides), rising groundwater and salt water intrusion. Because, in the long-term, sea level rise would be compounded by rising groundwater and would likely overcome barrier-like shoreline structures, Humboldt Bay would expand and reclaim thousands of acres of former tidelands.

The next step in planning for sea level rise is to develop adaptation policies and measures. The City of Arcata is preparing adaptation polices for its LCP planning area. However, the Commission retains the authority to issue coastal development permits pursuant to the Coastal Act for tidelands, submerged lands and public trust lands. In the case of the City of Arcata, the Commission retains permit jurisdiction on approximately 969 acres (86%) of the 1,550 acres that are vulnerable to tidal inundation with 4.9 ft. (1.5 M) of sea level rise. The challenge for the City of Arcata and the Commission will be to integrate the application of their authorities to effectively and efficiently address the impacts of sea level rise on coastal resources and developments.

1 Introduction

The purpose of this report is to inform the public, property owners, agencies, and land use and resource decision-makers of the vulnerability and risk from sea level rise and tidal inundation that exists on Humboldt Bay.

This vulnerability assessment is needed to apply the tidal inundation modeling and mapping prepared for Humboldt Bay and inform people about areas and assets that are vulnerable to and at risk from sea level rise and tidal inundation. Relative sea level rise projections have also been developed for Humboldt Bay that can be utilized to assess risk to areas and assets. A region-wide vulnerability assessment of sea level rise exposure can provide opportunities for coordinating adaptation strategies, policies, and measures across jurisdictional boundaries.

The City of Arcata is updating its LCP and desires to identify areas that may be exposed to sea level rise. This inventory and assessment of the assets at risk to sea level rise builds on prior work by the Humboldt Bay Sea Level Rise Adaptation Planning Project. That planning effort began with inventorying and mapping (structure, cover, and elevation) the 102 miles of shoreline on Humboldt Bay and assigning a vulnerability rating to the shoreline reflecting its vulnerability to erosion or overtopping by extreme tides or projected sea level rise by 2050 (Laird and Powell 2013). The project also involved preparing relative sea level rise projections through 2100 (NHE 2014a) and a sea level rise hydrodynamic model and potential inundation maps of areas surrounding Humboldt Bay (NHE 2015). These potential inundation maps are available to the public as GIS shapefiles and Google Earth kmz files from the Humboldt Bay Harbor, Recreation and Conservation District (Harbor District) sea level rise adaptation planning project web site, http://humboldtbay.org/humboldt-bay-sea-level-rise-adaptation-planning-project .

The Humboldt Bay Sea Level Rise Adaptation Planning Project also involved the formation of a regional sea level rise adaptation planning group which included the City and twenty-one other regional stakeholders with land use, land management, or resources management responsibilities or advisory roles on lands adjacent to Humboldt Bay that are vulnerable to sea level rise impacts, and culminated in the production of a regional vulnerability assessment adaptation plan for Humboldt Bay (Laird 2015). These assessment and planning efforts led all three LCP authorities on Humboldt Bay (City of Arcata and Eureka, and Humboldt County) to request and secure grants to address sea level rise as part of the update of their LCPs.

The City would also like to assess what developments or land uses (assets) may be vulnerable (exposed, susceptible, and unable to cope) to sea level rise. This report would describe current sea level datums and shoreline conditions on Humboldt Bay (Laird 2013), potential sea level rise inundation areas for MAMW (1.1 ft.), and three sea level rise elevations—1.6 ft. (0.5 M), 3.3 ft. (1.0 M) and 4.9 ft. (1.5 M)] (NHE 2015). This report builds on previous vulnerability and risk assessments that were prepared by regional sea level rise adaptation planning efforts on Humboldt Bay, such as Laird and Powell (2014), NHE (2015), and Laird (2015 and 2016).

This report's assessment of asset vulnerability and risk is presented under five major asset classes: shoreline, land uses, transportation, utilities, and coastal resources. While this report summarizes and presents information based on available GIS-based shoreline and inundation mapping of Humboldt Bay, it is not a substitute for using these mapping tools for site-specific information.

In summary, this vulnerability and risk assessment utilizes the best available science to identify areas and assets that might be exposed to sea level rise. This report would also describe existing asset vulnerabilities and risks not directly attributable to sea level rise but due to potential barrier-type (dike) shoreline failures. This information is critical to property owners, the public, and the City to inform land use decisions.

The City's LCP, occupies approximately 1,550 acres above or landward of mean sea level (MSL) 3.4 ft. (Figure 2). The state has retained jurisdiction under the Coastal Act on approximately 969 acres (62.5%) of the 1,550 acres that are vulnerable to tidal inundation with 4.9 ft. (1.5 M) of sea level rise. There an additional 10 acres that are vulnerable to tidal inundation by 4.9 ft. (1.5 M) of sea level rise, which are inland of the City's LCP planning area.

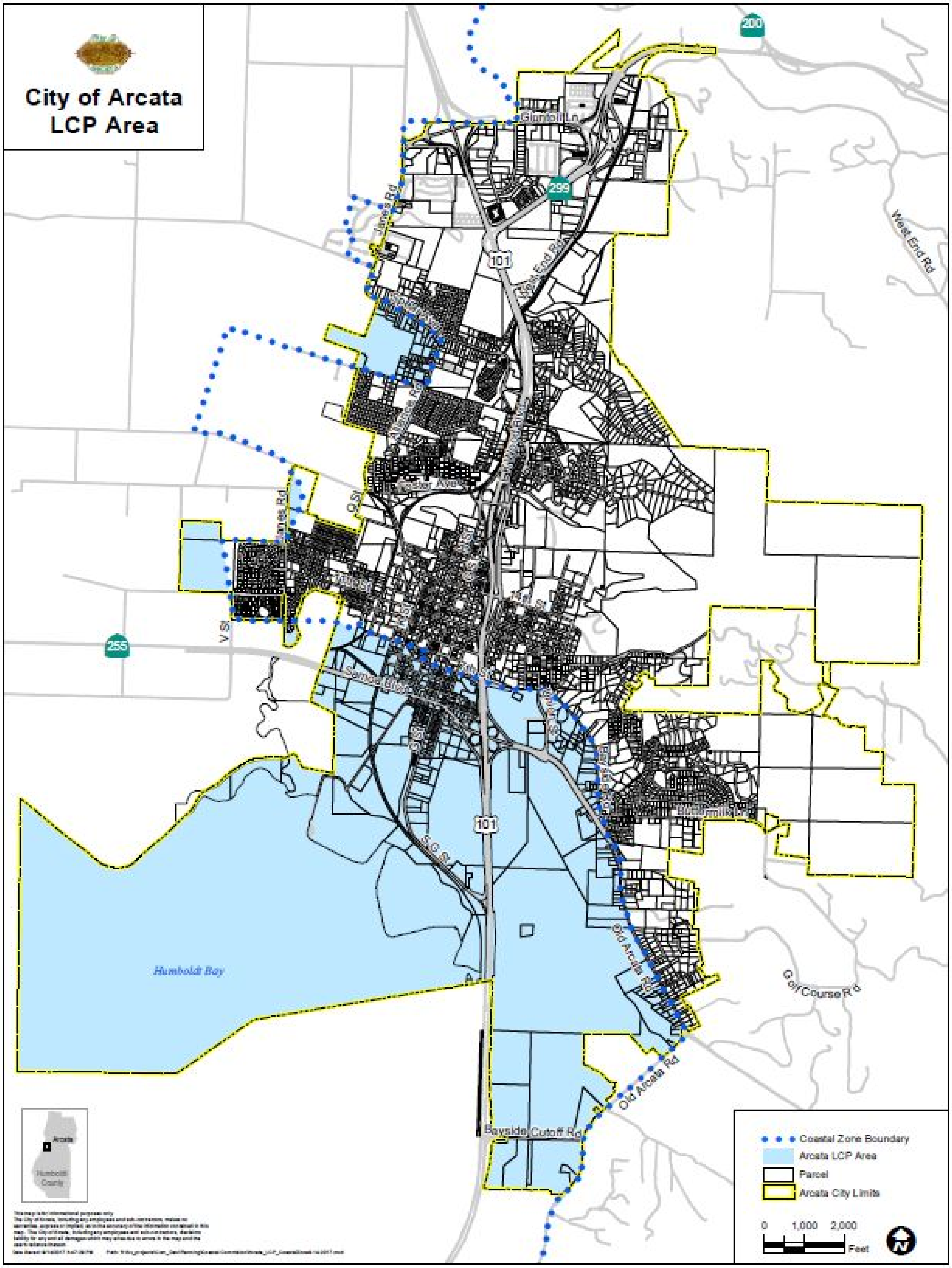

Figure 2. City of Arcata's LCP area.

The hydrodynamic model of Humboldt Bay produced in 2014 (NHE 2014b) is the source of potential tidal inundation (still-water) area predictions used to assess vulnerability and risk in this report. The inundation mapping assumes there are no shoreline structures and identifies potential conditions that could occur if barrier-like shoreline structures are breached or overtopped absent future implementation of sea level rise preparedness measures (NHE 2015). The limits of inundation that have been delineated are based on 2012 surface elevations (Figure 3). The Federal Emergency Management Agency (FEMA) has revised its Flood Insurance Rate Maps (FIRM) for Humboldt Bay. FEMA also did not consider existing shoreline structures on Humboldt Bay when it mapped flood hazard zones, unless they were federally certified structures. There are no federally certified structures on Humboldt Bay (FEMA 2016).

In this report, asset exposure is described using the following criteria:

- Assumes failure of barrier-like shoreline structures,
- Exposure to 1.1 ft. of sea level rise, equivalent to the MAMW elevation (8.8 ft.), and
- Sea level rise above the MMMW elevation in increments of 1.6 ft. (0.5 M) to 4.9 ft. (1.5 M).

Figure 3. Predicted tidal inundation areas (stillwater) on Mad River Slough, Mad River Bottom, and Arcata illustrate increasing inundation footprint for 1.1 ft. (MAMW), 1.6 ft. (0.5 M), 3.3 ft. (1.0 M), and 4.9 ft. (1.5 M) of sea level rise.

2 Sea Level Rise

2.1 Humboldt Bay Tidal Datums

There are a variety of different reference points, or tidal datums, used to measure tidal elevations, depending on the tidal phase of interest and the type of tides present along a shoreline (NOAA 2001). A typical tidal cycle involves two high tides and two low tides within a single daily cycle. On Humboldt Bay, the two high tides are not equivalent; one is higher than the other. The same is true for the low tides. These types of mixed tidal cycles result in tidal datums such as mean lower low water (MLLW) and mean higher high water (MHHW). Other recognized tidal datums include mean low water (MLW), mean sea level (MSL), mean high water (MHW, considered representative of the wetted shoreline), and mean annual maximum water (MAMW), often referred to as king tides (Table 1). The North Spit tide gauge record can be found at (http://tidesandcurrents.noaa.gov/stationhome.html?id=9418767).

Table 1. Tidal datums and elevations for Humboldt Bay as measured at the NOAA North Spit tide gage.

Tidal Datum	Description	Elevation (ft.)
MLLW	Mean Lower Low Water	-0.34
MLW	Mean Low Water	0.91
MSL	Mean Sea Level	3.36
MHW	Mean High Water	5.8
MHHW	Mean Higher High Water	6.51
MMMW	Mean Monthly Maximum Water	7.74
MAMW	Mean Annual Maximum Water	8.78

Because sea level is rising in response to climate change, the tidal datum against which sea levels are measured should be consistent. The Regional Humboldt Bay Sea Level Rise Adaptation Planning Project utilized MMMW of 7.7 ft., known as spring tides, as the tidal base elevation to assess shoreline vulnerability to map areas that could be vulnerable to tidal inundation should the existing barrier-like shoreline be breached. While not an official tidal datum that NOAA normally provides for its tide gauges, MMMW was selected. On Humboldt Bay MMMW is closely associated with the upper elevation of tidally influenced vegetation on natural shorelines and the tidal and upland boundary and is easy to delineate.

During a single year, sea levels on Humboldt Bay can vary by three ft. (±1.0 M). Daily MHW is 5.8 ft. and MMMW is 7.7 ft., and annual king tides (MAMW) are 8.8 ft. Sea levels on Humboldt Bay tend to be highest in the winter months. Mean annual maximum tides (MAMW) occur in winter and are typically one foot higher than MMMW. In addition, El Niño events, low pressure systems, stormwater runoff, and storm surges can also add up to one foot to winter tidal elevations. In 1983, a severe El Niño raised tides to 9.4 ft. Since 2001, there have been four years where annual maximum tides reached similar or greater elevations than the last significant El Niño events: 2001 (9.3 ft.), 2003 (9.5 ft.), 2005 (9.5 ft.), 2006 (9.5 ft.) (Figure 4).

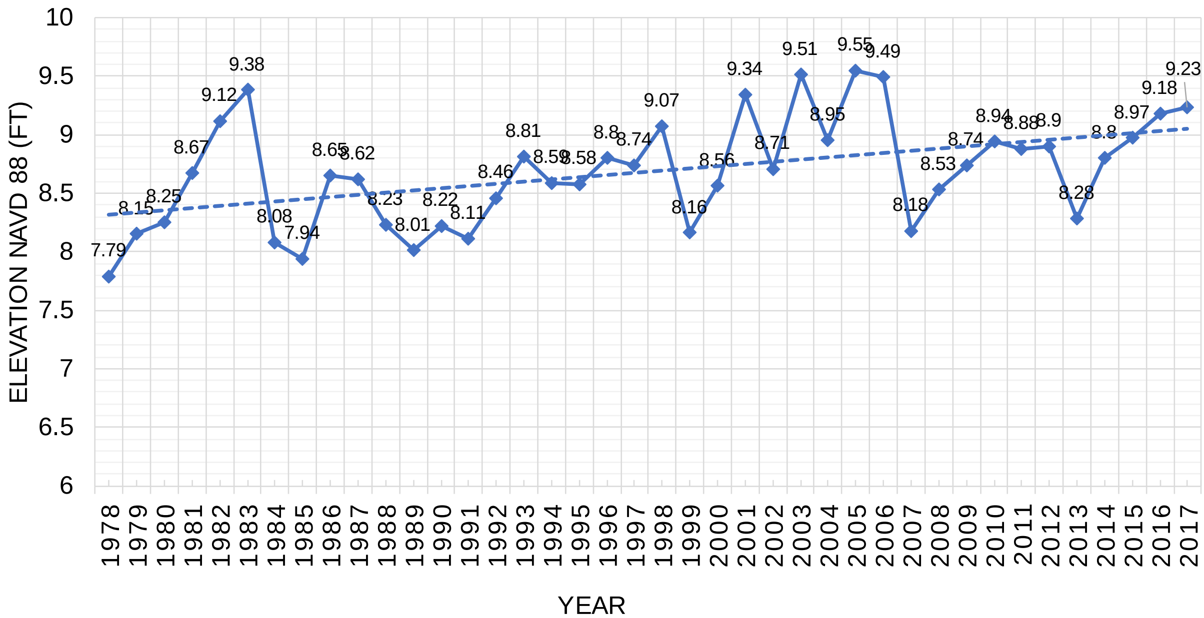

Figure 4. Annual maximum high tide elevations (king tides) at the North Spit tide gage.

Annual maximum or king tides elevations have varied by 1.8 ft. (ranging from 7.8 to 9.5 ft.) during the North Spit's 40-year record. The highest tide was 9.55 ft. and is illustrative of 1.9 ft. of sea level rise over the MMMW elevation of 7.7 ft., which is the high projection for 2050. The Governor declared a state of disaster on Humboldt Bay in 2006 in the aftermath of storm damage largely due to high rainfall and high winds, with storm surge combined with that extreme tide of 9.5 ft. as a contributing factor. This same tidal elevation could become the MMM—the monthly norm— tide elevation by 2050.

Unlike extreme storm events, also known as 100-year floods that have 1% probability of occurring in any year, sea levels are very predictable. The date, time, and expected height of king tides are known. Local and regional weather can affect water levels; therefore, there are often observable differences from the predicted tide elevations. This report, unlike hazard mitigation plans, does not utilize extreme storm events to conduct its vulnerability and risk assessment of assets on Humboldt Bay.

Tide frequency is also a predictable parameter. For example, the number of days that current MAMW elevation of 8.8 ft. is equaled or exceeded is four days per year, but with 1.6 ft. (0.5 M) of sea level rise, these high tides would equal or exceed 8.8 ft. 125 days per year. With 3.3 ft. (1.0 M) of sea level rise, these same high tides would equal or exceed MAMW 355 days per year (NHE 2017). Sea level rise would likely manifest as tidal inundation from king tides as nuisance flooding and increase in frequency with sea level rise to become chronic flooding and ultimately tidal conversion.

2.2 Sea Level Rise and Impacts

Currently, tidal elevations in Humboldt Bay are affected by regional sea levels and vertical land motion trends. Combining sea level rise and tectonic subsidence would result in a greater net change in water elevations than what would be experienced from sea level rise alone. Conversely, sea level rise combined with tectonic uplift could result in no net change in water elevation, which appears to be what is occurring at Crescent City. According to Cascadia GeoSciences, since 1977 Humboldt Bay has been subsiding -0.09 inches/year at an average rate of 0.18 inches/year (18 inches per century), which is greater than anywhere else in California (Patton 2014). While the Commission's Policy Guidance recommends assessing impacts from sea level rise based on high projections for 2030, 2050, and 2100, this report is focusing on specific water elevations for MAMW and 0.5-meter intervals of sea level rise (0.5, 1.0 and 1.5 M). Under present shoreline conditions, 51% of the diked shoreline on Humboldt Bay could be breached or be overtopped by approximately three feet (1.0 M) of sea level rise.

Sea level rise is an effect of climate change, specifically from the warming of the atmosphere and oceans up until now. Melting ice from areas like Greenland and Antarctica have the potential to greatly accelerate the rate and elevations of sea level rise, particularly after 2050. Sea levels can also increase or decrease because of vertical land movement, from tectonic forces. Rising sea levels would directly affect the shoreline and consequently adjacent lands and developments.

Sea level rise would likely exacerbate coastal hazards experienced in Humboldt Bay, including: tidal inundation (via shoreline breaching and/or overtopping), flooding (drainage impaired backwater and emerging groundwater), shoreline erosion and retreat, and salt water intrusion. Sea level rise would increase the hazard effects of extreme tides, wind waves, and low-pressure systems/storm surges on the shoreline of Humboldt Bay would reduce drainage capacity of water control structures, resulting in rising groundwater and salt water intrusion.

Rising sea level effects include:

- Increase in elevation of daily and monthly high tides as well as extreme high tides and 100-year storm flood elevations.
- Shoreline erosion and retreat.
- Overtop, slump, and/or breach of barrier-type shoreline structure such as earthen dikes.

- Increase in elevation of low tides and increased flooding of low-lying areas by delaying drainage through tide gates, impeding stormwater runoff.
- Increase in groundwater elevations and flooding of low-lying areas.
- Saltwater intrusion of low-lying agricultural lands, adjacent aquifers or underground structures such as sewer lines and potentially wastewater treatment facilities.
- Expansion of Humboldt Bay's tidal prism as diked former tidelands become inundated, which could increase wave heights in the entrance channel and affect sediment movement in and throughout Humboldt Bay.

Diked shorelines can and have breached under existing tidal and storm conditions. Sea level rise would increase the frequency of these breaches until dikes are overtopped, resulting in the tidal inundation of the lands behind the dikes. Flooding refers to dry land becoming temporarily covered in water, either episodically (*e.g.*, storm or tsunami flooding) or periodically (*e.g.*, tidal flooding). Floods do recede, and flooded lands generally do dry out again. Inundation as used in this report is a form of tidal flooding. Inter-tidal areas are those lands above the lowest tide and below the highest tide elevations. Areas that are below the lowest tide elevation are submerged lands, and thus are permanently inundated. Inundation maps used in this report depict areas that could be inundated by MMMW under various sea level rise scenarios, absent storm surge or wind wave conditions.

Sea level rise has the potential to adversely affect assets located in the coastal zone. Coastal developments are vulnerable and at risk from tidal inundation, and flooding caused by rising groundwater, stormwater runoff backwater, and increased 100-year flood elevations. Assets on diked former tidelands are vulnerable under contemporary condition if dikes are eroded or breached these assets could be tidally inundated now.

Low-lying areas are subject to saltwater intrusion and flooding as the capacity of drainage structures such as tide gates and culverts are reduced by rising low tides. Saltwater intrusion of shallow agricultural wells particularly in areas behind dikes may increase.

Coastal habitats such as dunes and seasonal freshwater wetlands may be eroded or converted, while other habitats like inter-tidal wetlands may drown if there are no physical pathways for their migration inland in response to sea level rise. Public access to the bay and sloughs may become impaired by shoreline erosion, tidal inundation, or flooding of boating facilities. There are also tribal cultural resource sites located on the lands around the bay that may become tidally inundated by 2100. Open, or un-treated, contaminated sites could become tidally inundated or flooded resulting in pollution of waterways and degradation of water quality.

While not a sea level rise impact, shoreline erosion under the current tidal regime could have significant consequences on Humboldt Bay. The Humboldt Bay Shoreline Inventory, Mapping, and Sea Level Rise Vulnerability Assessment provided the first comprehensive evaluation of shoreline conditions (Laird and Powell 2013). Seventy-five percent (77 miles) of Humboldt Bay's shoreline is artificial, predominately consisting of earthen dikes (53%, 41 miles) and railroad beds (14%, 11 miles). These two types of linear shoreline structures were constructed between 1890 and 1915, which today, more than a century later, are approximately 1.5 ft. lower relative to current sea levels due to tectonic subsidence and global sea level rise (Russell and Griggs 2012). The dikes were built to hold back extreme high tides around the turn of the 20th century; those extreme high tide elevations are currently reached by our annual maximum tides (king tides) due to sea level rise and subsidence of land in and around Humboldt Bay (NHE 2014a). At this time, the railroad has not been used commercially for more than two decades, and much of the railroad bed has not been maintained. As a result, much of the diked and railroad beds shoreline are currently vulnerable to overtopping by MAMW, storm surges and stormwater runoff, low pressure systems, wind waves, and El Niño conditions.

The vulnerability of these shoreline structures is compounded by the fact that no single entity is responsible for their improvement or maintenance. Approximately 21 miles of shoreline composed of dikes and railroad beds are rated highly vulnerable to breaching or being overtopped (Laird and Powell 2013). Shoreline vulnerability rating is a quantitative measure of vulnerability that uses combinations of shoreline attributes (cover type and relative elevation to modeled MMMW) to rank shoreline segment's vulnerability to erosion and/or overtopping due to extreme tides, storm surges, and sea level rise (Laird and Powell 2013).

These dikes are a historical legacy that could enable tidal inundation of the assets behind these dikes if they are breached. This is occurring with increasing frequency on Humboldt Bay. Sea level rise would only increase the risk posed by these dikes on protected assets, unless adaptation measures are employed to increase their resiliency.

3 Vulnerable and at-Risk Assets

Coastal hazard assessments can occur at many scales: regional, city-wide, or parcel specific. This sea level rise vulnerability and risk assessment report addresses assets within the City's LCP planning area, on Arcata Bay. This assessment includes assets that are in areas that could be tidally inundated by sea level rise of up to 4.9 ft. (1.5 M), which is an approximate elevation of 13 ft. at the North Spit tide gage. Assets have been treated equally regardless of ownership. Many assets critical to a region like Humboldt Bay are privately owned (PG&E's Humboldt Bay Power Plant (HBPP), Generating Station (HBGS), and Independent Spent Fuel (Nuclear) Storage Installation (ISFSI)) or under the control of another agency, such as state highways 101 and 255.

