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Humboldt County Humboldt Bay Area Plan Diked Shoreline Sea Level Rise Adaptation Feasibility Study

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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.

DISCLAIMER: The following Humboldt Bay Area Plan Diked Shoreline Sea Level Rise Feasibility Study was prepared for Humboldt County. All statements are the sole responsibility of Aldaron Laird of Trinity Associates and do not necessarily reflect the views or policies of Humboldt County. This study is for planning purposes and is not a substitute for site-specific analysis of vulnerability and risk from sea level rise.

All photographs in this report were taken by Aldaron Laird, unless otherwise noted.

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Pursuant to the California Coastal Commission (CCC) Sea Level Rise Policy Guidance dated August 12, 2015 (CCC 2015), and the CCC's January 2017 Memorandum summarizing steps for conducting sea level rise vulnerability assessments and practical lessons learned, 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. Utilizing specific water elevations in addition to planning horizons is also encouraged to reduce concerns over uncertainty of sea level rise projections, particularly for planning horizons after 2050.

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, 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 three approaches to address sea level rise on Humboldt Bay:

1) sea level rise projections for specific planning horizons,
2) shoreline elevation profile and vulnerability rating, and
3) inundation modeling and mapping.

Projections for sea level rise have been prepared for Humboldt Bay by Northern Hydrology and Engineering (NHE) for the North Spit tide gauge. High projections for the following planning horizons are utilized in this report: 2030 (0.9 ft), 2050 (1.9 ft), 2070 (3.2 ft), and 2100 (5.4 ft) (NHE 2014). A shoreline elevation profile, utilizing as a baseline the mean monthly maximum water (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 NHE depicts areas that are potentially vulnerable to inundation, with the assumption that shoreline structures (dikes) are absent or not functioning, by specific water elevations: MMMW (7.7 ft), mean annual maximum water (MAMW) (8.8 ft), MMMW+0.5 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 stillwater conditions and does not incorporate wave run-up or storm surge.

Introduction

Humboldt County received a grant from the CCC to identify coastal and community resources at risk to inundation due to the condition of shoreline structures in Humboldt County's Humboldt Bay Area Plan (HBAP) planning area. This grant helped to fund the *Humboldt County Humboldt Bay Area Plan Sea Level Rise Vulnerability Assessment* (Laird 2018), as well as this report, which builds on the HBAP Vulnerability Assessment with a focus on diked shorelines. The purpose of this report is to inform the public, property owners, agencies, and land use and resource decision-makers of the vulnerability of the diked shoreline on Humboldt Bay and the risk to land use, development, utility and transportation infrastructure and coastal resource assets protected by existing dikes from tidal inundation and sea level rise. The report will also explore a range of sea level rise adaptation strategies and a suite of adaptation measures that are applicable to diked shoreline structures.

This report also builds on the vulnerability assessments recently prepared for the City of Arcata (Laird 2018) and the City of Eureka (Laird 2016), *Humboldt Bay Sea Level Rise Adaptation Planning Project* (Laird 2015), and the *Humboldt Bay Shoreline Inventory, Mapping and Sea Level Rise Vulnerability Assessment* (Laird 2013). This study benefitted greatly from the information contained in a recently released report for California's Fourth Climate Change Assessment, *Toward Natural Infrastructure to Manage Shoreline Change in California* (Newkirk 2018). This report also investigates cost related issues for constructing proposed adaptation measures and identifies potential funding sources.

Lastly, this report explores regulatory constraints and opportunities that the CCC could apply, pursuant to the California Coastal Act policies in Chapter 3 to further the adaptation of diked shoreline structures to sea level rise. Seeking workable solutions to the exposure of diked structures and the assets they protect is critical on Humboldt Bay. The diked shorelines are in the CCC's retained jurisdiction. Therefore, the Coastal Act is the standard of review for proposed developments, such as adaptation measures described in this study.

Sea Level Rise Projections for Humboldt Bay

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. According to Cascadia GeoSciences, Humboldt Bay has been subsiding -0.09 inches/yr. since 1977. Humboldt Bay's average rate of relative sea level rise is 0.18 inches/year (18 inches per century), which is greater than anywhere else in California (Patton 2017). A dataset of relative sea level rise projections has been prepared for the North Spit tide gauge from 2000 to 2100, including low, projected, and high greenhouse gas emission scenarios (Figure 1, NHE 2014). While the CCC's Policy

Guidance recommends assessing impacts from sea level rise for 2030, 2050, and 2100, this report also assesses potential impacts for current conditions and 2070. Under present shoreline conditions, 51% of the diked shoreline on Humboldt Bay could be breached or be overtopped by approximately three feet of sea level rise, which is equivalent to the high projection for 2070.