Generally, underground assets would be at risk earlier from sea level rise due to tidal inundation, rising ground water, and salt water intrusion. Impacts to most above ground assets, except for current shoreline structures such as dikes and those assets located behind dikes on former tide lands, would follow. It is important to note that most of the underground assets are utilities essential to sustaining above ground developments and land uses, independent of whether the above ground assets are presently vulnerable to or at risk from sea level rise or flooding.

Diked former tide lands have compacted as much as two to three feet over the last century and are very prone to flooding by rising ground water, stormwater runoff, and rising tides that reduce drainage capacity of water control structures such as dikes and culverts. Because of compaction, these lands would have increased water depths due to stormwater runoff and tidal inundation if the dikes are breached or overtopped. Maintenance of utilities traversing these lands would be much more difficult.

The assets that are vulnerable and at risk from sea level rise have been grouped into five broad classes: shoreline structures, land uses, transportation, utilities, and coastal resources. These asset classes are further stratified into discrete asset types composed of individual assets (Table 2).

Table 2. Summary of asset classes and individual assets affected by sea level rise.

Asset Class	Individual Assets
Shoreline Structures	Artificial Natural
Land Uses	Agricultural Residential Commercial Industrial Public
Transportation	Surface Rail
Utilities	Drinking (Municipal) water Wastewater Electrical Natural Gas
Coastal Resources	Public access sites Environmentally sensitive habitat areas Cultural sites

3.1 Existing Shoreline

The shoreline of any coastal waterbody is where the effects of changing sea levels are likely to manifest first. Shoreline structures are the first line of defense in protecting assets inland from the shoreline. Depending on surface topography, a breach or overtopping of a shoreline structure in one location can result in the tidal inundation of low-lying areas away from the shoreline. It is often the case that the owners of vulnerable assets inland of shoreline structures do not own or maintain the structures protecting their assets. On Humboldt Bay, many shorelines result from historical legacies of tideland developments and are among the most critical assets to the future of the Humboldt Bay region as it adapts to sea level rise.

The shoreline on Humboldt Bay consists of 670 individual assessor parcels and several layers of overlapping shoreline development authorities and jurisdictions. Pursuant to the California Coastal Act, there are three LCPs that cover the Humboldt Bay shoreline: City of Arcata's LCP (29 parcels or 4.3%), Humboldt County's Humboldt Bay Area Plan (450 parcels or 67.2%), and City of Eureka's LCP (191 parcels or 28.5%). LCP's contain land use and zoning regulations applicable within the coastal zone and provide the local jurisdiction with coastal development permitting authority in areas outside retained state permit jurisdiction. In areas within the state's retained jurisdiction, which is generally the entire shoreline on Humboldt Bay, coastal development permits are issued by the Commission.

This chapter describes Humboldt Bay's and the City of Arcata's existing shoreline conditions, and shoreline exposure and sensitivity to the current tidal regime (Figure 5) and future sea levels. This chapter relies on the comprehensive field work and findings of the *Humboldt Bay Sea Level Rise Adaptation Planning Project's Shoreline Inventory, Mapping, and Vulnerability Assessment* (Laird and Powell 2013).

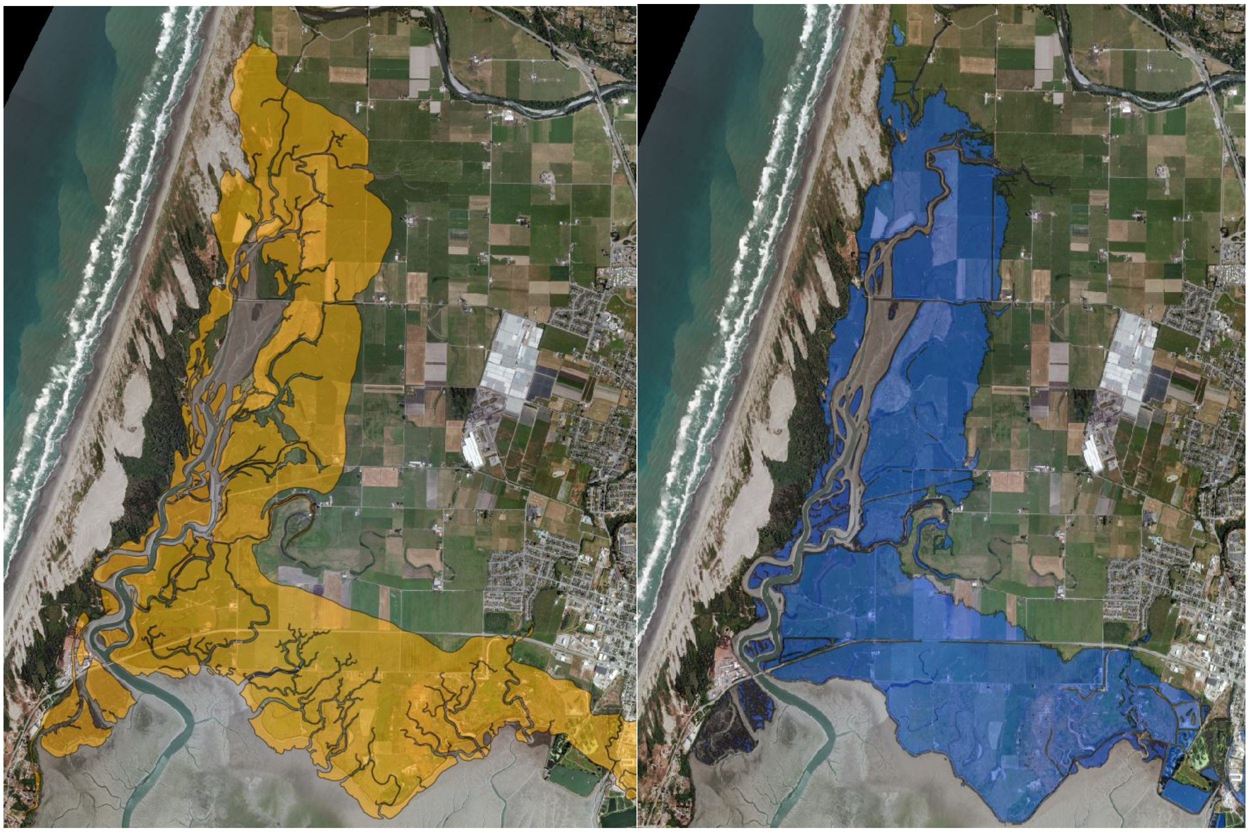

Figure 5. An example of the historic extent of tidal inundation on Mad River Slough and Arcata Bay, and the western portion of the City of Arcata (1870, yellow) and potential tidal inundation (stillwater), under current conditions by mean monthly maximum tides, if protective shoreline dikes are breached (blue).

3.1.1 Affected Shoreline Structures

Historically, as depicted in the original U.S. Surveyor General Township Plats of 1854, Humboldt Bay occupied approximately 25,800 acres: 15,300 acres (60%) was open water and inter-tidal mudflats, and 10,500 acres (40%) was inter-tidal wetlands (Laird 2007). Today Humboldt Bay still has roughly 15,300 acres of open water/mudflats. Only 1,545 acres of salt marsh remain today due to tideland reclamation for agricultural uses.

The shoreline of Humboldt Bay is defined as the boundary between the upper reach of the tidal zone and adjacent upland, often visible as the boundary between salt tolerant vegetation versus freshwater vegetation. Humboldt Bay naturally had approximately 60 miles of shoreline, which has increased to 102 miles under present conditions due to reclamation. On Humboldt Bay, the natural shoreline is closely associated with the MMMW surface elevation. Shorelines can be described, and their vulnerability assessed based on three attributes: structure, cover, and elevation.

There are two basic types of shoreline structure: natural and artificial (Figure 6). Beginning in 1892, the natural shoreline of Humboldt Bay underwent dramatic changes as the era of “tideland reclamation” began with the construction of a series of dikes to isolate salt marsh areas from tidal inundation. Tidegates were installed to allow the reclaimed fields to drain stormwater runoff during ebbing tides while preventing salt water inundation. By the 1930s, approximately 41 miles of earthen dikes had been constructed and nearly 8,100 acres (90%) of the salt marsh on Humboldt Bay was reclaimed for agricultural uses.

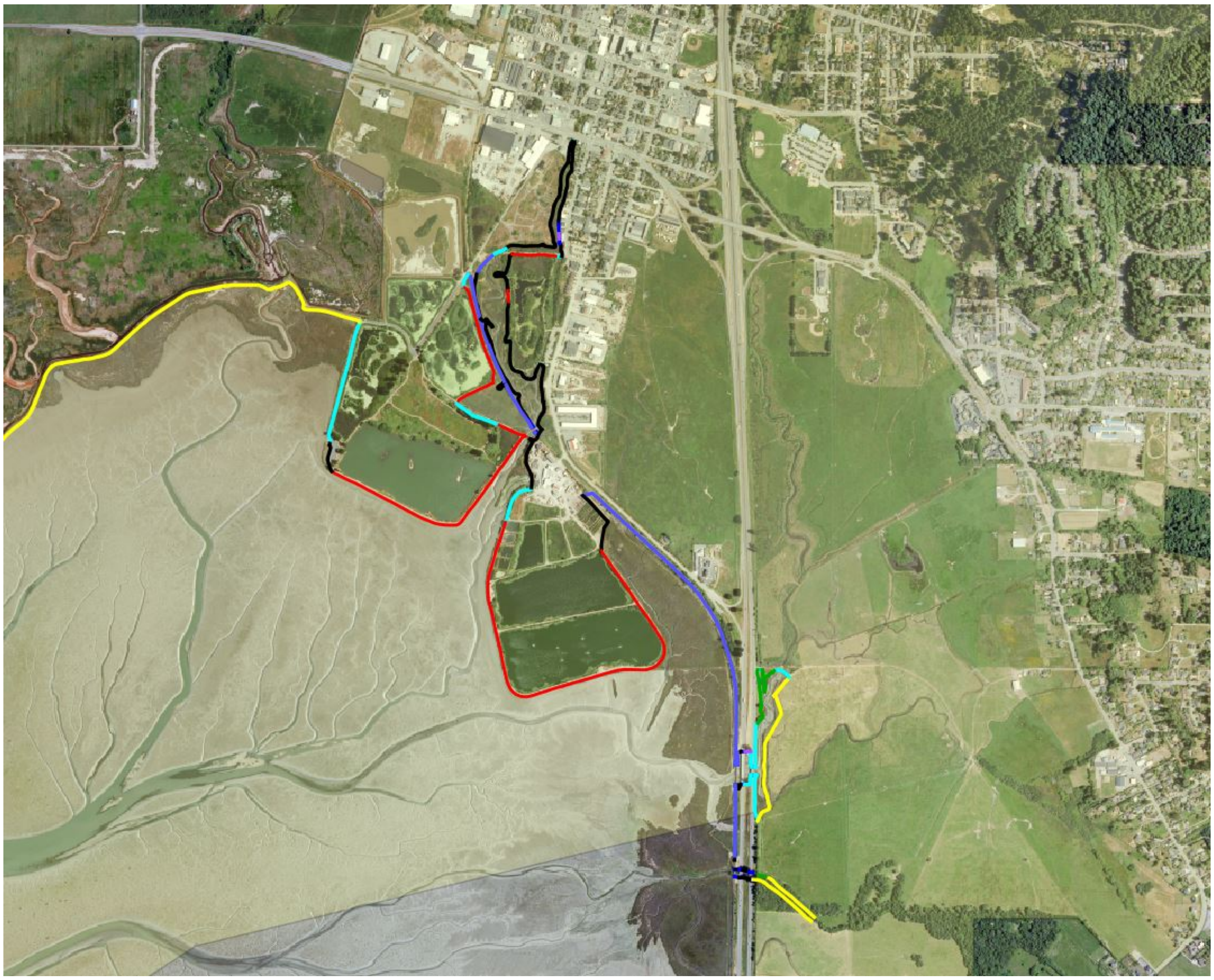

Figure 6. City of Arcata distribution of shoreline types: wastewater pond/marsh pond (red), fill (black), railroad grade (blue), dikes (yellow), and roads (turquoise).

Over the last century, with the loss of sediment accretion from daily tidal inundation, the surface elevation of these diked former tidelands has lowered due to compaction as organic material in the former salt marsh soils decomposed. Also, tectonic subsidence, as recorded at the North Spit tide gauge, has lowered the elevation of lands on Humboldt Bay by 15 inches in the past 100 years. Today, the combination of compaction and subsidence has caused former tidelands behind dikes to be much lower in elevation than adjacent salt marsh in Humboldt Bay. This circumstance, combined with the increased susceptibility of dikes overtopping by increasingly high tides, results in significant inundation risks to diked former tidelands because of sea level rise.

In 1895, a second wave of shoreline development ensued with construction of the first railroad tracks from the Eel River to Eureka, and then on to Arcata and Samoa. By 1904, railroad tracks would form 11 miles of shoreline on Humboldt Bay, isolating hundreds of acres of salt marsh. In 1912, the Redwood Highway (Highway 101) was constructed parallel to the railroad on the eastern shoreline of Humboldt Bay, thereby further reinforcing the tidal barrier and isolation of these former tidelands. Since the dramatic shoreline changes of the 1890s to 1910s, there have been only localized changes to the location of the shoreline. Today, there is no single entity responsible for the maintenance of the artificial shoreline on Humboldt Bay, which consists of 670 individual parcels and many different property owners.

In the City of Arcata's LCP planning area, there is approximately 7.0 miles of shoreline composed of the following types of structures (Figure 6):

1. wastewater pond/marsh dikes (1.9 miles or 27.1%),
2. fill (1.8 miles or 25.7%),
3. railroad grade (1.1 miles or 15.7%),
4. dike (1.0 miles or 14.3%), and
5. roads (0.8 miles or 11.4%).

In the City, there is only a limited 800-foot reach of natural shoreline located in the tidal zone of lower Jacoby Creek. Essentially the entire shoreline is composed of artificial structures located on 29 assessor parcels.

3.1.2 Exposure

Both natural and artificial shorelines are affected by extreme high tides and would be affected by sea level rise. On Humboldt Bay, artificial shoreline structures are primarily vulnerable to wave induced erosion and overtopping. Assets behind artificial shorelines are at risk from tidal inundation, flooding, and salt water intrusion. Sea level rise would reduce the drainage capacity of water control structures, while simultaneously causing rising groundwater and salt water intrusion.

One of the approaches to address sea level rise is to utilize the shoreline profile created for Humboldt Bay (Laird 2013). NOAA's 2012 LiDAR dataset, which reflects surface elevation in 2010, was used to generate a shoreline profile; an average relative elevation to MMMW elevation (7.7 ft.) was calculated in one-foot increments for each one-meter shoreline segment. With 75% of the shoreline on Humboldt Bay composed of man-made structures, it is important to establish the elevation of these structures. This information is necessary for an assessment of the shoreline's vulnerability to overtopping and inundation of the lands behind. Most (92%) of the artificial shoreline is less than or equal to an elevation that is six feet higher than MMMW elevation (13.7 ft.), 27% is less than or equal to an elevation that is just two feet higher than MMMW (9.7

ft.), and the majority (58%) of the artificial shoreline is less than or equal to an elevation that is only three feet higher than MMMW (10.7 ft.). As noted earlier, the extreme high tide of record on Humboldt Bay reached 9.5 ft., just 1.8 ft. higher than MMMW elevation. The resulting shoreline damage warranted the Governor declaring a state of emergency.

Barrier-like shoreline structures (dikes, railroad, and roads) can be breached by wave induced erosion, slumping, or overtopping. Independent of the size of the breach, this can tidally inundate significant areas of former tidelands.

Tidal inundation of other types of artificial shorelines (fortified and fill) can occur when tides overtop the shoreline structure. Under current conditions, overtopping would not tidally inundate significant areas of interior lands unless they are lower in elevation than the shoreline.

- Erosion

The shoreline segments in the City of Arcata that are actively eroding are limited in length and located at the foot of I Street at the Arcata Marsh parking lot, on Butcher Slough in the Arcata Marsh, and the earthen dikes on Gannon Slough. Should the earthen dikes on Gannon Slough be breached, approximately 360 acres could become tidally inundated by MMM tides reaching 7.7 ft. in elevation.

- Overtopping

Shoreline elevation is a critical attribute to the resiliency of shoreline structures to extreme high tides and sea level rise. While a well-fortified dike may not be vulnerable to coastal erosion on its waterward slope, if overtopped, a dike may be susceptible to breaching as the landward slope erodes.

Overtopping of shoreline structures is most likely to occur during MAMW or extreme high tides. Under the current tidal regime, MAMW elevation on Humboldt Bay is 8.8 ft., but it has varied by 1.8 ft. (7.8 ft. to 9.5 ft.) (Figure 4). In addition to the extreme high tides, FEMA has recently adopted a new 100-year flood elevation for Humboldt Bay of 10.2 ft., which is also capable of overtopping shoreline structures.

There are 4.3 miles of shoreline less or equal to 12.7 ft. in elevation that are vulnerable to five feet of sea level rise (Table 3).

Table 3.Shoreline structure length (miles) potentially overtopped by 1 feet (8.7 ft.), 2 feet (9.7 ft.), 3 feet (10.7 ft.), and 5 feet (12.7 ft.) of sea level rise and total length of shoreline type in City's LCP planning area.

Structure	8.7 ft.	9.7 ft.	10.7 ft.	12.7 ft.	Total Shoreline
Pond	0.0	0.1	1.1	1.8	1.9
Fill	0.3	0.5	1.0	1.1	1.8
Railroad	0.0	0.0	0.1	0.1	1.1
Dike	0.3	0.6	0.8	0.8	1.0
Road	0.1	0.1	0.3	0.3	0.8
None	0.1	0.1	0.1	0.1	0.2
Misc.	0.1	0.1	0.1	0.1	0.1
Total	**0.7**	**1.4**	**3.4**	**4.3**	**7.0**

Sea Level Rise of One foot

The current MAMW (8.8 ft.) approximates one foot of sea level rise, albeit for a limited number of days, and can result in nuisance flooding.

In the City, only 3,882 ft. (0.7 miles) of artificial shoreline are vulnerable to overtopping by one foot of sea level rise that would reach an elevation of 8.7 ft., potentially affecting:

- 1,374 ft. (0.26 miles) of dikes,
- 1,364 ft. (0.26 miles) of fill,
- 337 ft. (0.06 miles) of roads, and
- 183 ft. (0.03 miles) of pond dikes.

With one foot of sea level rise, the frequency of overtopping by MMMW of 8.6 ft. would be much greater than our current MAMW of 8.8 ft. The future MAMW would become approximately 9.7 ft., which is two feet higher than our current MMMW (7.7 ft.), and 1.4 miles of shoreline could be overtopped.

Sea Level Rise of Two feet

Based on the 2013 shoreline vulnerability assessment, there is a critical shoreline elevation threshold on Humboldt Bay between 9.7 feet and 10.7 ft. if the elevations of current artificial shoreline structures remain as they are today. With two feet of sea level rise, MMMW and MAMW elevations would reach 9.6 ft. and 10.7 ft.

With existing shoreline elevations, approximately 1.4 miles (20%) of the shoreline would be vulnerable to being overtopped in the City by two feet of sea level rise. Two feet of sea level rise would reach an elevation of 9.7 ft. potentially affecting:

- 2,727 ft. (0.5 miles) of shoreline on Butcher Slough, potentially tidally inundating the industrial and residential property west of H Street south of Samoa Blvd.,
- 2,893 ft. (0.6 miles) of earthen dikes primarily on Gannon Slough, which would place nearly 400 acres of agricultural lands,
- 8.7 acres of public facility lands at risk of being tidally inundated, daily, and
- overtopping of the Treatment Plant's pond dikes potentially could increase to 346 ft.

The rising MAMW by 2050 could increase to 10.7 ft.—higher than our current 100-year base flood elevation—which would significantly increase the number of miles of artificial shoreline vulnerable to overtopping by three feet to 3.4 miles. It is important to highlight that the Treatment Plant's pond dikes, in their current condition with two feet of sea level rise, would begin to experience overtopping by MAMW on 5,910 ft. (1.1 miles) or 58% of the pond dikes.

Sea Level Rise of Three feet

With three feet of sea level rise, MMMW could reach 10.9 ft. and MAMW 12.0 ft. elevation. Approximately 3.4 miles (48.6%) of shoreline would be vulnerable to being overtopped in the City by three feet of sea level rise. Three feet of sea level rise would reach an elevation of 10.7 ft. potentially affecting:

- 9,261 ft. (1.7 miles) of pond dikes,
- 5,179 ft. (1.0 miles) of fill mostly on Butcher Slough,
- 4,326 ft. (0.8 miles) of dikes, and
- 1,422 ft. (0.3 miles) of roads.

If current shoreline conditions are not enhanced, 48.6% of the shoreline in the City would experience overtopping, resulting in substantial tidal inundation of the Treatment Plant, residential, industrial, public facility properties, Arcata Marsh, and agricultural lands south of Samoa Boulevard. The future MAM tide would increase to 11.8 ft.

Sea Level Rise of Five feet

Five feet of sea level rise would raise MMM tide elevation from 7.7 to 13.1 ft. elevation. Based on existing artificial shoreline elevations, approximately 4.3 miles (61.7%) of the shoreline is vulnerable to being overtopped by five feet of sea level rise. Five feet of sea level rise would reach an elevation of 12.7 ft., potentially affecting:

- 9,261 ft. (1.7 miles) or 91% of Treatment Plant pond dikes,
- 5,971 ft. (1.1 miles) or 62% of the fill shoreline mostly along Butcher Slough,
- 4,415 ft. (0.8 miles) or 85% of the dikes,
- 1,708 ft. (0.3 miles) or 42% of the road, and
- 322 ft. or just 5% of the railroad.

The dikes on Arcata Bay outside of the City would also be overtopped with five feet of sea level rise. Highway 255, also outside of the City's limits, would become tidally inundated, which would expose residential properties on Villa Way in the Windsong subdivision in the City to tidal inundation. The future MAMW would increase to 13.8 ft.

- Flooding

Flooding or overtopping of artificial shoreline structures can occur, infrequently, from extreme storm events. Flooding of low-lying lands behind barrier type shorelines (dikes, railroad and road grades) can also occur during heavy rainfall when drainage to Humboldt Bay is impaired, resulting in backwater ponding. Flooding and ponding of water behind earthen dikes by stormwater runoff from interior watersheds can result in erosion and/or slumping of dike slopes, as fortification of dike slopes is generally limited to the bay side of the dikes.

Tsunamis are another form of flooding, and they are also not predictable. Tsunamis from a major Cascadia subduction event would overwhelm (overtop) any shoreline structures currently on Humboldt Bay, even if those shoreline structures were not affected by liquefaction. A tsunami would come into Humboldt Bay in waves. The height, velocity, and direction of these tsunami waves would likely be very different from normal tidal currents and or wind waves. The potential for erosion and overtopping of shoreline structures such as dikes or fill areas would depend on the height, velocity and direction of the tsunami waves.

3.1.3 Susceptibility

Susceptibility is the degree to which an asset may be adversely affected. By design, shoreline structures can be made to withstand coastal hazards such as erosion and tidal inundation. With appropriate design and maintenance, shoreline structures can continue to function even when exposed to sea level rise to some degree. There is no one entity responsible for maintaining the artificial shoreline, and there are 39 individual parcels that make up the artificial shoreline in the City's LCP planning area. Assets and land uses in a common hydrologic unit are very susceptible if a shoreline breach were to occur on just one of these 39 parcels.

The Humboldt Bay vulnerability index developed by Laird and Powell (2013) uses combinations of shoreline attributes (cover type and relative elevation to modeled MMMW) to rate a shoreline segment's vulnerability to erosion and/or overtopping due to extreme tides, storm surges, and future sea level rise. Shoreline segments that are vulnerable to overtopping and breaching in the City's LCP planning area have been identified (Figure 7). Results show there are 3.9 miles of shoreline rated highly vulnerable, 2.0 miles moderately vulnerable and 1.1 miles with a low vulnerability rating.

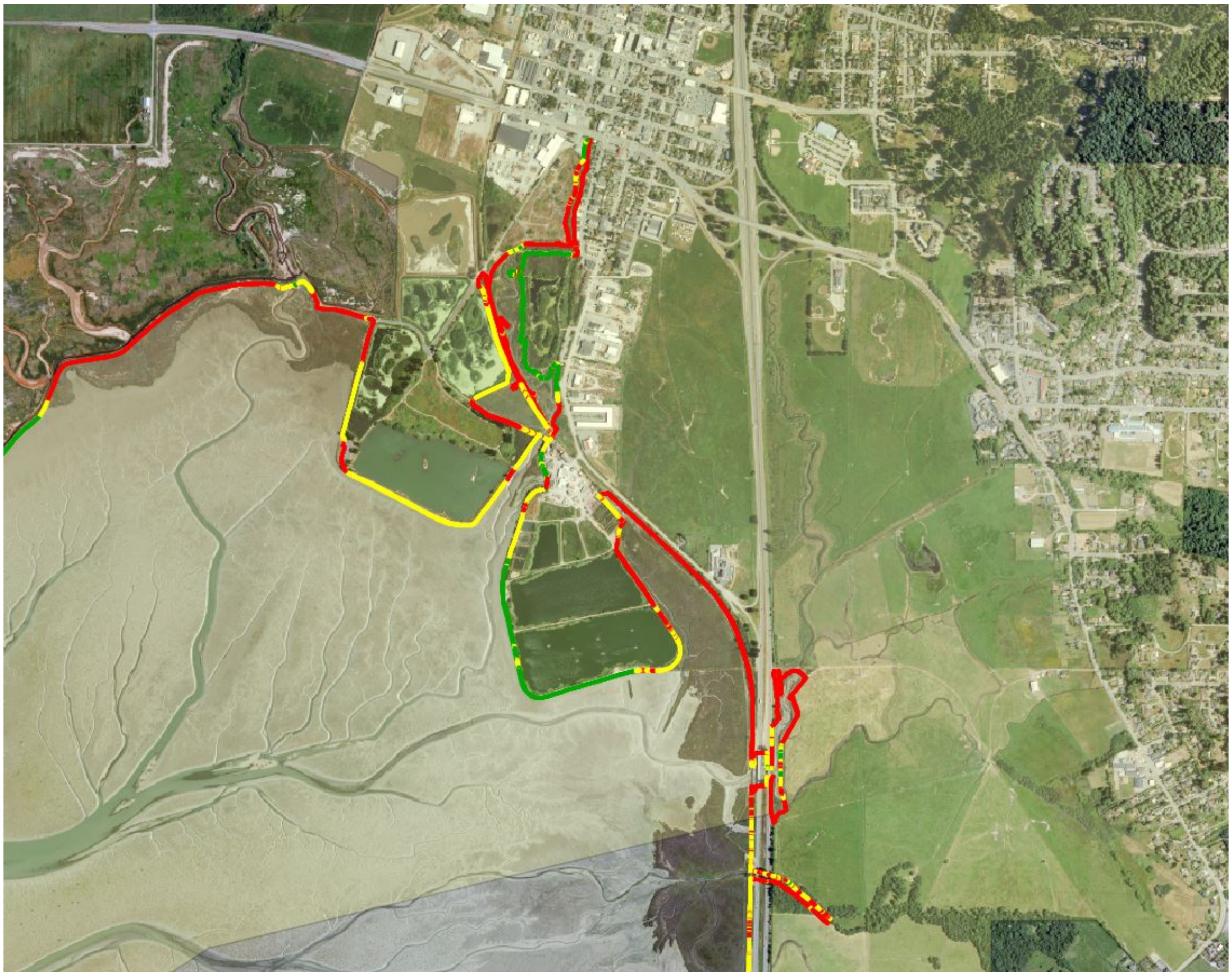

Figure 7. City of Arcata shoreline vulnerability rating: high (red), medium (yellow), and low (green).

The unfortified earthen dikes on Gannon Slough are the most susceptible shoreline segment to erosion and overtopping in the City's LCP planning area from two feet of sea level rise. While mostly agricultural lands and the City's wildlife reserve are at risk behind the dikes on Gannon Slough, it is the critical utility assets (City of Eureka's municipal water transmission lines, PG&E gas line and electrical transmission towers) that are currently very much at risk from tidal inundation. With 1.6 ft. (0.5 M) of sea level rise, the use of residential and industrial properties adjacent to the filled shoreline on Butcher Slough are at risk if the bank is allowed to be overtopped and inundate these properties. With three feet of sea level rise, the Treatment Plant oxidation ponds would be in jeopardy of tidal inundation resulting from 1.1 miles of overtopped dikes. The operation of the Treatment Plant ponds is very susceptible to salt water inundation and services provided by this facility are critical to the City of Arcata.

The shoreline in the Arcata Marsh is also vulnerable to overtopping by two to three feet of sea level rise. The freshwater wetlands are very susceptible to salt water inundation.

Most of the urban (residential, industrial and commercial) development south of Samoa Blvd, is not located on the shoreline of the Bay yet the continued use of these properties and developments and the mostly underground utilities that service these properties are very susceptible to tidal inundation beginning with 1.6 ft. (0.5 M) of sea level rise and resulting in full inundation with 3.3 ft. (1.0 M) of sea level rise.

3.2 Land Uses

The City's LCP and Zoning Ordinance, establish allowable land uses and development density. In the Coastal Zone, and on Humboldt Bay, the state has retained development jurisdiction on current and former tidelands pursuant to the Coastal Act. The state's retained jurisdiction on Humboldt Bay covers development on 86% (969 acres) of the area in the City of Arcata that is vulnerable to approximately 4.9 ft. (1.5 M) of sea level rise. There are also ten acres, inland of the City's LCP planning area and Coastal Zone, that are vulnerable to tidal inundation by 4.9 ft. (1.5 M) of sea level rise.

3.2.1 Affected Land Use Types

The City's LCP occupies approximately 1,542 acres, excluding areas below MHHW. Land use is predominately rural-open space (agricultural and natural resource) (76%) with a lesser amount of urban-developed areas (residential, industrial, commercial and public facility) (24%). The six land use types within the LCP are: agriculture, natural resources, residential, industrial, public facility, and commercial (Table 4).

Table 4.City of Arcata's LCP land use types, acreage, and percentage of total LCP area.

Zoning	Total Acres	Total %
Agriculture Exclusive	875	57%
Natural Resources	296	19%
Residential	141	9%
Industrial	136	9%
Public Facility	78	5%
Commercial	17	1%
Total	**1,542**	

There are no vulnerable coastal dependent industrial parcels or uses in the City of Arcata. The Arcata Marsh is zoned natural resource, which is a coastal-related use because it supports inter-tidal wetlands and public access and recreational opportunities associated with Humboldt Bay. The City's Treatment Plant is zoned public facility, also discharges to the Bay, and is therefore a coastal related land use.

3.2.2 Exposure

Artificial shorelines can be characterized as either barrier or fill structures. Agricultural and natural resource lands are strongly associated with barrier type shorelines (dike, railroad, and road). Urban lands are more closely associated with fill type shorelines. There are also urban lands inland of barrier type shorelines. The City's Treatment Plant and Arcata Marsh ponds are protected by a specially built system of dikes, roads, and pathways. The vulnerability of land uses in the City is strongly associated with the shoreline structures that are protecting these uses from coastal hazards.

In the City, the rural-open space lands that are vulnerable, specifically agricultural and natural resource lands, are concentrated on the north-eastern shore of Humboldt Bay on former tidelands behind barrier-type shorelines (dikes, railroad and highways). Nearly all the agricultural lands are former tidelands. Approximately 86% of the lands that are vulnerable to approximately 4.9 ft. (1.5 M) of sea level rise are rural open-space and 14% are urban-developed. The urban-developed areas in the City that are vulnerable are clustered mostly south of Samoa Boulevard on G and H Streets and south of Old Arcata Road (Figure 8).

A significant portion of the lands in the City vulnerable to sea level rise are also currently exposed to coastal hazards such as flooding and tidal inundation. There are approximately 618 acres of low-lying areas in the City that are vulnerable <u>today</u> from tidal inundation if protective shoreline structures are compromised or breached. These areas are also in FEMA's 100-year flood zone, as are most of the areas vulnerable to 3.3 ft. (1.0 M) of sea level rise. All the areas vulnerable to sea level rise of 4.9 ft. (1.5 meters) are also in California's tsunami evacuation area.

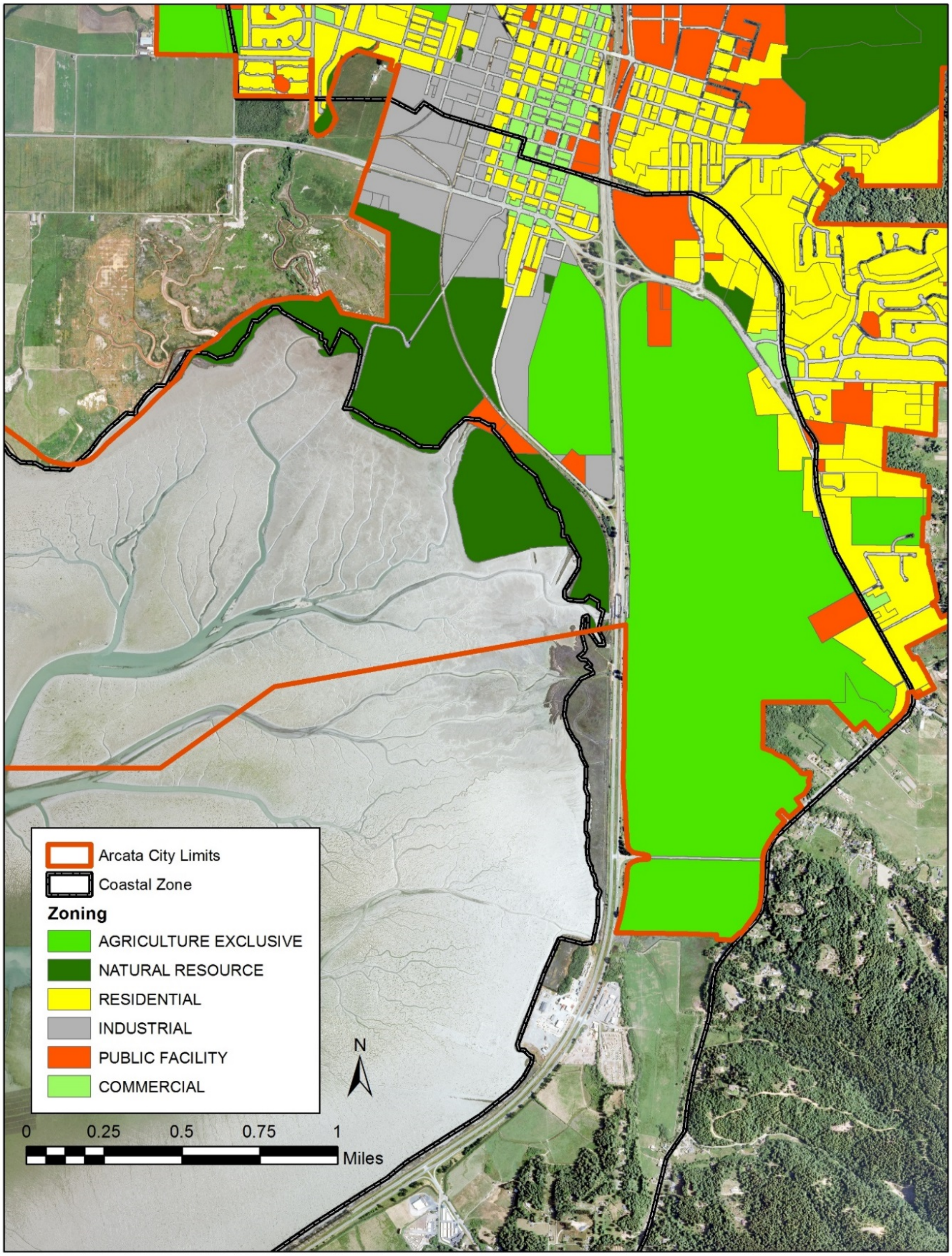

Figure 8. A portion of the City of Arcata's Local Coastal Program land use distribution that potentially could be tidally inundated by 4.9 ft. (1.5 M) of sea level rise.

Agriculture

Unlike much of the agricultural lands on Humboldt Bay, the 875 acres in the City of Arcata are not predominately protected by dikes. The agricultural lands to the west of Highway 101 are protected from tidal inundation by the railroad grade and South G Street, which drains through tide gates to Butcher Slough. The agricultural lands to the east of Highway 101 from Old Arcata Road south to Washington Gulch are also predominately protected from tidal inundation by the railroad grade and Highway 101. However, there are approximately 2,100 feet of dikes on Gannon Slough that also protect these agricultural lands to the east. Outside of the City's LCP planning area, approximately 2,000 feet of dikes on Washington Gulch prevent tidal inundation of the lands in the City to the north and to Bayside Cutoff.

Natural resources

There are approximately 260 acres of natural resources land in the City that are vulnerable to 4.9 ft. (1.5 M) of sea level rise, located predominately in the vicinity of the Arcata Marsh and Wildlife Sanctuary, on Janes Creek at Windsong Village, and east of Union Street north of Old Arcata Road. Approximately 188 acres are behind fortified dikes, roads, and pathways, and 72 acres are inter-tidal wetlands.

Residential

There are approximately 38 acres of residential properties that are vulnerable to 4.9 ft. (1.5 M) of sea level rise, predominately located south of Samoa between E and H Streets, south of 5th Street between the Highway off-ramp and E Street, in Windsong Village along Villa Way, and the apartment complexes at Union Street and Samoa Blvd., south of Old Arcata Road at Buttermilk Lane.

Industrial

Most of 75 acres of industrial zoned properties that are vulnerable to 4.9 ft. (1.5 M) of sea level rise are located south of Samoa Boulevard between E and H Streets, and the end of G Street at Highway 101.

Commercial

There is one acre of commercially zoned properties along Samoa Boulevard that is vulnerable to 4.9 ft. (1.5 M) of sea level rise.

Public Facility

Public facility zoned properties that are vulnerable to 4.9 ft. (1.5 M) of sea level rise are located at the Treatment Plant and communications property on south G Street, ball parks and California Highway Patrol offices south of Samoa Boulevard, Arcata Community Center, and the western portion of the Jacoby Creek School property.

Tidal Inundation

Shoreline structures and lands vulnerable to tidal inundation would be exposed first to extreme tides like the MAMW, (king tides), with the frequency of these exposures increasing to MMMW. Eventually the frequency of tidal inundation would increase to weekly and eventually daily high tides (MHHW) (Table 2).

Sea level rise vulnerability assessments on Humboldt Bay have utilized MMMW (7.7 ft.) elevation as the base from which to measure sea level changes. When assessing an asset's exposure to a specific level of sea level rise, evaluation of the corresponding MMMW elevation is necessary. The MAMW would also increase in elevation with sea level rise. MAMW are the event that would likely place vulnerable assets at risk of being tidally inundated. For example, areas exposed to two feet of sea level rise on a monthly frequency, as measured by MMMW elevations, would also be exposed to approximately three feet of sea level rise, although less frequently, by MAMW or (king tides). Both water levels would be assessed to understand the degree of exposure in the near-term that assets may experience in a given year from one to two feet of sea level rise. The frequency that MAMW (8.8 feet elevation) are equaled or exceeded is currently four times a year. With two feet of sea level rise, there could be 125 days a year that tides exceed 8.8 feet.

The acreage for each land use types vulnerable to tidal inundation by MMMW for 1.1 ft. to 4.9 ft. of sea level rise is described below (Table 5).

Table 5.City of Arcata's LCP planning area land use zones, acres of each land use zone, percentage of the total LCP area the zone occupies, and acreage that could be tidally inundated by 1.1 (MAMW), 1.6 ft. (0.5 M), 3.3 ft. (1.0 M), and 4.9 ft. (1.5 M) of sea level rise.

ZONING	LCP Acres	% of LCP	1.1 Ft.	1.6 Ft.	3.3 Ft.	4.9 Ft.
Agriculture Exclusive	875	63.2%	618	638	684	707
Natural Resources	296	23.2%	204	217	249	260
Residential	141	3.4%	2	5	21	38
Industrial	136	6.7%	29	40	63	75
Public Facility	78	3.4%	14	19	29	38
Commercial	24	0.1%	0	0	1	1
Total	**1,550**		**868**	**920**	**1,046**	**1,119**

- ### Sea Level Rise of 1.1 Ft.

Every year Humboldt Bay experiences on average 1.1 ft. of sea level rise above MMMW, reaching 8.8 ft. (MAMW, or king tide). Most of the shoreline (89%) in the City is higher than MAMW of 8.8 ft. and prevents tidal inundation of areas behind the shoreline from 1.1 ft. of sea level rise. The residential and industrial properties along the bank of Butcher Slough on H Street currently experience a minor amount of tidal inundation, particularly during king tides of 8.8 ft., when approximately 1,364 ft. of shoreline can be overtopped. The 72 acres of natural resources zoned inter-tidal wetlands outside of the Treatment Plant/Arcata Marsh are tidally inundated during king tides. The agricultural lands east of Highway 101 and south of Jacoby Creek down to Bayside Cutoff are also regularly tidally inundated during king tides and flooded during stormwater runoff from Jacoby Creek.

If the diked shorelines on Gannon Slough and Washington Gulch were to be breached, potentially 618 acres of agricultural lands could become tidally inundated, daily, impacting 71% of the agricultural lands in the City's LCP planning area.

Because the tidal inundation model does not consider shorelines that are currently protecting low-lying areas, it depicts that MMMW with 1.1 ft. of sea level rise (8.8 ft.) with the potential to inundate:

- 618 acres of agricultural lands,
- 204 acres of natural resource lands,
- 2 acres of residential lands,
- 29 acres of industrial property, and
- 14 acres of public facilities.

Unless the dikes are breached or the pathway at the outlet to Butcher Slough is overtopped, the areas to the east of G Street and Highway 101 would not be tidally inundated by 1.1 ft. of sea level rise.

However, with 1.1 ft. of sea level rise, future king tides would be two feet higher (9.8 ft.) than our current MMMW (7.7 ft.), at which point 1.4 miles of shoreline could be infrequently overtopped.

➢ Sea Level Rise of 1.6 Feet

With 1.6 ft. (0.5 M) of sea level rise, approximately 920 acres (63%) of the LCP planning area is vulnerable to tidal inundation (Figure 9):

- 638 acres (72.9%) of the agricultural lands,
- 217 acres (73.3%) of natural resource lands,
- 5 acres (3.6%) of residential property,
- 40 acres (29.4) of industrial property, and
- 19 acres (24.4) of public facilities.

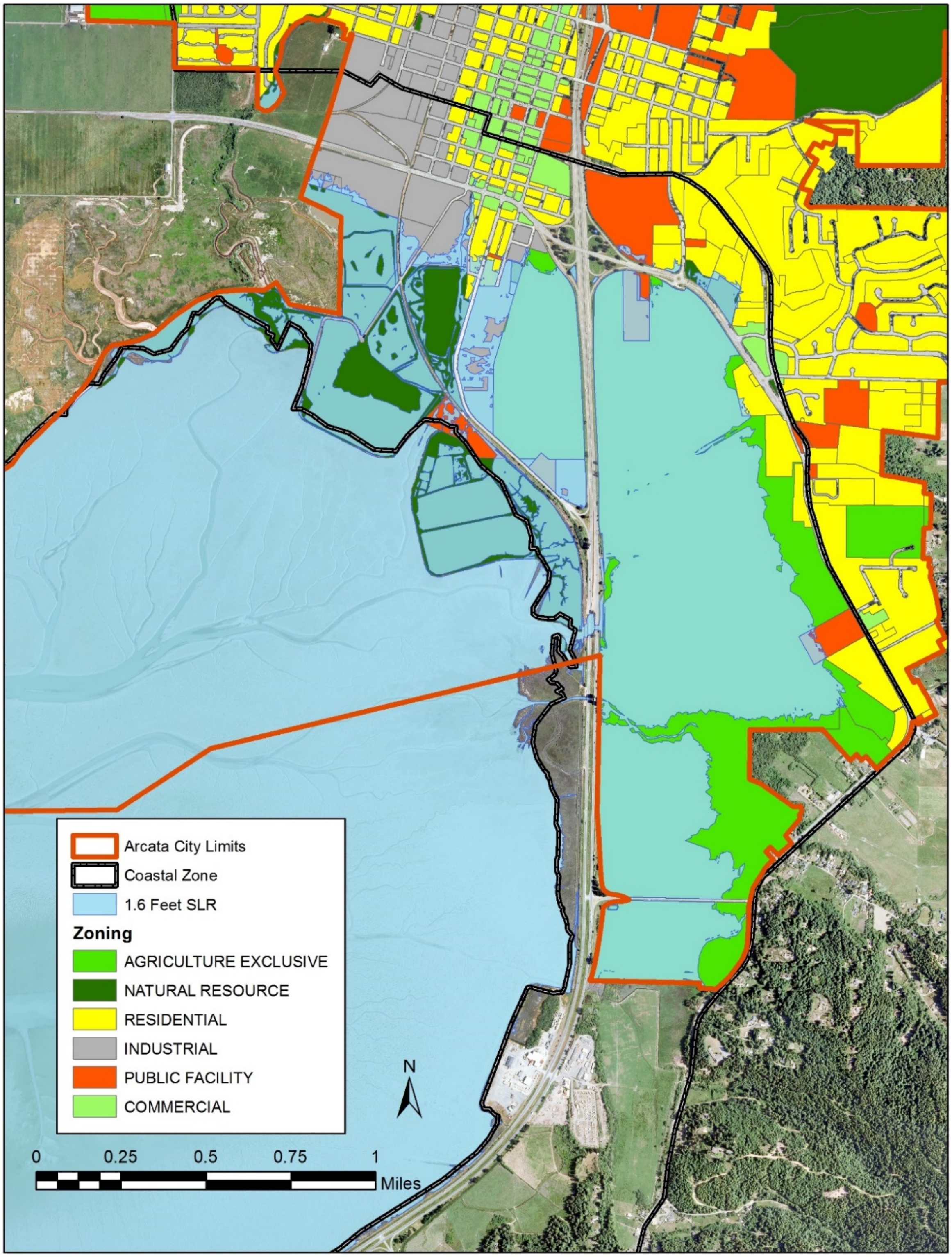

Figure 9. City of Arcata's Local Coastal Program land use distribution and potential areas of tidal inundation by 1.6 ft. (0.5 M) of sea level rise.