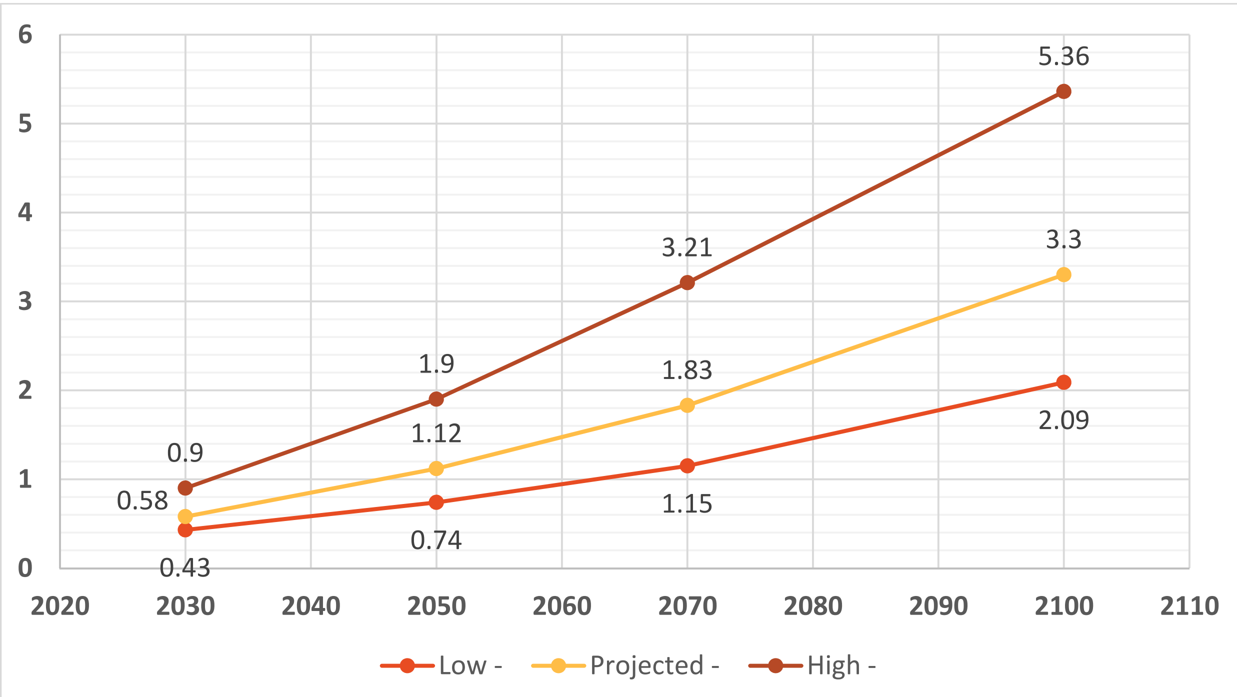

Figure 1. Relative sea level rise projections for four planning horizons (2030, 2050, 2070, and 2100), including low, projected, and high greenhouse gas emission scenarios (NHE 2014) in ft.

The recent Ocean Protection Council's Science Advisory Team report (Griggs et al. 2017) did not utilize the North Spit tide gauge record and local science reports to describe relative sea level rise conditions and projections for the Humboldt Bay region, north of Cape Mendocino. Unfortunately, the 2017 report relied on the Crescent City tide gauge, which has lowest rate of sea level rise in California and the west coast. The CCC's 2015 sea level rise guidance document reported both the high rates of land subsidence and relative sea-level rise unique to the Humboldt Bay region of California.

Humboldt Bay's Diked Shoreline

The shoreline on Humboldt Bay is 102 miles long. Seventy-five percent (76.7 miles) of the shoreline consists of artificial structures (dike, railroad grade, fill, fortified, or road), and 25% is in a natural state. Shoreline structures are critical assets that protect inland assets. The dominant shoreline structure are earthen dikes that occupy approximately 41 miles (53%) of the artificial shoreline. Dikes are barrier-like structures/embankments that prevent daily tidal inundation of low-lying former tidelands. Comparatively, levees are engineered barrier-like structures that prevent rising flood waters or stormwater runoff from flooding dry lands.

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 retains roughly 15,300 acres of open water/mudflats. Only 1,545 acres of salt marsh remain today, due primarily to dike construction and tideland reclamation for agricultural uses.

On Humboldt Bay, the era of dike building spanned the 1890s through 1930s, and generally relied on a floating dredge for dike construction. Farmers and ranchers built earthen dikes, often at the boundary between mudflat and salt marsh. By excavating a ditch to float the dredge, the bay mud was side cast to drain and build up a berm, eventually forming a dike. With the installation of tide gates and a few winters of rainfall, the salt from the former salt marsh soil behind the dike flushed, enabling agricultural practices to ensue. This type of land reclamation occurred in each of Humboldt Bay's six major hydrologic units: Arcata Bay, Eureka Bay, South Bay, Mad River, Eureka Sough, and Elk River Slough.

Today these diked former tidelands are often lower in elevation than the salt marsh on the opposite side. Salt marsh on Humboldt Bay forms near the mean high water (MHW) elevation of 5.8 ft and can extend up to the mean monthly maximum water (MMMW) elevation of 7.7 ft. The lower elevation of diked former tidelands is primarily due to the oxidizing of organic material from the former salt marsh soils, which results in soil compaction, and without daily inundation, sediment accretion no longer occurs to help maintain soil elevations. Soil compaction of the diked former tidelands results in elevations that are 1.0 to 3.0 ft lower than MHW.