The eastern shoreline on Butcher Slough would likely be overtopped, tidally inundating of industrial and residential property west of H Street south of Samoa Boulevard In the Arcata Marsh and Wildlife Sanctuary, the tide gate next to the railroad and the WWTF provides a potential pathway for tidal inundation of industrial properties along South G Street and public facility and agricultural lands to the east. The eastern shoreline along the northern arm of the inter-tidal wetlands between the WWTF and the railroad south of the entrance to the facility may be overtopped and inundate south G Street and the agricultural and industrial lands to the east.

The dikes on Gannon Slough would likely be overtopped, as would the left bank of Jacoby Creek, Bayside Cutoff and the dikes on Washington Slough. This would inundate most of agricultural lands to the east of Highway 101 and south and west of Old Arcata Road, as well as 8.7 acres of public facility lands. The loss of the Gannon Slough dikes would result in the tidal inundation of the City of Eureka's two Mad River Pipelines. Sea level rise of 1.6 ft. (0.5 M) would overtop 346 feet of pond dikes, roads, and pathways protecting the Treatment Plant/Arcata Marsh complex. Overtopping of these dikes by MAMW (10.7 ft.), with 1.6 ft. of sea level rise, could significantly over top 5,910 ft. the pond dikes .

➢ Sea Level Rise of 3.3 Feet

With 3.3 ft. (1.0 M) of sea level rise, approximately 1,046 acres (67.5%) of the City's LCP planning area could be vulnerable to tidal inundation (Figure 10):

- 684 acres (78.2%) of the agricultural lands,
- 249 acres (84.1%) of natural resource lands,
- 21 acres (14.9%) of residential property,
- 63 acres (46.3%) of industrial property,
- 29 acres (37.2%) of public facility lands, and
- 1 acre (0.4%) of commercial property.

A substantial increase in tidal inundation by 3.3 ft. (1.0 M) of sea level rise and impact, residential lands (from 5 to 21 acres), industrial (from 40 to 63 acres), and public facility (from 19 to 29 acres). Tidal inundation, of the urban areas south of Samoa Boulevard and the Treatment Plant/Arcata Marsh complex would become significant.

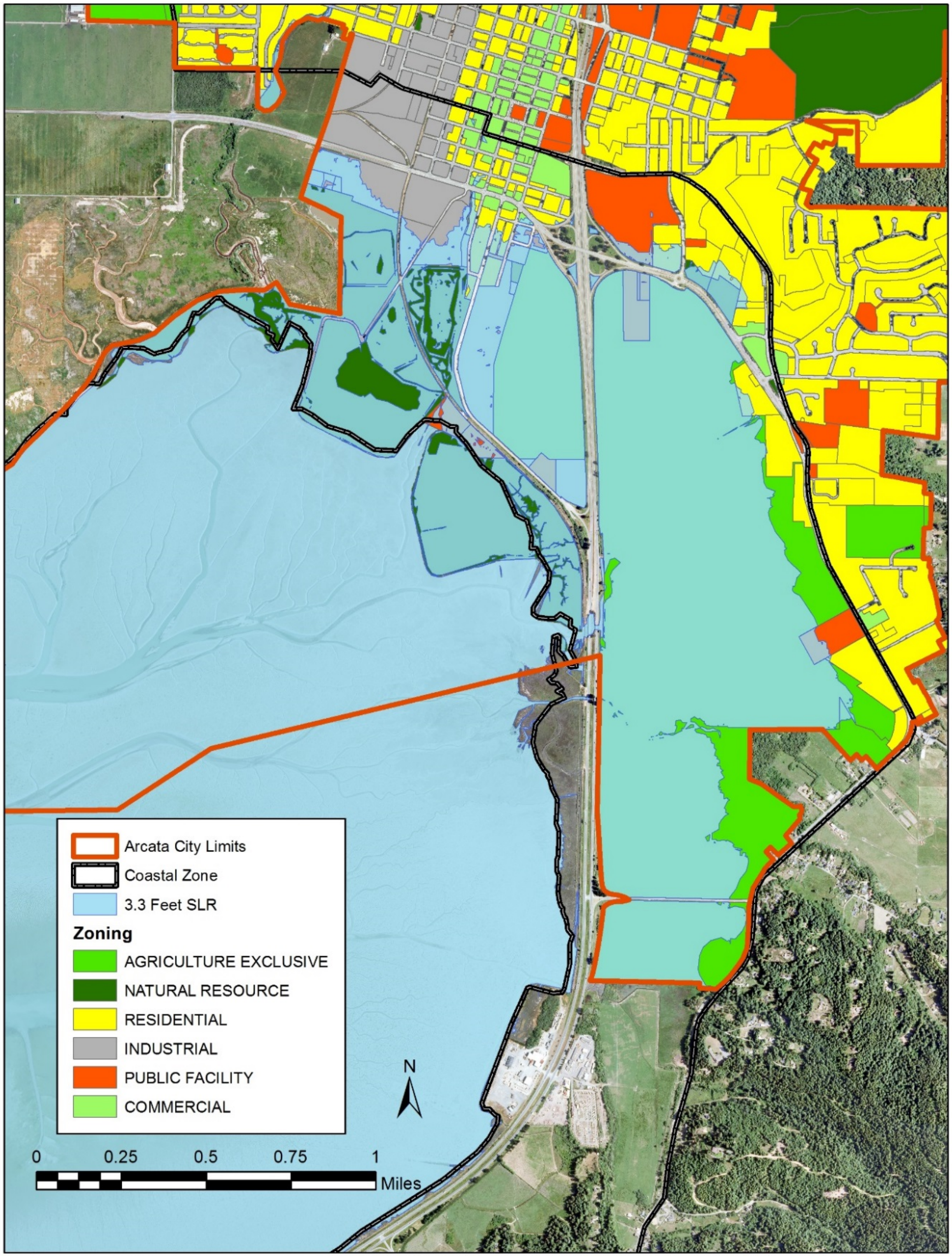

Figure 10. City of Arcata's Local Coastal Program land use distribution and potential areas of tidal inundation by 3.3 ft. (1.0 M) of sea level rise.

The dike along Arcata Bay to the west of the City limits could be overtopped and tidal inundation could overtop Highway 255, providing a pathway for tidal inundation of Janes Creek near Windsong. The dike, road, and pathway shoreline in the Arcata Marsh would be overtopped, leading to tidal inundation of most of the Arcata Marsh and providing a pathway for inundation of the urban area to the east, south of Samoa Blvd., and the Treatment Plant. Overtopping several reaches of perimeter dikes. The railroad and South G Street would be overtopped, allowing tidal inundation of the lands to the east. Segments of south bound lanes of Highway 101 could be tidally inundated. The area east of Highway 101 from Samoa Boulevard to Washington Gulch would become tidally inundated, including Bayside Cutoff.

While the inundation maps indicate that natural resources, public facility, and residential lands north of Samoa Blvd./Old Arcata Road would be inundated, there are no visible pathways for inundation, as the road would not be overtopped at this water level. However, pursuant to the author's disclaimer at the beginning of the report, this is a good example of the value of site specific knowledge, by City Staff, that contrary to the fact that a pathway for inundation is not evident as depicted on the inundation map this low-lying does have drainage issues and would likely be inundated.

While only a short segment of Highway 101 in the City would become tidally inundated by 3.3 ft. (1.0 M) of sea level rise, most of the south bound lanes of the highway south of the City to Bracut would be tidally inundated, as would Highway 255 west of the City near Mad River Slough.

➢ Sea Level Rise of 4.9 Feet

With 4.9 ft. (1.5 M) of sea level rise, approximately 4.2 miles (61.7%) of the shoreline based on current conditions is vulnerable to being overtopped and approximately 1,119 acres (72.2%) of the City's LCP planning area are vulnerable to tidal inundation (Figure 11):

- 707 acres (80.8%) of the agricultural lands,
- 260 acres (87.8%) of natural resource lands,
- 38 acres (26.9%) of residential property,
- 75 acres (55.1%) of industrial property,
- 38 acres (48.7%) of public facility lands, and
- 1 acre (0.4%) of commercial property.

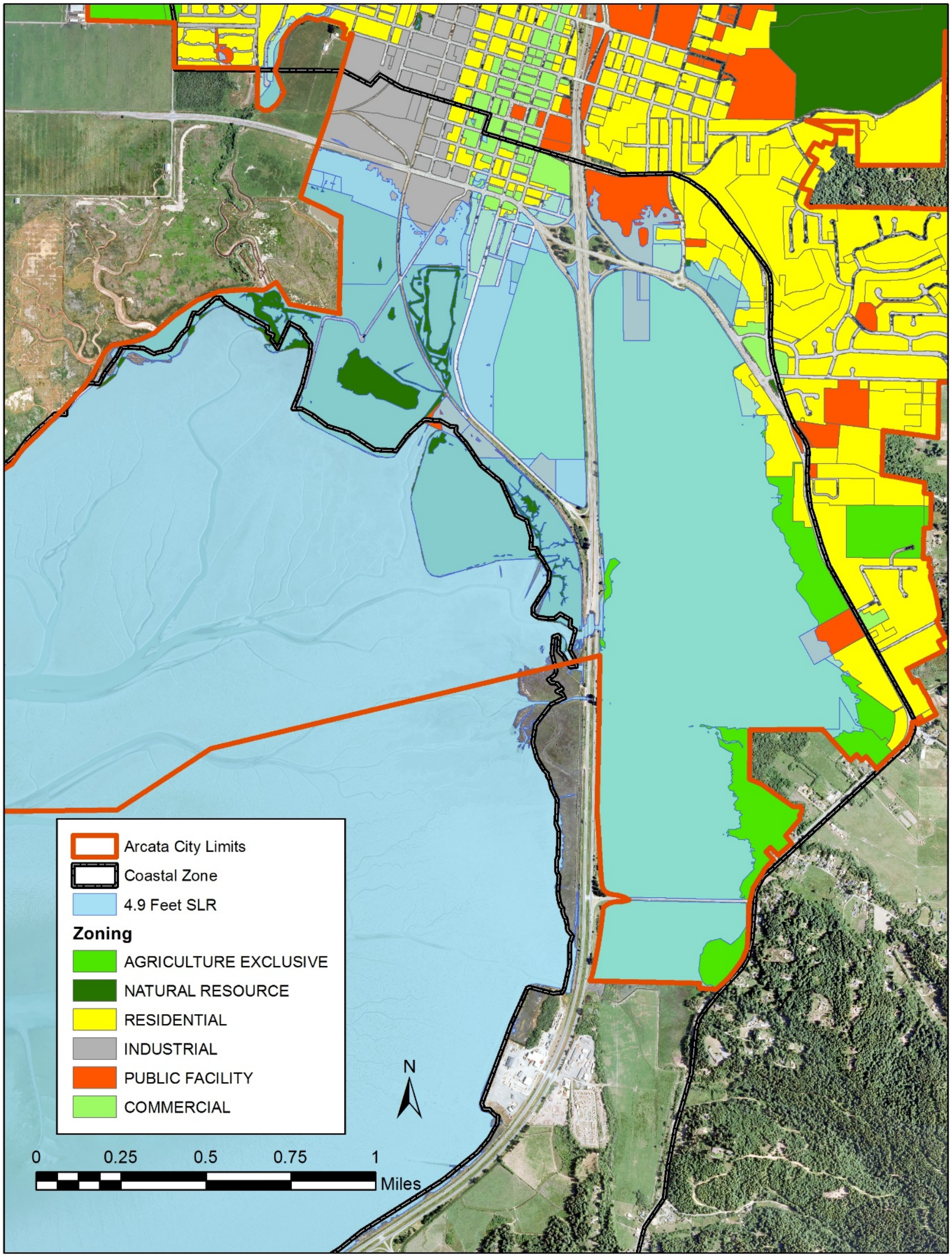

Figure 11. City of Arcata land uses vulnerable to 4.9 ft. (1.5 M) of sea level rise.

Flooding

Stormwater runoff from McDaniel Slough (Janes Creek), Butcher Slough (Jolly Giant Creek), Gannon Slough (Campbell and Beith Creeks), and Jacoby Creek drain large watersheds to the east directly to Humboldt Bay. Stormwater runoff during king tides can result in significant flooding of the agricultural lands east of Highway 101, both north and south of Bayside Cut-off, and Old Arcata Road at Jacoby Creek.

Flooding or overtopping of artificial shoreline structures can occur infrequently from extreme storm events (100-year flood). Flooding during a 100-year event (BFE 10.2 ft.) would likely affect the same 1,046 acres in the City that are vulnerable to 3.3 ft. (1.0 M) of sea level rise with a MMMW of 11.0 ft. Potentially 3.3 miles of shoreline would be vulnerable to overtopping. The extent of backwater flooding during a 100-year event would likely extend inland of the areas that are vulnerable to tidal inundation.

Flooding of low-lying lands behind barrier type shorelines (dikes, railroad and highway grades) can also occur during heavy rainfall as drainage to Humboldt Bay is impaired, resulting in backwater ponding. Flooding and ponding of water behind earthen dikes by stormwater runoff from interior watersheds can result in erosion and/or slumping of dike slopes, as fortification of dike slopes is generally limited to the bay side of the dikes.

Likewise, flooding can occur when rising groundwater emerges onto the surface in low-lying areas in response to winter storms or rising sea levels. Regardless of the type or condition of shoreline structures, fortifications, or elevation, low-lying areas such as diked former tidelands are vulnerable to flooding from rising groundwater in response to sea level rise. With sea level rise, this type of flooding would likely begin as nuisance flooding during the winter and slowly increase in duration over time until it becomes chronic flooding. The average elevation of groundwater on land adjacent to the shoreline is generally above MSL elevation of 3.4 ft. Diked former tidelands that were salt marsh were generally equal to or less than 6.5 ft. (MHHW) in elevation but have compacted as organic material in the original salt marsh soil has oxidized and are now much lower in elevation.

Groundwater elevations depend on surface elevations and the season. For example, groundwater near Mad River Slough can fluctuate from being at the surface down to three feet below the surface (Hoover 2015) (Figure 12 and Figure 13). As sea level rises, the denser saltwater would push fresh groundwater to higher elevations until the groundwater eventually emerges and floods the surface. Rising groundwater flooding would cause vegetative conversions, adversely affecting agricultural lands and natural resource areas. Rising groundwater can also affect foundations of structures such as building and roads, as well as permanently flood low-lying areas.

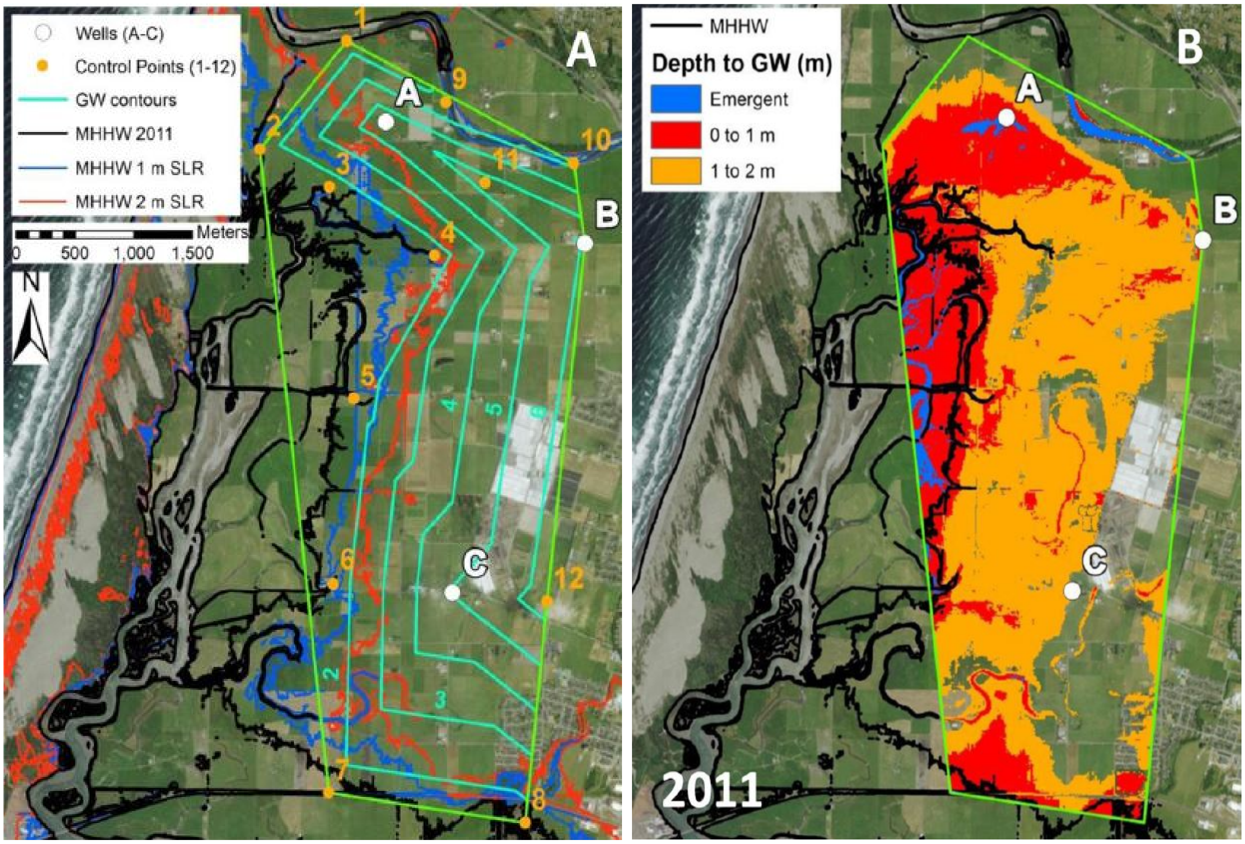

Figure 12. From Hoover 2015, as based on the work of Willis 2014. Fresh groundwater floats on higher-density seawater, and the average elevation of the water table would be above MSL 3.4 ft. MHHW is 6.5 ft.

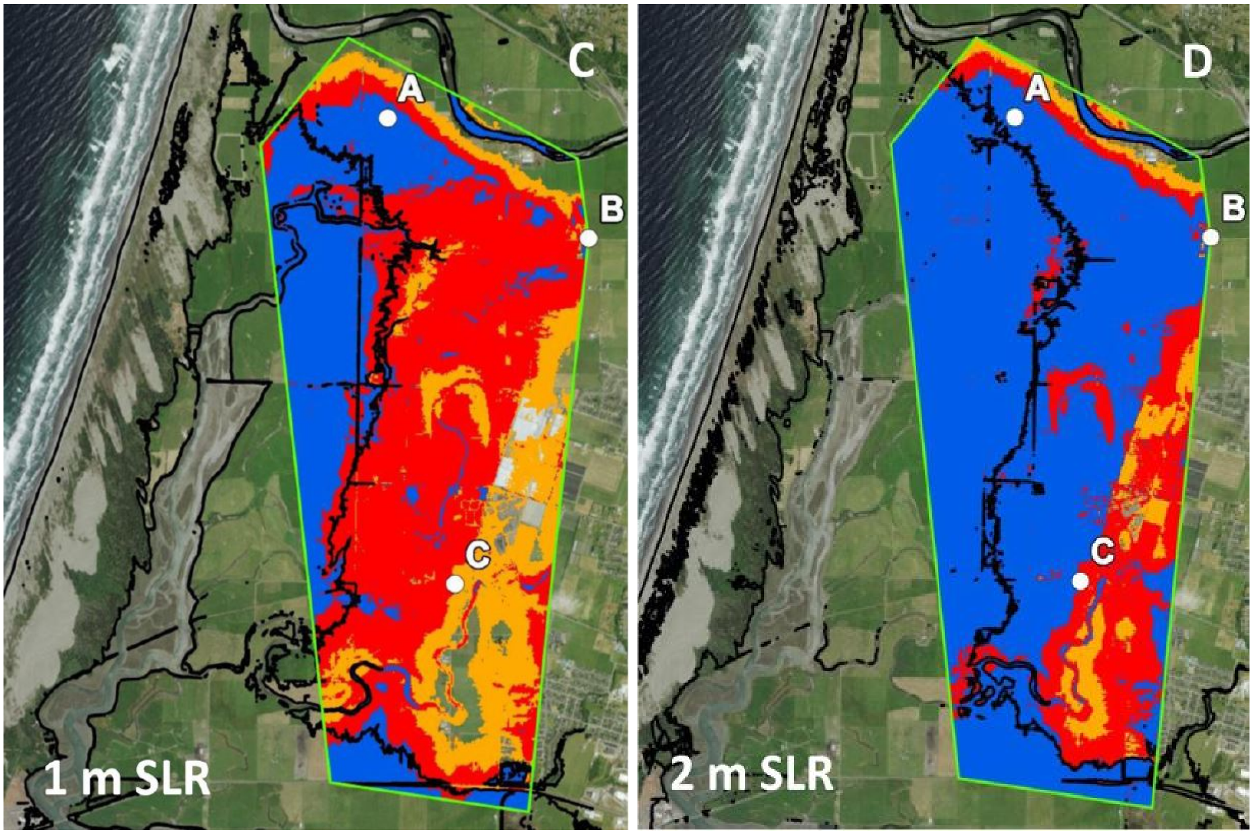

Figure 13. From Hoover 2015, based on Willis 2014, illustrating the difference of 1 M (3.3 ft.) of sea level rise. Blue = emergent, Red = 0 to 1 M, and Orange = 1 to 2 M (6.6 ft.).

Salt Water Intrusion

Salt water intrusion can contaminate shallow wells that support agricultural, residential, and other land uses. The largest extent of irrigated agricultural lands is on the Mad River bottom lands adjacent to the City of Arcata (Figure 14).

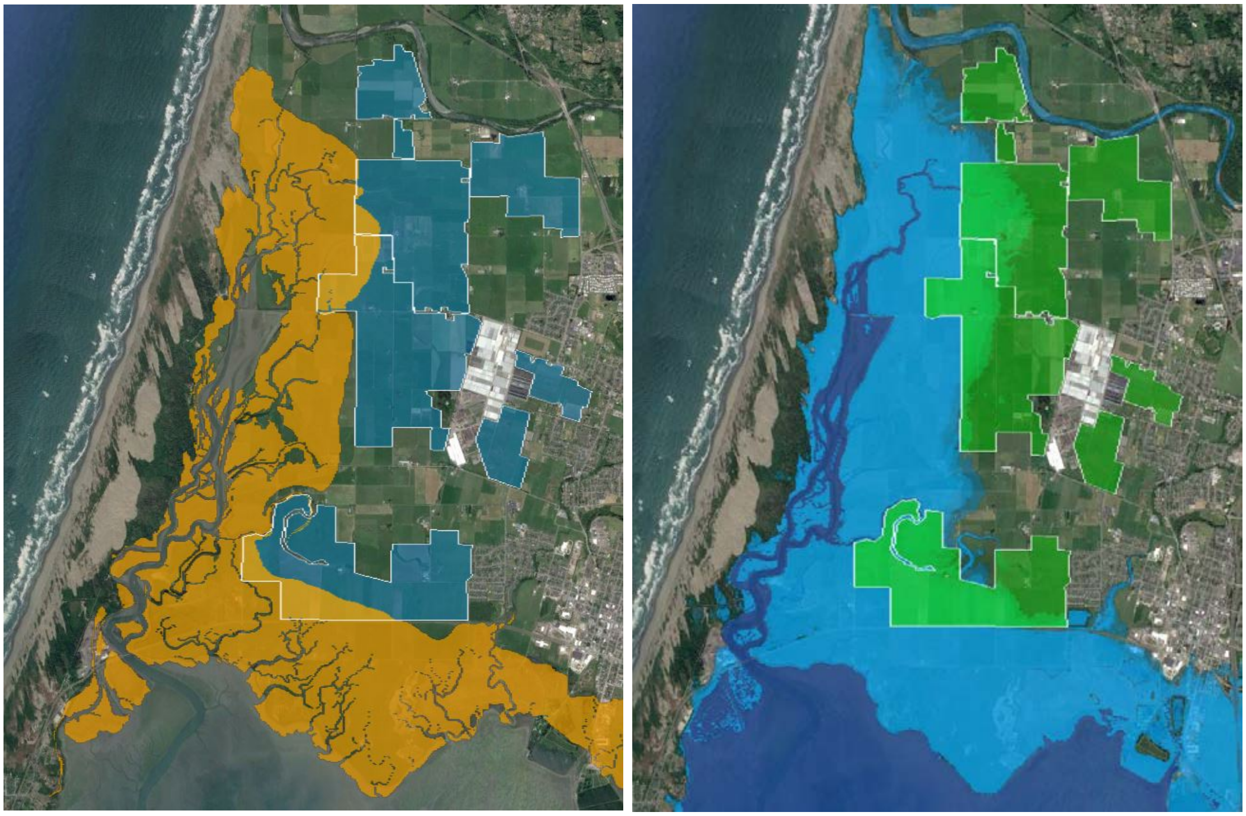

Figure 14. Irrigated agricultural lands adjacent to the City of Arcata, on Mad River bottom land, in relation to diked former tidelands (orange area) and potential 4.9 ft. (1.5 M) tidal inundation area (blue area).

Salt water intrusion can result in salt water entering the wastewater system in the form of infiltration to wastewater transmission lines and can lead to impairment or collapse of the biological processes required to treat wastewater. Salt water intrusion can also corrode underground structures (pipelines and culverts) or equipment (lift and pump stations).

Salt water intrusion and rising fresh groundwater flooding are linked as fresh groundwater floats on higher-density seawater. The elevation of groundwater can range across MSL 3.4 ft., MHW 5.8 ft., and MHHW 6.5 ft. Salt water intrusion of freshwater areas can lead to significant vegetative conversions from salt intolerant species to salt tolerant species, which would lead to changes in agricultural practices, wildlife and habitat (ESHA) distribution and abundance.

The agricultural lands in the City that are vulnerable to salt water intrusion average 6 to 7 ft. in elevation. During winter months, ground water often rises to the surface in these areas (Figure 15).

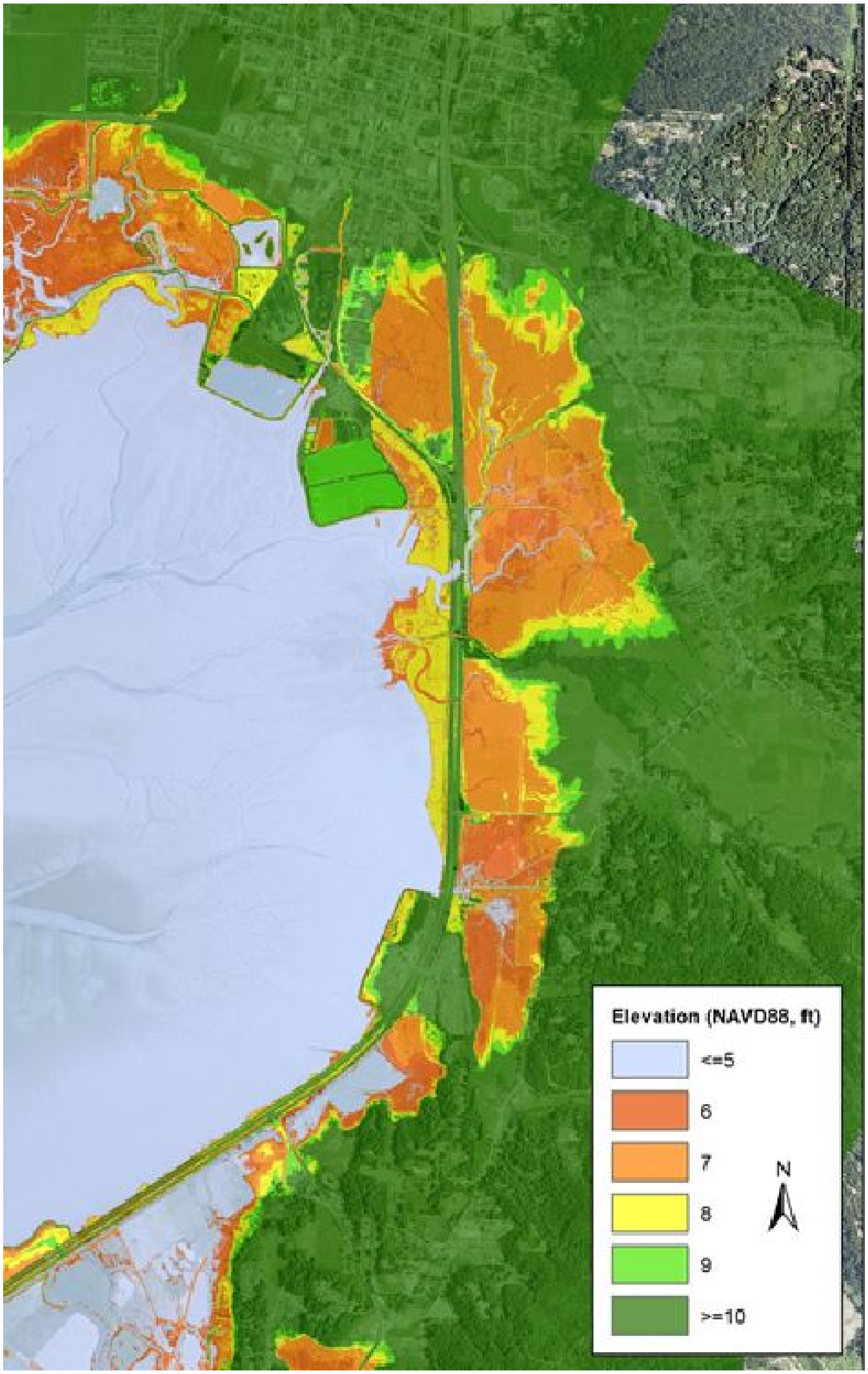

Figure 15. City of Arcata surface elevations in low elevation diked former tidelands, predominately used for agriculture and as a wildlife reserve.

3.2.3 Susceptibility by Land Use Type

Agriculture

The agricultural lands in the City's LCP planning area are vulnerable to tidal inundation are low-lying diked former tidelands. Approximately 81% of the agricultural zoned lands in the City are vulnerable to 4.9 ft. (1.5 M) of sea level rise. Grazing practices and pastures dominate the agricultural landscape. Current agricultural uses are based on raising forage for livestock grazing. They are very susceptible to tidal inundation, which would lead to a cessation of these agricultural uses. Saltwater inundation, even for short durations, can have a significant impact on saltwater intolerant plants. Frequent or chronic saltwater flooding would likely result in a vegetative conversion to salt tolerant plant species, and the collapse of agricultural endeavors.

Flooding from extreme storm events is infrequent, and current agricultural uses can recover from such flooding. Backwater flooding in the winter and spring months can seasonally restrict agricultural lands uses. Without improved drainage in response to rising sea levels, such flooding may lead to pastures converting to freshwater or brackish water wetlands. Emerging groundwater in response to sea level rise may ultimately cause the conversion of forage to wetland vegetation, which would be a significant impediment to continuing agricultural uses. Saltwater intrusion of shallow wells would impact irrigated agricultural lands significantly. Saltwater intrusion of groundwater as it emerges in response to sea level rise would lead to vegetative conversions to salt tolerant species and a reduction or elimination of livestock grazing.

Natural Resources

In the City, natural resource lands in the Arcata Marsh/Treatment Plant are composed of freshwater habitats that would be significantly impacted by salt water from tidal inundation, likely resulting in their conversion to salt water or brackish wetlands. The dikes protecting the natural resource lands are exposed to high energy waves. While they are fortified on the waterward side, over topping and erosion of the back side could lead to breaches.

Residential/Industrial/Commercial

Residential, industrial, and commercial structures and the utility and transportation infrastructure that supports these developments can recover from nuisance flooding. As the frequency of flooding increases and becomes chronic flooding, these structures, utilities and access/drainage infrastructure would become impaired, damaged, and economically infeasible to maintain. As mentioned earlier, a MAMW of 8.8 ft. is reached or exceeded on average four times a year, but with 1.6 ft. (0.5M) of sea level rise, the number of times tides would equal or exceed this 8.8 ft. elevation are likely increase to 125 times a year. This will result in chronic flooding, ultimately leading to weekly and then daily tidal inundation.

Existing residential, industrial, and commercial structures, their utility infrastructure, and access streets are not designed to accommodate frequent or chronic flooding or permanent tidal inundation. Electrical systems and metal structures are susceptible to salt water corrosion. Unsealed underground pipes may experience saltwater infiltration, which would cause a significant impairment of the affected wastewater system. Flooding from extreme storm events is infrequent, and residential areas can recover or rebuild from such nuisance flooding. Backwater flooding in the winter and spring months can impact streets and seasonally restrict access to residential areas, if not result in complete flooding of such areas. Residential, industrial, and commercial structures in low-lying areas are also susceptible to flooding from rising groundwater and salt water intrusion.

Public

Approximately 49% (38 acres) of the City's public facility properties in the LCP planning area are vulnerable to 4.9 ft. (1.5 M) of sea level rise, including the Treatment Plant, communications parcel on South G street, Arcata Community Center complex, California Highway Patrol office and ball park, and the Jacoby Creek School.

Existing structures, their utility infrastructure, and access streets are not designed to accommodate frequent flooding or permanent tidal inundation. Electrical systems and metal structures are susceptible to salt water corrosion.

Tidal inundation of Treatment Plant's ponds, buildings, pavement, infrastructure, particularly from chronic salt water inundation, would render this facility non-operational. Likewise, the California Highway Patrol office would not be able to function if tidally inundated. Buildings and parking areas at the Jacoby Creek School would not become tidally inundated and therefore are not susceptible. Public recreation properties and structures and access to these properties would be impaired and possibly eliminated by tidal inundation.

Flooding from extreme storm events are infrequent, and these structures can recover or rebuild from such flooding. Rising groundwater could compromise building foundations, asphalt covered areas, and possibly Highway 101, which is a non-city owned critical public facility.

3.3 Coastal Resources

3.3.1 Public Access and Recreation

The Arcata Marsh provides public access to approximately 300 acres of coastal habitats including freshwater marshes, salt marshes, tidal sloughs, grassy uplands, mudflats, brackish marsh, over five miles of walking and biking paths, an Interpretive Center, a boat launch, and multiple parking areas. The City has extended its Bay Trail, a significant new coastal access and recreational facility, south of the Arcata Marsh 1.9 miles toward Bracut. Of this trail expansion, approximately 1.0 miles is beyond the City LCP planning area.

Exposure

Tidal inundation of the Arcata Marsh was previously assessed under land use. The boat launch at the Arcata Marsh is nearly completely inundated during MAMW of 8.8 ft., and similarly with 1.6 ft. (0.5 M) of sea level rise. With 3.3 ft. (1.0 M) of sea level rise, the boat launch, parking area, and access streets are completely tidally inundated.

Based on the elevation of the adjacent railroad the new Bay Trail, which is not higher in elevation, 0.47 miles could become tidally inundated with 1.6 ft. (0.5M) of sea level rise, nearly all the new trail will inundate with 3.3 ft. (1.0 M).

Susceptibility

The public's use of the recreational boating facilities at Arcata Marsh could be adversely impacted by tidal inundation of access roads, parking lot, and boat ramp. With rising sea levels and repeated tidal inundation, the base of the Bay Trail would become saturated, causing the asphalt to buckle and require resurfacing. Rising tides can impair the capacity and function of water control structures, such as bridges, tide gates, and culverts, associated with the trail, which could increase flooding of adjacent areas.

3.3.2 Environmentally Sensitive Habitat Areas

The California Coastal Act defines ESHA as "any area in which plant or animal life or their habitats are either rare or especially valuable because of their special nature or role in an ecosystem and which could be easily disturbed or degraded by human activities and developments" (Section 30107.5).

On Humboldt Bay, there are five general types of ESHA that are being assessed for impacts from sea level rise: open water, eelgrass, mudflats, salt marsh, and seasonal freshwater wetlands on diked former tidelands. These ESHA types may undergo significant adjustments in response to changing shoreline conditions. Tidal habitats and seasonal freshwater wetlands are especially valuable habitats for a multitude of commercial and special status species.

One of the first surveys of Humboldt Bay depicts that it once occupied approximately 25,800 acres: 15,300 acres (59%) of open water, tidal channels, and mud flats, and 10,500 acres (41%) of inter-tidal wetlands (salt marsh and tidal channels) (USSG Township Plats 1854). Historically, seasonal freshwater wetlands (i.e. short-grass pasture that Aleutian geese currently use for grazing) did not exist. Today, Humboldt Bay occupies approximately 20,462 acres. Open water (5,776 acres) and mud flat (13,141 acres, including eelgrass habitat) cover approximately 18,917 acres (92.5%), and salt marsh covers approximately 1,545 acres (7.5%) (NOAA 2009 Imagery).

On Humboldt Bay, there are approximately 7,000 acres of diked former tidelands that presently support seasonal freshwater wetlands, known as "farmed wetlands", generally less than eight feet in elevation. This ESHA is predominately pasture that is used to graze livestock, and which significant numbers of Aleutian geese also use for grazing.

Humboldt Bay, as bound by the MHW shoreline, is 20,462 acres in extent and composed of open water (5,776 acres), eelgrass habitat (8,129 acres), mud flats (5,012 acres) and salt marsh (1,545 acres).

Exposure

Diked former tidelands, now pasture (waterfowl grazing habitat) and seasonal freshwater wetlands, (ESHA), are vulnerable to tidal inundation if barrier type shorelines are breached or overtopped. These lands and ESHA are also vulnerable to rising groundwater and salt water intrusion in response to sea level rise, even if the shorelines remain intact.

- Tidal Inundation

Eroding dike structures are at risk of breaching under our current tidal regime. The consequences of a dike breach could be significant, potentially tidally inundating ESHA throughout thousands of acres of former tidelands that are now pasture, seasonal freshwater wetlands, and Aleutian goose grazing habitat. The shoreline elevation profile for Humboldt Bay was in one-foot increments. Currently, there are 2.4 miles of diked shoreline that are vulnerable to being overtopped by MAMW of 8.8 ft. With 0.9 ft. of sea level rise, MAMW (9.7 ft.) could place 11.4 miles of dike at risk. With two feet of sea level rise, 23.4 miles would be at risk from MAMW (10.7 ft).

If the diked shoreline were compromised, today, Humboldt Bay could expand to 30,308 acres, which is 4,508 acres (17.5%) greater than what was mapped in 1850. The additional acreage is comprised predominately of potential inundation areas associated with Elk River, Swain Slough and Martin Slough, that were not mapped as salt marsh in 1854 (USSG) or 1870 (USCS) as well because of the 18 inches of relative sea level rise that has occurred over the last century, on Humboldt Bay. Sea level rise of 1.6 ft. to 4.9 ft. (0.5 M to 1.5 M) would incrementally increase the bay from 32,279 acres up to 34,987 acres as the area subject to tidal inundation expands (Figure 16). Conversely, the 15,459 acres of mostly agricultural pasture land in the HBAP planning area would decrease 13% to 13,490 acres if the diked shoreline is breached because of the 18 inches of relative sea level rise that has occurred over the last century, on Humboldt Bay. With 4.9 ft. (1.5 M) of sea level rise, the decrease would be approximately 30%, or 10,780 acres.

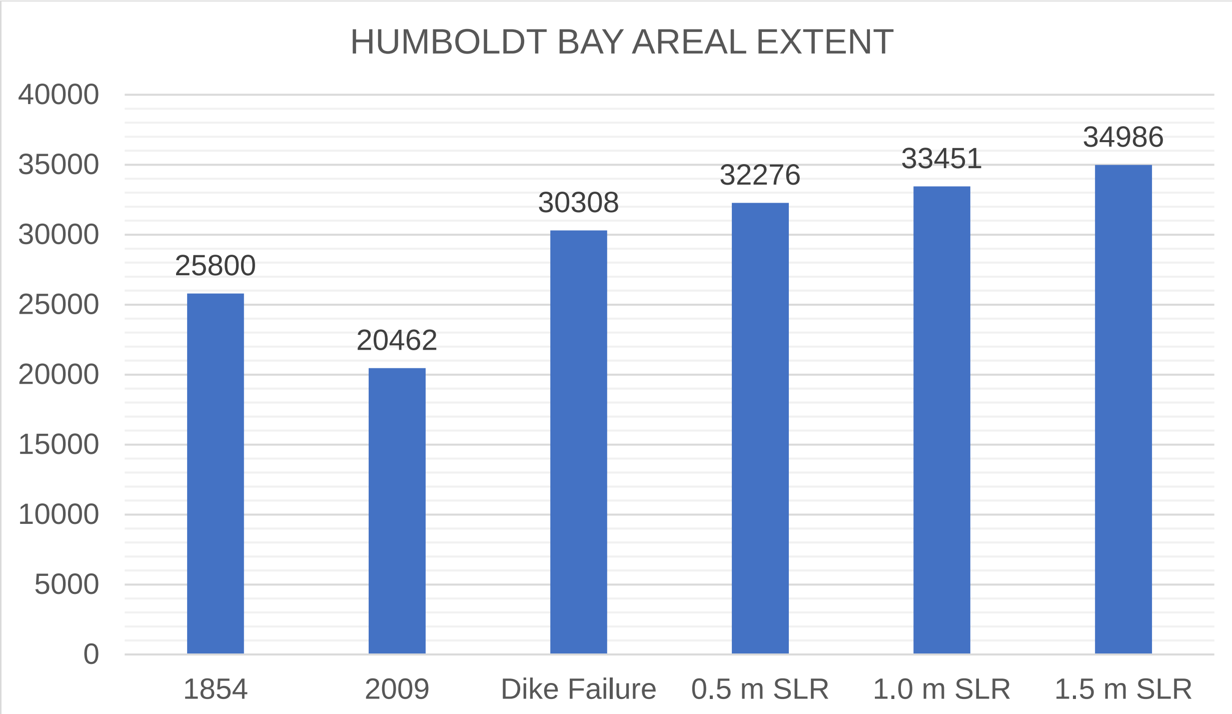

Figure 16. Areal extent (acres) of Humboldt Bay over time, if the diked shoreline is compromised, accounting for sea level rise projections ranging from 1.6 ft. to 4.9 ft. (0.5 M to 1.5 M).

Tidal habitat on Humboldt Bay can be segregated by maximum elevations for each type of habitat (Figure 17). With the addition of sea level rise, each habitat's maximum elevation increases, and its potential areal extent can be determined by surface elevations (Lidar). Due to a lack of data, estimates of areal extent of assume no sediment accretion.

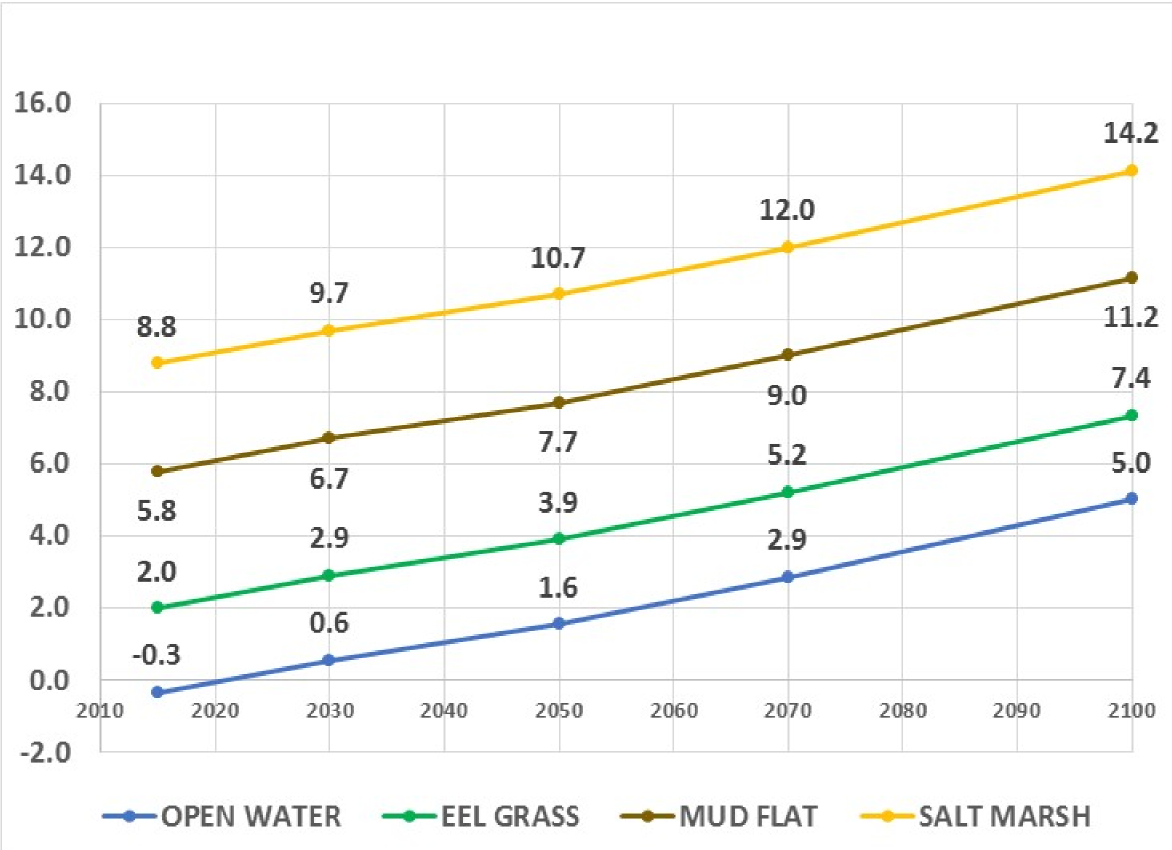

Figure 17. Maximum surface elevations in feet of Humboldt Bay habitat types with high projections for sea level rise of 0.9 ft. by 2030, 1.9 ft. by 2050, 3.2 ft. by 2070, and 5.4 ft. by 2100.

In the City's LCP planning area, there are 4.3 miles of shoreline vulnerable to being overtopped by 4.9 ft. (1.5 M) of sea level rise, which would cause Humboldt Bay and its tidal habitats to expand by 1,178 acres (Table 6). The responses of each of the five habitats (open water, eelgrass, mud flat, salt marsh, and pasture, which includes seasonal freshwater wetlands) to tidal inundation under existing tidal conditions and to sea level rise based on current (2010) surface elevations has been quantified.

Table 6.Change in habitat coverage (acres) if diked shoreline were to be compromised (2010), and with sea level rise of 1.6 ft., 3.3 ft., and 4.9 ft. (0.5 M, 1.0 M, and 1.5 M).

Habitats	Dike Failure	1.6 Ft.	3.3 Ft.	4.9 Ft.
Open Water	1	4	7	64
Eelgrass	3	32	62	552
Mud Flat	106	629	735	394
Salt Marsh	675	305	261	168
Pasture	854	669	574	461
Total	**1,639**	**1,639**	**1,639**	**1,639**

With sea level rise, each habitat's maximum surface elevation increases. Potential areal extent can be determined by surface elevations, utilizing 2009 Lidar surfaces. However, the most accurate depiction of the change in habitat distribution is the difference between the intact diked shoreline and the compromised diked shoreline because sediment accretion would not be a factor. Habitat distribution in response to sea level rise over time will need to account for sediment accretion, which for example would allow salt marsh habitat to rise in elevation in place; without sediment accretion, salt marsh would drown as sea levels rise.

Salt marsh habitat could expand by 675 acres if the diked shoreline is compromised. However, with 1.6 ft. (0.5 M) of sea level rise, salt marsh extent would actually decline to 305 acres unless sediment accretion is sufficient to maintain salt marsh with 1.6 ft. of sea level rise. Salt marsh habitat would continue to decline in areal extent with sea level rise, if sediment accretion cannot keep pace with sea level rise, to approximately 168 acres with an increase in water elevation of 4.9 ft. (1.5 M).

Similarly, mud flats would reach maximum coverage of 735 acres with 3.3 ft. (1.0 M) of sea level rise, absent sediment accretion of salt marsh areas before declining in areal extent with additional sea level rise. If sediment accretion cannot keep pace with sea level rise, mudflat ESHA will decline to 394 acres with 4.9 ft. (1.5 M) of sea level rise.

Eelgrass would expand significantly to 552 acres, and, to a lesser extent, open water habitat would increase in areal extent by 64 acres with 4.9 ft. (1.5 M) sea level rise. Existing surface topography of the lands around the bay would limit the areal extent of sea level rise. As Humboldt Bay gets deeper, salt marsh and mudflats would be submerged. Ultimately, the historical salt marsh extent of 10,000 acres in 1854 would not be restored with sea level rise; salt marsh would remain the rarest of tidal ESHAs on Humboldt Bay.

➢ Existing Tidal Conditions with Shorelines Compromised

If the barrier type shorelines are compromised or breached within the City's LCP planning area, salt marsh habitat could expand by 675 acres. This is a substantial increase considering there are presently only 1,545 acres of salt marsh on Humboldt Bay (Figure 18 and Figure 19). Mudflats would expand by 106 acres in areas where existing surface elevations are less than 5.8 ft. There would be approximately 854 acres of upland and pasture habitat in the City's LCP planning area.

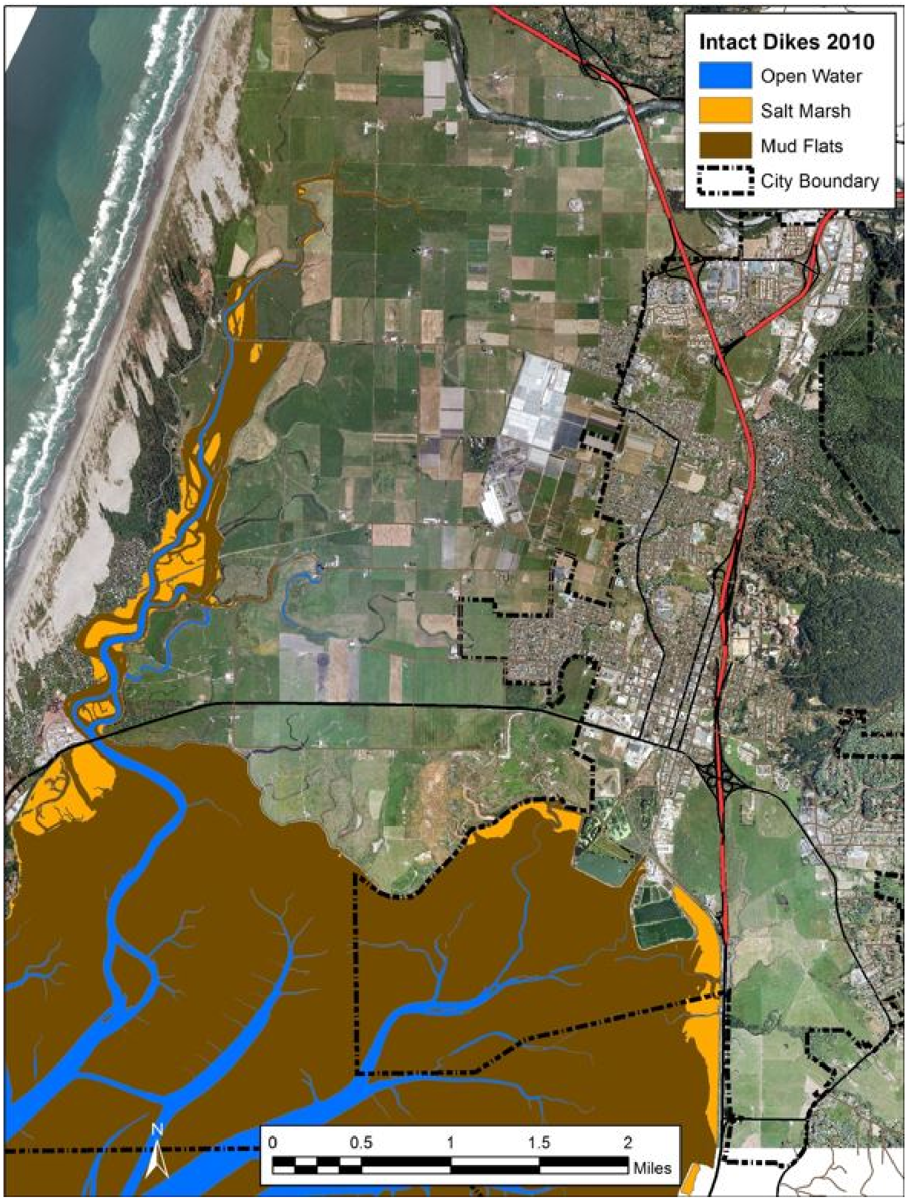

Figure 18. Mad River Slough-Mad River Bottom-City of Arcata habitat type distribution with diked shoreline intact (2009 Lidar).

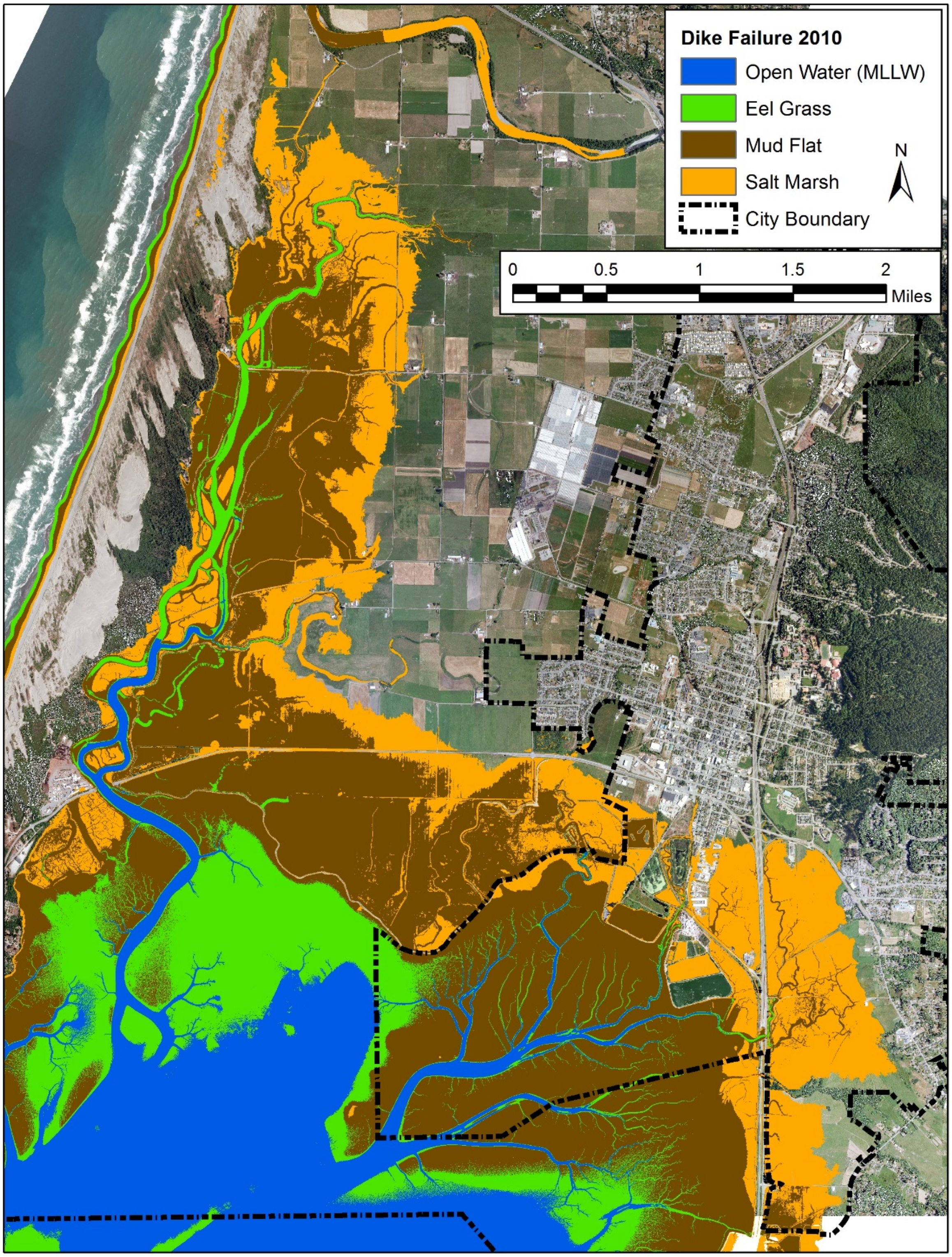

Figure 19. Mad River Slough-Mad River Bottom-City of Arcata habitat type distribution with diked shoreline compromised (2009 Lidar).

Sea Level Rise of 1.6 Feet

If the barrier type shorelines are compromised with 1.6 ft. (0.5 M) of sea level rise, eelgrass habitat could increase by 32 acres. Mudflats would increase substantially by 629 acres. Salt marsh habitat could decline substantially by 370 acres without sufficient sediment accretion to maintain its distribution with sea level rise. The initial expansion of salt marsh to 675 acres without sea level rise in response to shoreline failure, would decline to 305 acres (Figure 20). Upland and pasture habitat would decline to 670 acres.

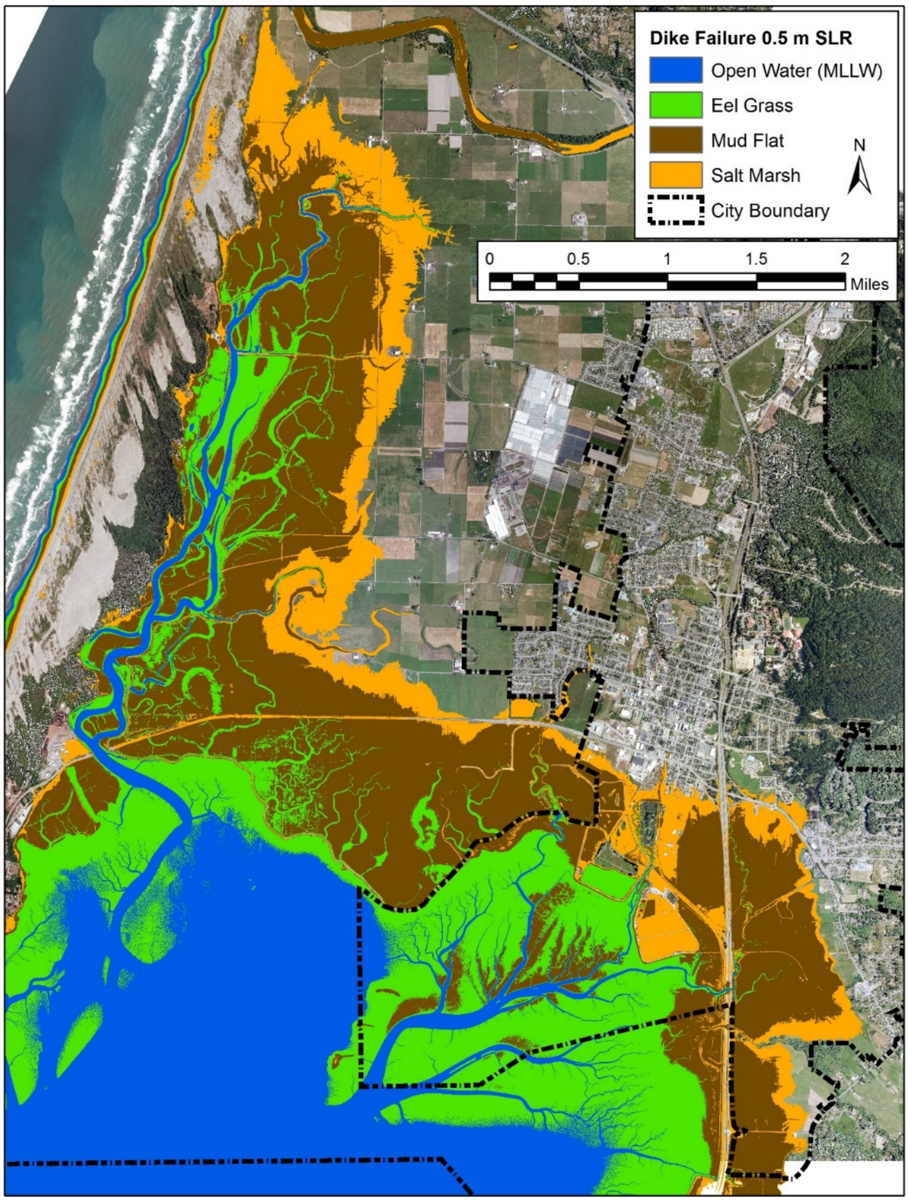

Figure 20. Mad River Slough-Mad River Bottom-Bayside habitat type distribution with diked shoreline compromised and 1.6 ft. (0.5 M) of sea level rise (2009 Lidar).

Sea Level Rise of 3.3 Feet

With 3.3 ft. (1.0 M) of sea level rise, eelgrass habitat could increase to 62 acres, mudflats could increase to 735 acres, and salt marsh habitat could decline to 261 acres without sufficient sediment accretion to maintain its habitat (Figure 21). Upland and pasture habitat would decline to 573 acres.

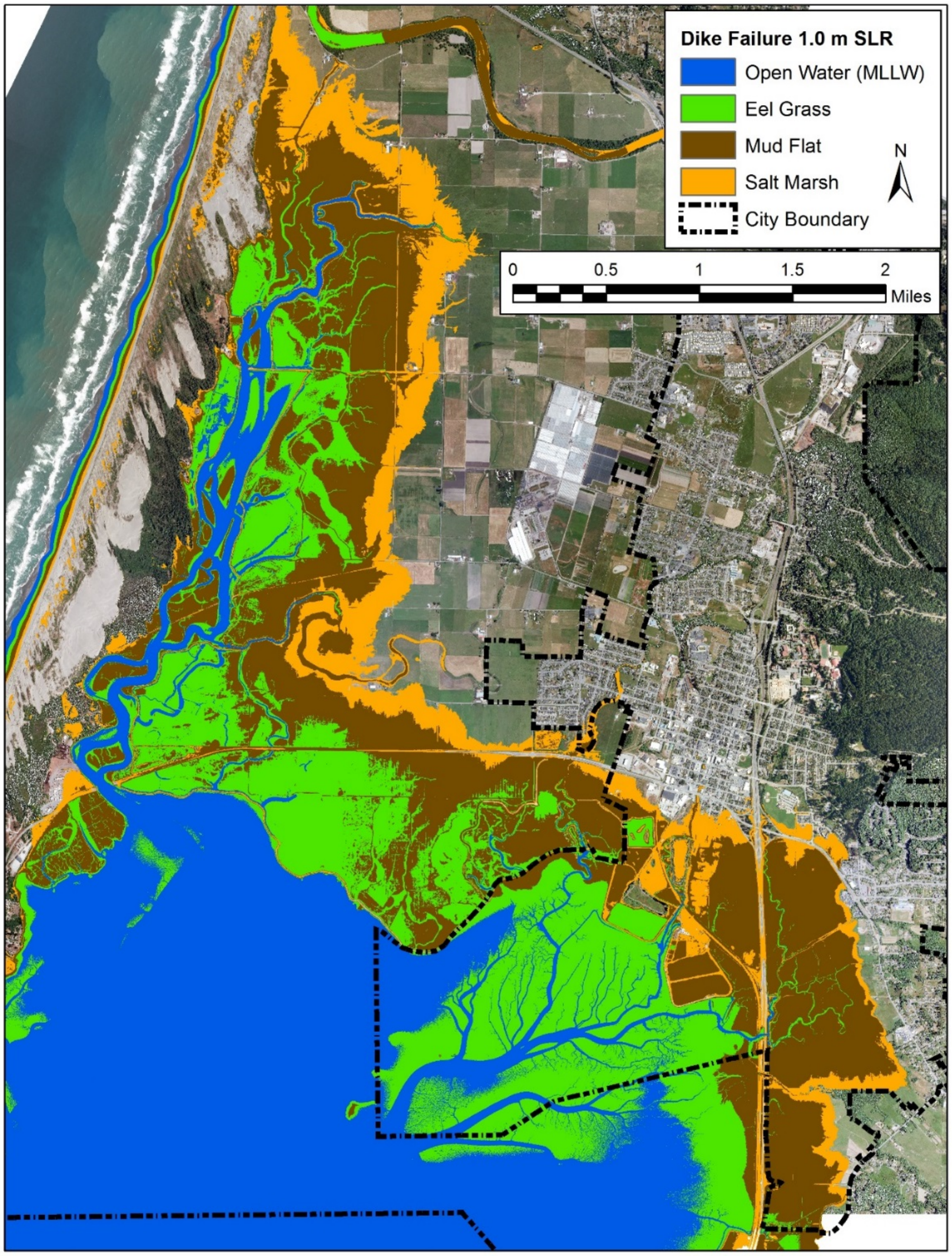

Figure 21. Mad River Slough-Mad River Bottom-Bayside habitat type distribution with diked shoreline compromised and 3.3 ft. (1.0 M) of sea level rise (2009 Lidar).

Sea Level Rise of 4.9 Feet

In the City, with 4.9 ft. (1.5 M) of sea level rise, eelgrass habitat could increase substantially to 552 acres on former tidelands. Mudflats could actually decrease substantially without sufficient sediment accretion to 394 acres. Salt marsh habitat could continue its decline to 168 acres without sufficient sediment accretion to maintain its habitat (Figure 22). Upland and pasture habitat would decline to 461 acres.

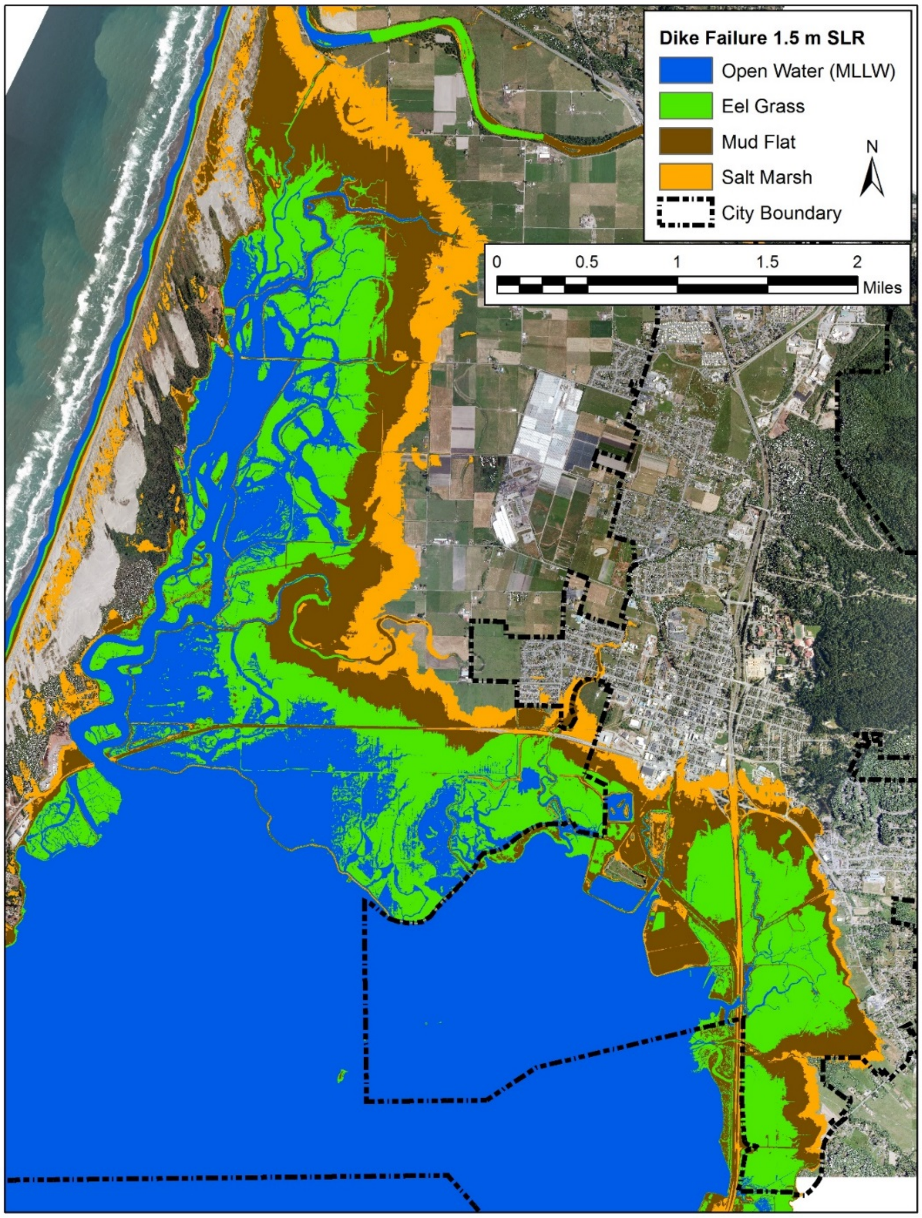

Figure 22. Mad River Slough-Mad River Bottom-Bayside habitat type distribution with diked shoreline compromised and 4.9 ft. (1.5 M) of sea level rise (2009 Lidar).

Flooding

Flooding during a 100-year event could rise to 10.2 ft., and overtop more than 20.9 miles of artificial shoreline structures that are less than or equal to 9.7 ft. elevation, or two feet above MMMW elevation.

The 100-year flood would likely affect the same diked former tidelands that are vulnerable to 3.3 ft. (1.0 M) of sea level rise (MMMW of 11.0 ft.), potentially putting 6,600 acres of seasonal freshwater wetlands and Aleutian goose grazing habitat at risk of tidal inundation in those areas where protective dikes are breached or overtopped.

Flooding of low-lying lands behind barrier type shorelines can also occur during heavy rainfall as drainage to the bay is impaired, resulting in backwater ponding. Flooding and ponding of water behind dikes by stormwater runoff from interior watersheds can also result in erosion and/or slumping of earthen dike slopes, as fortification of dike slopes is generally limited to the bay side of the dikes.

Likewise, flooding can occur in the short-term when rising groundwater emerges onto the ground surface in low-lying areas in response to winter storms, king tides or rising sea levels. Regardless of protective shoreline structure, fortification, or elevation, low-lying areas behind these structures such as diked former tidelands and seasonal freshwater wetlands, including Aleutian grazing habitats, are vulnerable to flooding from rising groundwater. Ultimately, if the land surface elevation is not increased, emerging groundwater would inundate these low-lying areas and they would transition to emergent and then submergent wetlands.

The average elevation of groundwater on land adjacent to the shoreline is generally above MSL elevation of 3.4 ft. On Humboldt Bay, diked former tidelands are generally equal to or less than 6.5 ft. MHHW in elevation. Groundwater, depending on surface elevations and the season, can fluctuate from the ground surface down to three feet (Hoover 2015). As sea level rises, the denser saltwater would push groundwater to higher elevations, eventually emerging and flooding the ground surface. With sea level rise, this type of flooding would likely begin as nuisance flooding during the winter and increase in duration over time until it becomes chronic flooding and eventually permanent inundation. King tides that equal or exceed MAMW elevation of 8.8 ft. presently occur now approximately four times a year. With 1.6 ft. (0.5 M) of sea level rise, similar tides would reach 8.8 ft. 125 days each year, constituting chronic flooding (NHE 2017).

On Humboldt Bay, rising groundwater during winter and spring months creates seasonal freshwater wetlands on diked former tidelands. If not tidally inundated, rising groundwater in response to sea level rise would likely form emergent and submergent freshwater wetlands and eventually open water habitat. Once barrier type shorelines are breached or overtopped, daily tidal inundation would convert freshwater wetlands to inter-tidal wetlands. With sea level rise, inter-tidal wetlands would become submerged or open water.

- Salt Water Intrusion

Salt water intrusion and rising groundwater flooding are linked, as fresh groundwater floats on higher-density seawater. Salt water intrusion, like tidal inundation, can lead to significant vegetative conversions from salt intolerant species to salt tolerant species, or even mudflats, if the area is inundated for extended periods of time. In the City's LCP planning area, the conversion of current freshwater ESHA, such as seasonal freshwater wetlands and Aleutian goose grazing habitat (pasture) would lead to significant changes in wildlife composition, distribution, and abundance. Diked former tidelands, now agricultural lands, that are vulnerable to salt water intrusion average six to seven feet in elevation. During winter months, ground water often rises to the surface in these areas.

Once barrier type shorelines are breached or overtopped, tidal inundation would convert freshwater wetlands. As a result, there would be no effect on inter-tidal wetlands from salt water intrusion under this scenario.

Susceptibility

The freshwater ESHA habitats in the City of Arcata that are vulnerable to tidal inundation, flooding, and salt water intrusion are mostly located on low-lying diked former tidelands, now agricultural lands. Approximately 81% of the agricultural lands in the City's LCP planning area are vulnerable to 4.9 ft. (1.5 M) of sea level rise.

Current agricultural uses are based on raising forage for livestock grazing. Saltwater inundation, even for short durations, can have a significant impact on non-saltwater tolerant plants such as forage. Agricultural practices are very susceptible to tidal inundation. Frequent or chronic flooding with salt water would likely result in a vegetative conversion to salt tolerant plant species, and the collapse of agricultural endeavors. Flooding from extreme storm events is infrequent, and current agricultural uses can recover from such flooding. Backwater flooding in the winter and spring months can seasonally restrict agricultural lands uses. Without improved drainage in response to rising sea levels, such flooding may lead to pastures converting to freshwater or brackish water wetlands. Emerging groundwater may also result in the conversion of forage to wetland vegetation, which would be a significant impediment to continuing agricultural uses. Saltwater intrusion of shallow wells would impact irrigated agricultural lands significantly. Saltwater intrusion of groundwater would lead to vegetative conversions to salt tolerant species and a reduction or elimination of livestock grazing.

3.3.3 Wiyot Cultural Resources

Humboldt Bay, or Wigi, is home to the Wiyot people. In 1918, L.L. Loud published his ethnographic report on the Wiyot, which included a map of 103 cultural sites on Humboldt Bay. A copy of his 1913 field map was used to delineate the location of cultural sites. Loud's field map did not cover all the area and sites contained in his published ethnographic report. Consultation with a Wiyot Tribal Historic Preservation Officer (THPO) enabled additional sites to be added in areas beyond Loud's field map, and enabled revisions to the location of several of Loud's field map site locations.

Consultation with the THPO confirmed the status (whether the presence of the site has been field verified) of all sites, locations and their uses. Of the 103 sites on Humboldt Bay identified by Loud, 6 are in the City of Arcata's LCP jurisdiction, 75 are within Humboldt County's HBAP planning area, 15 are in the City of Eureka's LCP jurisdiction, and 4 are in the unincorporated area of the County but inland of the HBAP planning area.

The number and distribution of the 103 Loud cultural sites near Humboldt Bay include:

- 11 sites on Mad River Slough
- 24 sites on Arcata Bay
- 12 sites on Eureka Slough
- 21 sites on Eureka Bay
- 1 site on Elk River Slough
- 34 sites on South Bay

Of the 103 sites located by Loud, there are three sites in the City's LCP planning area but only two appear to be vulnerable to 4.9 ft. (1.5 M) of sea level rise. These two sites may be located on publicly owned properties.

Exposure

Sea levels rise and increased wave action could erode unfortified shorelines, exposing cultural sites to erosion and inundation, including in low-lying areas generally consisting of diked former tidelands. The vulnerability of diked former tidelands to tidal inundation is dependent on the integrity of the entire shoreline of the hydrologic unit within which they are located. Therefore, those sites below 12.6 ft. elevation that are located behind diked shorelines could experience erosion and become tidally inundated if any segment along the shoreline (not just the segment in front of the site) of the hydrologic unit is breached or overtopped. Shoreline erosion could expose and destroy Wiyot artifacts, burials, and the structure of shell middens at these sites.

In 2006, the Wiyot Tribe installed composite fiberglass sheet piling protection at Tuluwat on Indian Island to prevent further shoreline erosion of the site. Rising groundwater and salt water intrusion, could also lead to acidification and calcification of buried artifacts from sea level rise. This may also affect the archaeological integrity of Wiyot sites characterized as shell middens.

With 1.1 ft. of sea level rise (8.8 ft.), one site in the City's LCP planning area could become tidally inundated and exposed to shoreline erosion. With 1.6 ft. (0.5 M) of sea level rise (9.6 ft.), another site could become vulnerable. It is not known if rising groundwater and salt water intrusion from sea level rise would further degrade these Wiyot sites.

Susceptibility

On Humboldt Bay, there are potentially 52 Wiyot sites that are likely to be physically damaged due to tidal inundation from sea level rise. Four sites could be damaged by shoreline erosion and bluff retreat. Permanent tidal inundation would prevent access and use of these sites. Shoreline erosion due to rising sea levels or extreme storm events could physically damage or even eliminate sites. The cultural and archaeological significance of sites actively eroded or destroyed would be diminished or lost. Impacts from sea level rise on these sites to the Wiyot people would be significant.

3.4 Transportation

There are currently three modes of transportation and supporting infrastructure in the City's LCP planning area include surface and rail transport. Rail transport was closed in 1998 by the Federal Railroad Administration. A third mode transportation, the Humboldt Bay Trail has just been completed and is located east of the railroad grade along the shoreline of Humboldt Bay. Infrastructure for all modes of transportation in the City's LCP planning area are vulnerable to the 4.9 ft. (1.5 M) of sea level rise projected for 2100. The City is responsible for the maintenance of local streets and the portion of the Humboldt Bay Trail in the City's LCP planning area. Caltrans is responsible for the state and inter-state infrastructure City's LCP planning area: Highways 101 and 255.

3.4.1 Affected Modes of Transportation

In the City's LCP planning area, the vulnerable local transportation system of streets is concentrated south of Samoa Boulevard (Highway 255). Other City streets that are in the potential tidal inundation footprint for 4.9 ft. (1.5 M) of sea level rise include the southern end of Villa Way, the area south of 5th Street, and streets east of E Street. City collector roads that could become tidally inundated are Old Arcata Road just west and east of Union Street and the Bayside Cutoff. Highway segments in the City that are vulnerable to tidal inundation are Highway 255at the intersection with H Street and on/off ramps connecting Highway 101. Both north and south bound lanes of Highway 101 are vulnerable from Highway 255 overpass south to Bracut (Figure 23).

There are approximately two miles of the NCRA railroad in the City's LCP planning area. Slightly more than one mile comprises the shoreline of Arcata Bay. The City has constructed a 1.8-mile trail along the Bay from the Arcata Marsh to Bracut.

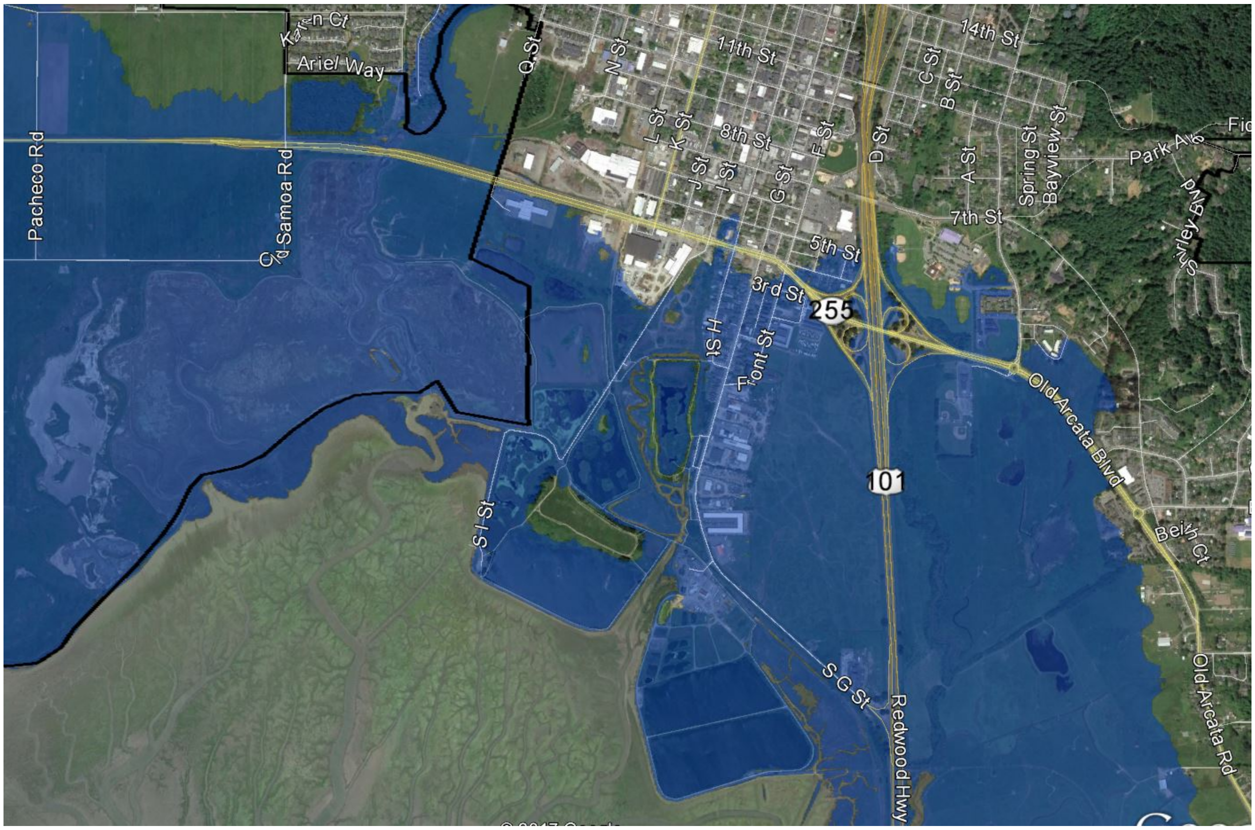

Figure 23. City streets, collectors, and highways that would be tidally inundated by 4.9 ft. (1.5 M) of sea level rise.

3.4.2 Exposure

Sea level rise would impact transportation assets that are in low-lying coastal areas. These impacts can manifest directly through erosion of street and highway fill/embankments or bridge abutments, and/or inundation of road and highway surfaces and drainage structures. Impacts can also manifest indirectly through impacts to road and highway fill/embankments or surfaces from rising groundwater and saltwater intrusion, which could corrode underground structures such as culverts.

Tidal Inundation

- Sea Level Rise of 1.1 Ft.

With 1.1 ft. of sea level rise, the inundation modeling and mapping depicts 1.3 miles of streets and 0.2 miles of collectors become inundated, which would not occur unless the protective shoreline structures on Butcher Slough and Washington Gulch are breached (Table 7). As is evident during king tides, there are just a few areas in the Arcata Marsh that become tidally inundated.

Table 7. Surface transportation infrastructure tidally inundated (miles) by 1.1 to 4.9 ft. of sea level rise.

Roadway Type	1.1 Ft.	1.6 Ft.	3.3 Ft.	4.9 Ft.
Streets	1.3	1.7	2.5	3.4
Collectors	0.2	0.3	1.0	2.2
Arterials/Highways	0.0	0.1	0.5	1.2
Total	**1.5**	**2.2**	**4.0**	**6.9**

Sea Level Rise of 1.6 Ft.

Based on existing shoreline elevations approximately 1.4 miles would be vulnerable to being overtopped by 1.6 feet (0.5 M) of sea level rise. Primarily, the 0.5 miles of shoreline on Butcher Slough, 0.6 miles of earthen dikes on Gannon Slough, and 0.4 miles on Washington Gulch could be overtopped by 1.6 ft. of sea level rise.

Approximately, 1.7 miles of streets south of Samoa Boulevard (I Street, H Street, G Street, and Front Street) and 0.3 miles of collectors (Bayside Cutoff) could become inundated. The only access routes to the City's Arcata Marsh and Treatment Facility: South G, H, and I Streets would be inundated. Approximately, 0.5 miles of railroad between the Treatment Facility and Gannon Slough would become tidally inundated.

Sea Level Rise of 3.3 Feet

With 3.3 ft. (1.0 M) (11.0 ft.) of sea level rise, 3.4 miles of shoreline may become tidally inundated, including:

- 5,179 feet (1.0 miles) of fill mostly on Butcher Slough,
- 4,326 feet (0.8 miles) of dikes, and
- 1,422 feet (0.3 miles) of roads.

Approximately 2.5 miles of streets south of Samoa Boulevard and south of 3rd Street down G Street to Highway 101 would become tidally inundated. Most of Bayside Cutoff would be inundated too. Approximately 0.5 miles of the north and south bound lanes of Highway 101 just south of the Samoa Blvd interchange would become inundated, and the south bound lanes south of Jacoby Creek to Bracut would be inundated.

Highway 255 outside of the City's LCP planning area could become tidally inundated as protective dike shorelines on Arcata Bay are overtopped, leading in turn to inundation of V Street and potentially Villa Way near Janes Creek and McDaniel Slough.

Nearly the entire length of railroad and Bay Trail from Samoa Boulevard south to the City's limit near Gannon Slough would become tidally inundated, approximately 1.4 miles.

➢ Sea Level Rise of 4.9 Feet

Approximately 4.2 miles (61.7%) of the shoreline based on current conditions is vulnerable to being overtopped by 4.9 ft. (1.5 M) of sea level rise.

The 3.4 miles of City streets that are in the potential tidal inundation area include the south and east sides of Villa Way, south of Samoa Boulevard, south of 5^{th} Street, and east of E Street. City collector roads that could become tidally inundated are Old Arcata Road just west and east of Union Street and the Bayside Cutoff. Highway segments in the City that are vulnerable to tidal inundation are Highway 255 at the intersection with H Street and on/off ramps with Highway 101. Both north and south bound lanes of Highway 101 would be tidally inundated between the Highway 255 overpass in the City south to Bracut.

Nearly the entire length of railroad and Bay Trail from Samoa Boulevard south to the City's limit near Gannon Slough would become tidally inundated, approximately 1.5 miles.

Flooding

Under current MMMW conditions, if the protective shorelines to the west and east are compromised by breaching or overtopping, Highway 101 would become a causeway, similar in function to a dike, traversing the low-lying segments on Humboldt Bay. The highway would continue as a causeway until it became inundated by rising tides. If the water control and drainage structures located in the protective shoreline to the east or beneath Highway 101 fail or are impaired, flooding of lands behind the protective shorelines may occur, flooding the road prism and surface of Highway 101.

On Arcata Bay, shorelines to the west and east of Highway 101 protect the highway from tidal inundation. The dikes at Gannon Slough have tide gates draining the low-lying areas east of the highway. There are three primary tributaries (Gannon-Beith Creeks, Jacoby Creek, and Washington-Rocky Gulch) draining watersheds to the east. Stormwater runoff from these streams, particularly during high tides, can overwhelm water control and drainage structures, resulting in overbank flows that can flood local roads and Highway 101 (Figure 24).

Figure 24. Highway 101 traverses several tributaries and streams to Arcata Bay that convey stormwater runoff and can flood land to the east of Highway 101.

3.4.3 Susceptibility

Streets, roads, and highways that traverse low-lying regions on Humboldt Bay are vulnerable to sea level rise and at risk of being tidally inundated. If protective dikes or railroad shoreline structures are breached and tidal waters allowed to reach U.S. Highway 101, State Highway 255 and local road prisms could become exposed. Over time and under chronic flooding or repeated tidal inundation (MMMW), road bases would become saturated, causing the asphalt to buckle and requiring resurfacing. Rising tides can also impair the capacity and function of water controls structures that are part of the surface transportation infrastructure such as tide gates and culverts. Roadway embankments, if not fortified in reaches that are exposed to wave action, are susceptible to erosion as well as overtopping.

Temporary or nuisance flooding may result in temporary closures of roadways and re-routing of traffic. Frequent or chronic inundation of street or highway segments would likely not be tolerable. The adaptive capacity to address sea level rise impacts on City or state roadways is complicated by that fact that most of the streets and highways do not form the shoreline on Humboldt Bay. On Humboldt Bay, diked shorelines that protect low-lying segments of streets and highways from tidal inundation or flooding consist of 170 parcels owned by a mix of public and private entities.

The railroad is susceptible to adverse impacts from tidal inundation during MAMW and wave action during storms and 100-year extreme events. The railroad has not been used since 1998 and has only been maintained or repaired at the sea wall. Without regular maintenance, bridges, culverts and tide gates in a marine environment would degrade. Tidal inundation could result in slumping, erosion and washing away of ballast. Like roadways, the capacity and function of drainage structures such as bridges, culvert and tide gates would be impaired with rising sea levels.

3.5 Utilities

The City's land uses are enabled by utilities that provide essential services. The utility infrastructure and services in the City are municipal water, waste water, energy (electrical and natural gas), and communications. Impairment of utility infrastructure can affect all land uses and properties served by the affected utility. Many of the utilities have underground infrastructure (water, sewer, gas lines, and optical fibers), exacerbating their vulnerability to sea level rise. The infrastructure and operations for energy and communications utility services in the City are the responsibility of private companies.

PG&E operates the Humboldt Bay Generating Station in King Salmon, which provides electricity in the City's LCP planning area. PG&E maintains a system of electrical transmission towers, sub-stations, and distribution poles to deliver electricity in the City. PG&E also provides natural gas via underground gas lines and associated infrastructure throughout the City's LCP planning area.

Communications systems (telephone, cable, optical fiber) in the City's LCP planning area are privately owned and maintained. Infrastructure can consist of cell towers, utility poles and overhead lines, underground lines, and various types of above and below ground infrastructure.

The exact location of underground natural gas and optical fiber infrastructure are not known due to utility company policies limiting access to location information for security purposes, making it difficult to assess the vulnerability of this infrastructure to sea level rise.

As urban areas become tidally inundated, the underground utilities (municipal water, waste water, gas lines, and optical fibers) serving these areas would also become tidally inundated. Overhead utilities structures can also be impacted, as flooding or tidal inundation can hamper access for their repair and maintenance, and can reduce the stability of above-ground structures supporting these utilities.

An inventory of utility infrastructure located in the City's LCP planning area that are vulnerable to sea level rise of 4.9 ft. (1.5 M) includes water lines and pump stations, sewer lines, lift stations, the Treatment Plant, natural gas lines, electrical transmission towers, and distribution poles (Table 8).

Table 8. Utility infrastructure located in the City's LCP planning area that are vulnerable to 1.1 ft. (MAMW), 1.6 ft. (0.5 M), 3.3 ft. (1.0 M), and 4.9 ft. (1.5 M) of sea level rise.

Utilities	1.1 Ft.	1.6 Ft.	3.3 Ft.	4.9 Ft.
Water Lines (miles)	2.0	2.1	2.6	3.3
Sewer Lines (miles)	1.4	2.0	3.7	4.4
Gas Lines (miles)	2.4	2.5	2.8	3.1
Electrical Transmission Towers	8	8	9	10
Electrical Distribution Poles	62	64	70	85

3.5.1 Municipal Water

The Humboldt Bay Municipal Water District (HBMWD) supplies the City with most of its municipal and potable water. The City also owns and operates wells to augment is municipal water supply that are not in the City's LCP planning area. The City then disinfects and distribute potable water to customers within its service area.

The City of Eureka has 2.3 miles of its Mad River Pipelines (MRP) (two 48-inch pipelines) convey water from the "Eureka Turnout," located at 7th and A Streets. The pipelines then traverse the City of Arcata's LCP planning area and are vulnerable now if the dikes on Gannon slough are breached, or when sea level rises 1.6 feet (0.5 M) and the dikes are overtopped.

Exposure

The City has one booster-pump station at an elevation 9.5 ft. that would be vulnerable when sea level rises 1.9 ft. The City also has water lines that are in areas which are vulnerable to tidal inundation, including 2.0 miles, 2.1 miles, 2.6 miles and 3.3 miles with 1.1 ft. (MAMW), 1.6 ft. (0.5 M), 3.3. ft. (1.0 M), and 4.9 ft. (1.5 M) of sea level rise, respectively (Figure 25).

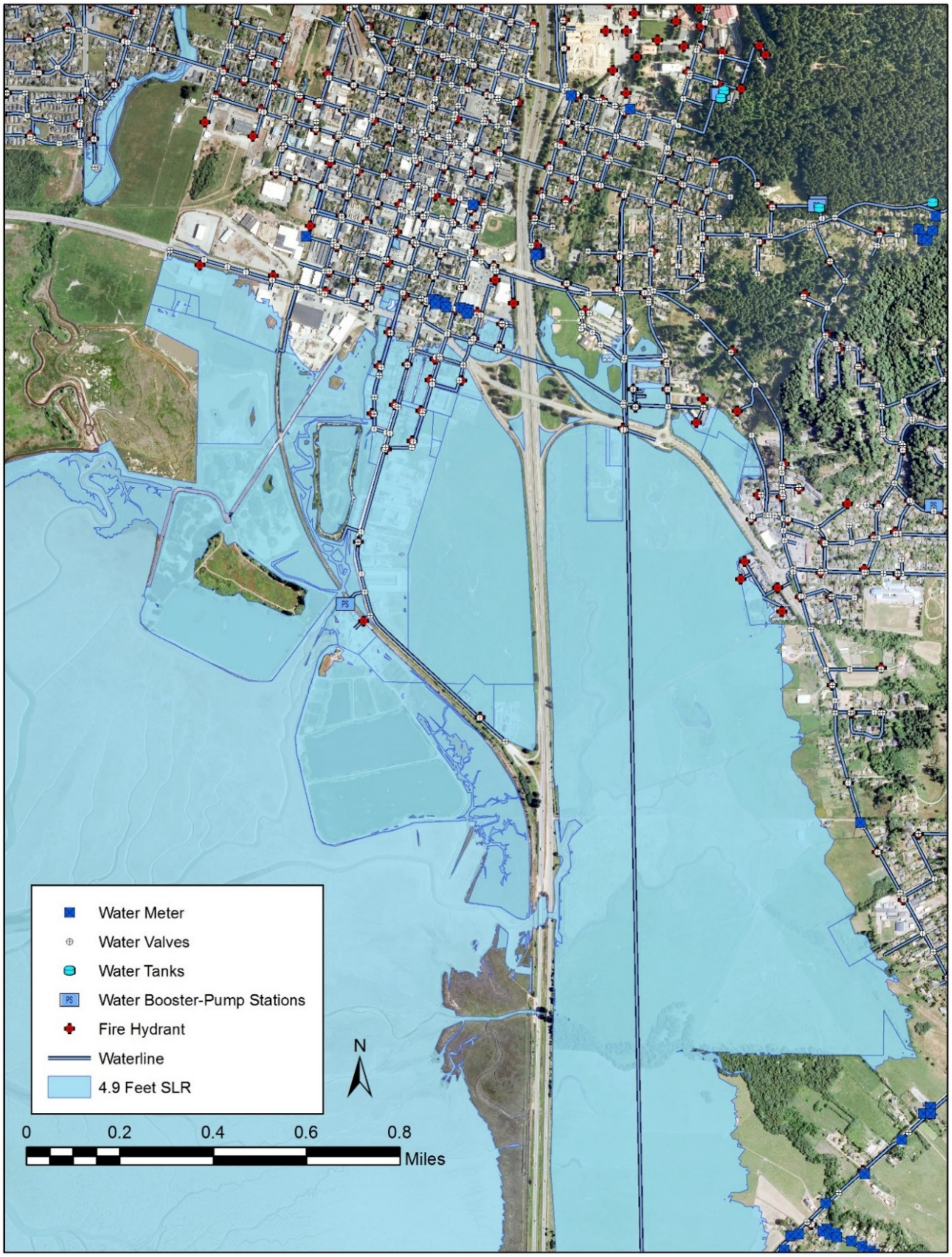

Figure 25. City's municipal water distribution infrastructure and with tidal inundation area of 4.9 ft. (1.5 M) of sea level rise. 3.3 miles of water line and one pump station are vulnerable.

Susceptibility

The vulnerability of the City's municipal water system to tidal inundation does not vary significantly from 1.1 ft. to 4.9 ft. (1.5 M) of sea level rise (2.0 to 3.3 miles of water lines). Most of the City's underground municipal water transmission pipelines are not susceptible to the adverse effects of sea level rise. However, older water transmission lines are chronically susceptible to corrosion if the cathodic protection systems are not maintained and from differential settlement, should the ground supporting the pipes become saturated and mobile. Ground saturation and mobility is likely to happen with rising ground water and tidal inundation.

Indirectly, the City's municipal water system may be susceptible to tidal inundation if the City's ability to perform maintenance and emergency repairs of the water transmission lines is impaired. Without regularly scheduled maintenance and repair, the pipeline would develop holes and cracks. Newer transmission lines would be resilient depending on the type of materials with which they are made (high-density polyethylene).

The City only has one booster-pump station that is vulnerable to sea level rise of 1.9 ft. Booster pump stations include mechanical and electrical systems that are very susceptible, should they be tidally inundated. The mechanical systems (valves and pumps) need regular maintenance.

If the dikes on Gannon Slough that are preventing tidal inundation of the areas that the City of Eureka's pipe lines traverse fail, getting trucks and heavy equipment access for emergency repairs may eventually become impossible. Deferred maintenance could cause long-term, chronic problems with that conveyance system, resulting in significant interruption of service and eventually complete failure of the system. The water transmission lines are the primary conveyance of potable water to the City of Eureka. Impairment of the conveyance capacity of these transmission lines would be catastrophic. The City of Eureka has approximately five days of water storage. Repairs that take longer than this would be consequential to the City of Eureka and likely necessitate drastic conservation efforts.

3.5.2 Wastewater

The City's wastewater infrastructure consists of a collection system of lift stations, sewer lines and the Treatment Plant. The City's Treatment Plant occupies approximately 71 acres. Primary treatment facilities include a series of treatment marshes and oxidation ponds to provide secondary treatment. Polishing marshes (equivalent to secondary treatment) are located at the Arcata Marsh. The Arcata Marsh is an innovative wastewater treatment technology, consisting of three treatment wetlands in series. The Treatment Plant discharges secondary treated wastewater to the Arcata Marsh and effluent from the Arcata Marsh is pumped back to the Treatment Plant for disinfection before final disposal to Humboldt Bay via an outfall on Butcher Slough (COA UWMP 2015). The Treatment Plant also has several sludge compost beds, pump stations and pipelines.

Exposure

Inflow and infiltration is an existing problem that could be exacerbated by tidal inundation and rising groundwater, which could adversely impact affected portions of the wastewater collection system and the operation of the Treatment Plant.

The City has four sewer lift stations (elevations: 10.5, 11.5, 12.1, and 13. ft.) and 4.4 miles of sewer lines within the tidal inundation area for 4.9 feet (1.5 M) of sea level rise (13.1 feet) (Figure 26).

The Treatment Plant has a 1.3-mile perimeter, of which 0.9 miles is composed of earthen pond dikes that enclose approximately 8.4 acres. While most of these dikes are fortified, approximately 0.5 miles would be overtopped by 3.3 ft. (1.0 M) of sea level rise, and 0.9 miles by 4.9 ft. (1.5 M) of sea level rise (Figure 27).

The Arcata Marsh has 3.9-mile perimeter that is composed of dikes, pathways/roads, and railroad that enclose 225 acres, of which 61 acres consist of treatment marshes and oxidation ponds adjacent to the Treatment Plant. Most of the perimeter of the Arcata Marsh, except for 0.5 miles of dikes on the oxidation ponds, would be overtopped by 3.3 ft. (1.0 M) of sea level rise. Essentially all the Arcata Marsh habitat areas would become tidally inundated.

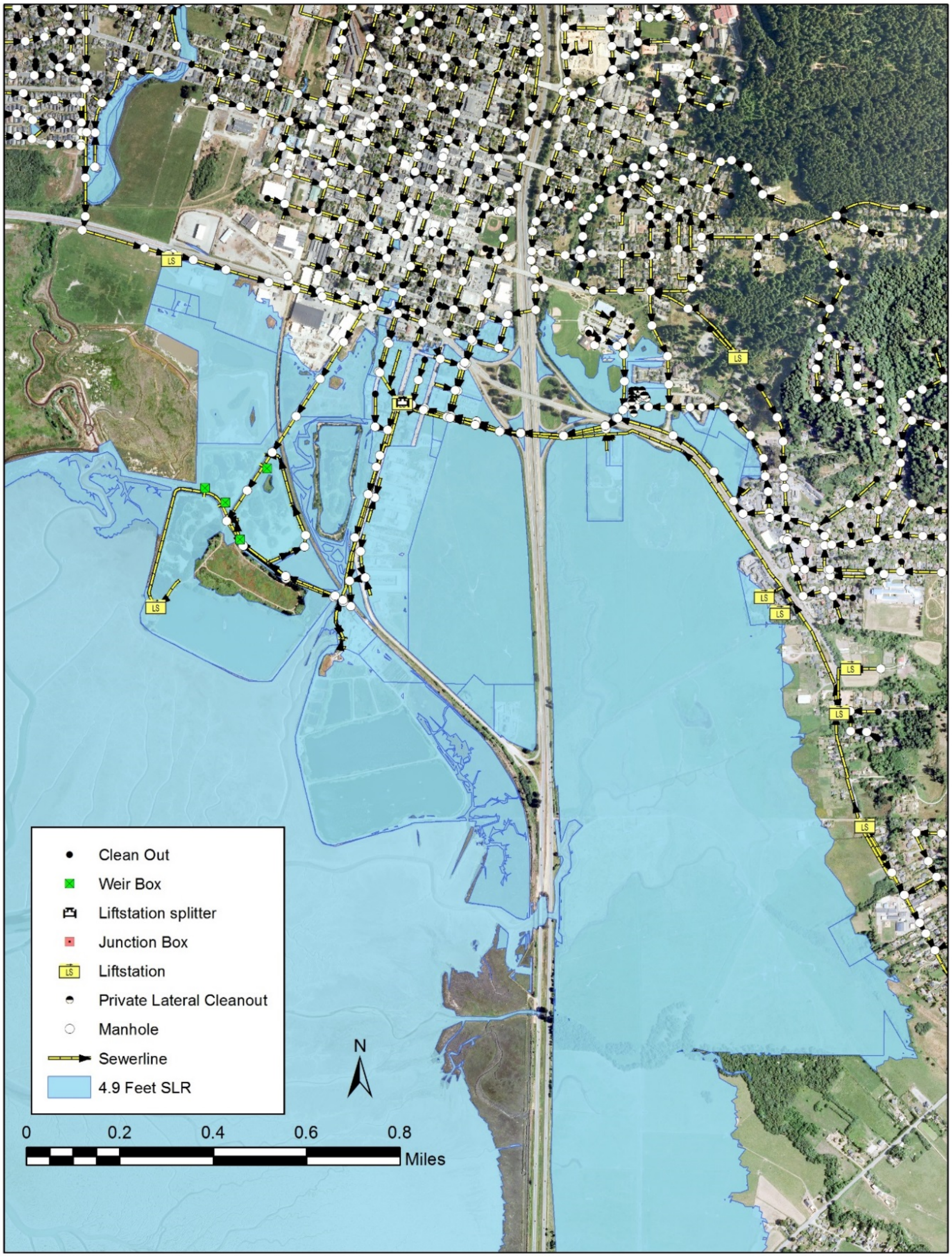

Figure 26. City's waste water distribution infrastructure within the tidal inundation area for 4.9 ft. (1.5 M) of sea level rise.

Figure 27. The City's wastewater treatment plant (yellow) and the Arcata Marsh and Wildlife Sanctuary (white) with respect to the tidal inundation area for 3.3 ft. (1.0 M) of sea level rise.

Susceptibility

With sea level rise, it is possible that increasingly long periods of ground saturation could result in settlement or movement and possibly floating of wastewater pipes. In general, the wastewater collection system (including the lift stations) is fairly insensitive to flooding and tidal inundation. However, the lift stations and collection pipe network's exposure to tidal inundation could allow salt water into the collection and treatment system. This would hydraulically overload the collection and treatment system and cause a breakdown in the treatment process. If too much salt water is introduced into the treatment process, the biological system within the treatment plant would cease to function, resulting in a failure of the treatment process. The biological system would not able to cope with this sea level rise impact.

Electrical components of the lift stations are very susceptible to being tidally inundated or flooded. If the electric supply and control systems are exposed to salt water, they are likely to malfunction.

The biological treatment process of a wastewater treatment facility is very sensitive to saltwater, that could be introduced by inflow/infiltration (I/I) to a collection system that traverses areas subject to tidal inundation.

The loss of functionality of the Treatment Plant would be devastating to the entire City. If the I/I become too big of an issue, the City may opt to restrict the use of the collection system in the affected areas. This would seriously impact the residential, commercial and industrial uses of those areas and areas upstream that are tributary to those sections of the collection system. Future growth could also be impacted by loss of treatment capacity if the system has excessive I/I. If the Treatment Plant ceases to function, the impacts would be felt by all the users in the City's service areas.

3.5.3 Energy

PG&E's Humboldt Bay Generating Station (HBGS) is a local natural gas-fired power plant in King Salmon, that provides electricity to the City. In the City, PG&E has electrical transmission and distribution infrastructure. There are no electrical substations in areas that are vulnerable to 4.9 ft. (1.5 M) of sea level rise. There are high voltage electrical transmission towers (69 kV (yellow) and 138 kV (white) are in low-lying areas protected from tidal inundation by earthen dikes, which are vulnerable to 4.9 ft. (1.5 M) of sea level rise (Figure 28).

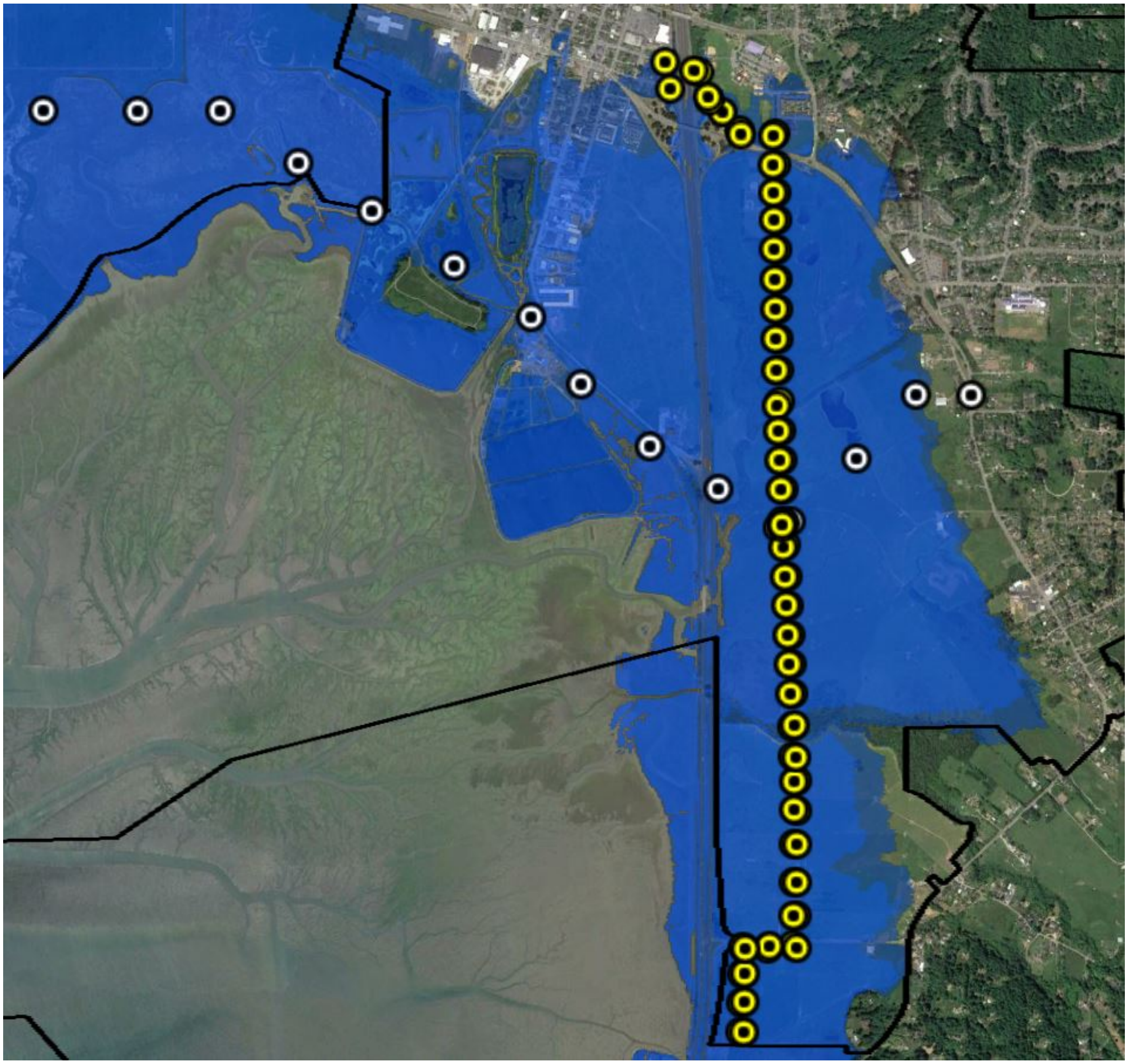

Figure 28. PG&E'S electrical transmission towers (white) and distribution poles (yellow) that could be affected by the tidal inundation from 4.9 ft. (1.5 M) of sea level rise.

Exposure

PG&E has electric transmission towers and distribution poles located in diked former tidelands that are low-lying areas behind dikes on Gannon Slough and Arcata Marsh.

Electric transmission towers and distribution poles in low-lying areas could be destabilized by tidal inundation and rising groundwater. Pole-mounted electrical distribution lines, transformers, and service panels run throughout low-lying areas along the bay and sloughs. Diked former tide lands and other low-lying areas would be tidally inundated if the shoreline structures fail, resulting in loss of adequate support of poles and guy wires due to increased and continuous soil saturation, exposure of ground mounted transformers and electrical equipment to salt water and flooding, causing burnout, and increased rates of equipment corrosion. Tidal inundation caused by dike failure or rising tide elevations may limit repair and maintenance access to electrical infrastructure during high tide and extreme weather events, leading to prolonged power outages. In some locations, access may be eliminated altogether.

With 1.1 ft. of sea level rise, eight electrical transmission towers could be tidally inundated along with 62 distribution poles. With 3.3 ft. of sea level rise, nine electrical transmission towers could be tidally inundated along with 70 distribution poles. With 4.9 ft. of sea level rise (1.5 M), ten electrical transmission towers could be tidally inundated along with 85 distribution poles.

Susceptibility

Electrical facilities are very susceptible to tidal inundation and flooding. In the City's LCP planning area, electric transmission towers and distribution poles in diked low-lying areas could become destabilized by tidal inundation and rising groundwater. Pole-mounted electrical distribution lines, transformers, and service panels run throughout low-lying areas along the bay. Diked former tide lands and other low-lying areas could potentially be tidally inundated if the shoreline structures fail, resulting in loss of adequate support of poles and guy wires due to increased and continuous soil saturation, exposure of ground mounted transformers and electrical equipment to salt water and flooding, causing burnout, and increased rates of equipment corrosion. Tidal inundation caused by dike failure or rising tide elevations may limit repair and maintenance access to electrical infrastructure during high tide and extreme weather events, leading to prolonged power outages. Access may be eliminated altogether. Areas protected by earthen dikes are vulnerable and at risk from tidal inundation now and increasingly vulnerable with high projections for sea level rise. Tidal inundation of these diked lands could significantly impact transmission and distribution support structures.

The sustainability of development in the City's LCP planning area is predicated on having secure and reliable electricity. The stability of the transmission towers and distribution poles are essential to delivering electricity to the City. These electrical distribution structures can be made resilient to tidal inundation.

3.5.4 Natural Gas

In the City, PG&E has underground natural gas pipelines that traverse former tidelands protected by earthen dikes, railroad grade, City streets, and Highway 101 (Figure 29). The exact location of natural gas pipelines and stations are not known and unavailable due to PG&E's security concerns, making it difficult to assess the vulnerability of this infrastructure to sea level rise.

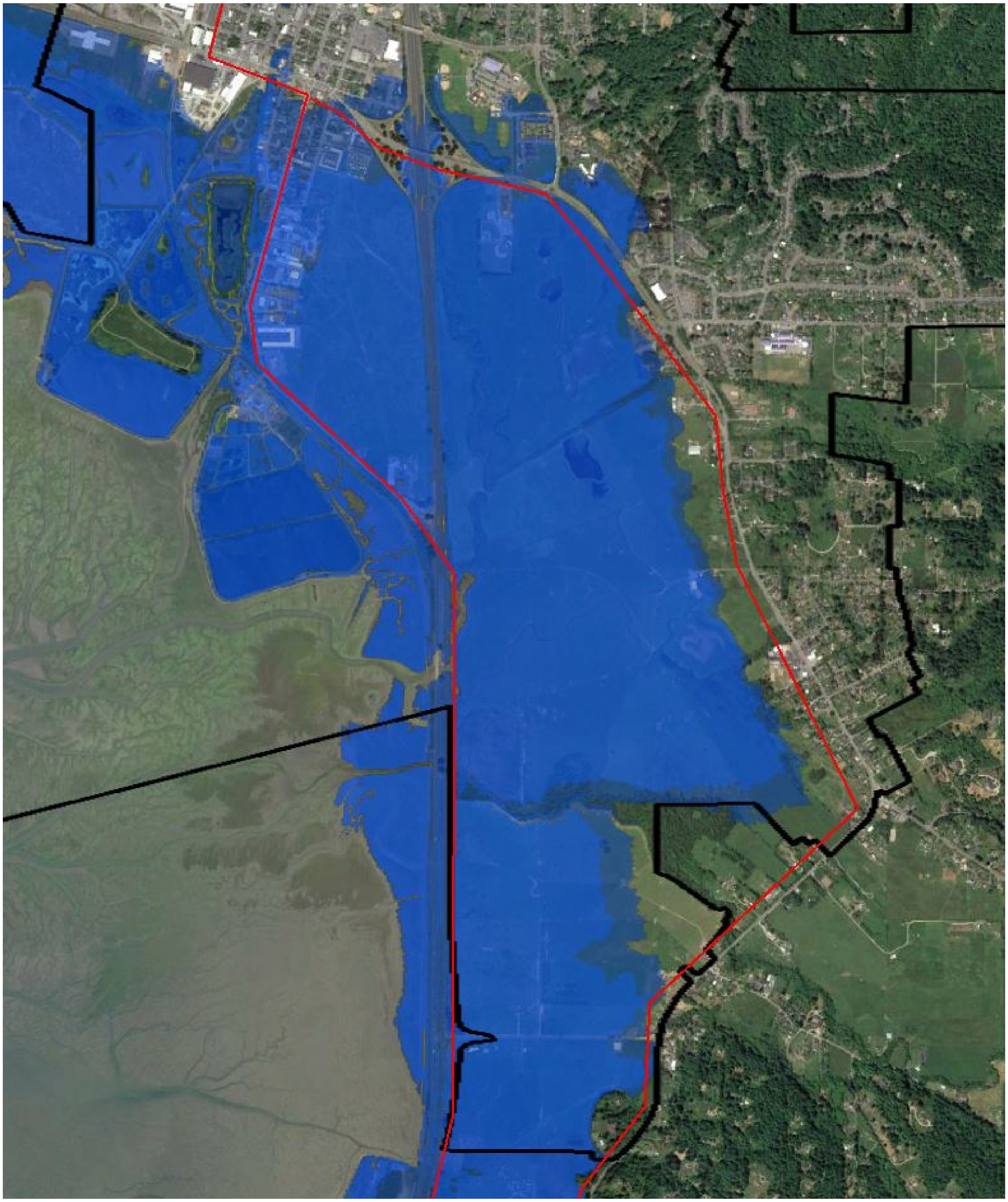

Figure 29. Approximate, location of PG&E natural gas transmission lines (red) in the City of Arcata (black lines) with respect to the 4.9 ft. (1.5 M) sea level rise tidal inundation area.

Exposure

Natural gas transmission and distribution systems within the City are vulnerable and at risk from tidal inundation, as they are in low-lying areas and can experience loss of access by maintenance personnel during tidal inundation and stormwater-created flood events. Additional coordination with PG&E is necessary to be able to more fully evaluate the vulnerability of this infrastructure.

Based on available information in the City's LCP planning area, there are approximately, 2.4 miles of gas lines located in areas that would be tidally inundated if protective shoreline structures such as dikes on Gannon Slough or Washington Gulch are breached. Additionally, 2.5 miles, 2.8 miles and 3.1 miles would become inundated with 1.6 ft. (0.5 M), 3.3 ft. (1.0 M), and 4.9 ft. (1.5 M) of sea level rise, respectively.

Susceptibility

Very little is known about the underground gas lines other than their approximate location. Tidal inundation is likely to infiltrate into the gravel bedding and potentially into the pipes through cracks and/or leaking joints. It is possible that increasingly long periods of ground saturation could result in settlement or movement of the pipes.

While saltwater may not affect underground gas lines significantly, tidal inundation and flooding could adversely affect access to these gas lines for emergency repairs and maintenance. A loss or interruption of access to natural gas would be a significant impairment to the City.

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