The legacy of this land reclamation era is that thousands of acres of land and critical assets are now at-risk of tidal inundation if the shoreline is breached or overtopped. Breaching of dikes has already been occurring over the last few decades, partially because of deferred dike maintenance. Additionally, rising annual maximum tide elevations, commonly referred to as a king tide, also contribute to occurrences of dike breaching (Figure 2). King tides may also be referred to as nuisance floods, defined by NOAA as equaling or exceeding 8.35 ft (0.5 m + MHHW 6.51 ft) at the North Spit tide gauge (NOAA 2014). The mean annual maximum water (MAMW) elevation is 8.8 ft.

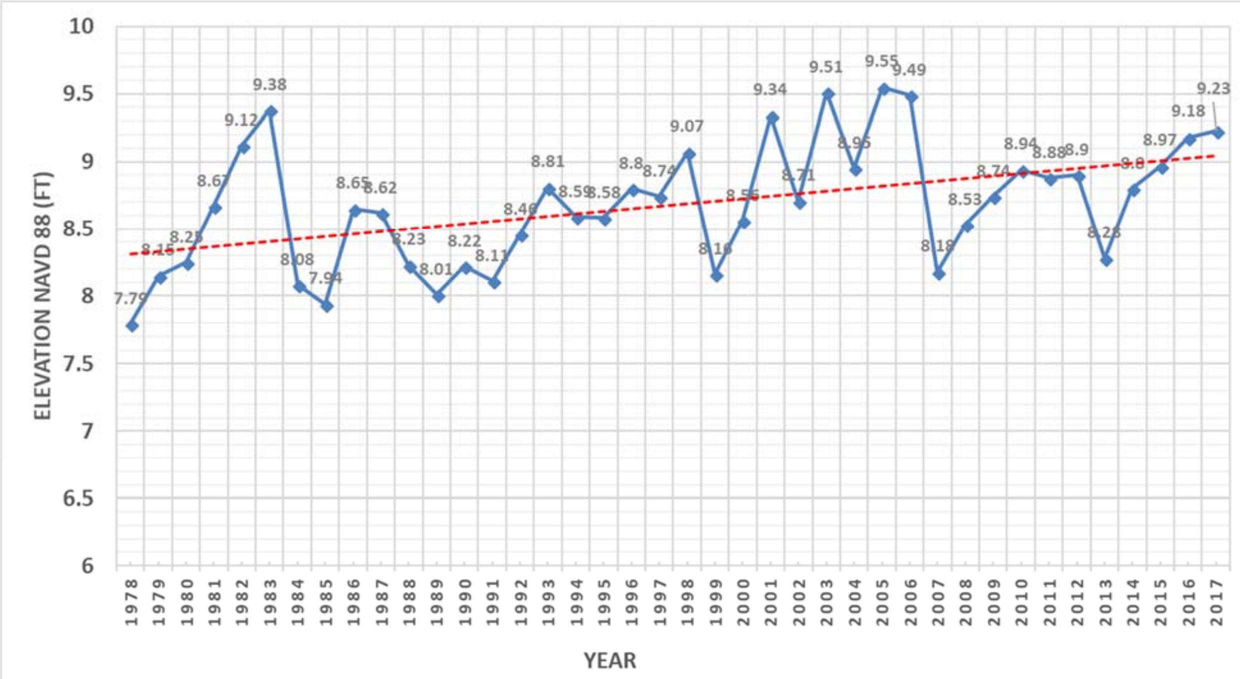

Figure 2. Annual maximum tide (king tides) elevations, North Spit tide gauge (NOAA).

During a single year, sea levels on Humboldt Bay can 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 occur and the MAMW is typically 1 ft higher than MMMW. In addition, El Niño events, low pressure systems, stormwater runoff, and storm surges can also increase winter tidal elevations up to 1 ft.

In 1983, a severe El Niño raised king tides to 9.4 ft. Since 2001, there have been four years where the annual maximum tide 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). King tides or MAMW 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 recorded at the North Spit tide gauge was 9.55 ft and is illustrative of 1.9 ft of sea level rise over the base MMMW elevation of 7.7 ft., and is equivalent to the high projection for sea level rise in 2050. The Governor declared a state of disaster on Humboldt Bay in 2006 when the storm surge combined with the extreme tide of 9.5 ft. This same tidal elevation of 9.5 ft could become the MMMW, the monthly norm tide elevation by 2050.

The dikes on Humboldt Bay now form 23 hydrologic sub-units (Table 1, Figure 3 - Figure 5). In these units, there are 39.6 miles of diked shoreline traversing 170 individual parcels that protect approximately 7,400 acres of mostly former tidelands (now agricultural land) from being tidally inundated by MAMW (8.8 ft) king tide events.

Table 1. Diked shoreline hydrologic sub-unit characteristics (length in miles, area in acres, miles less than 9.7 ft. elevation, miles between 9.7 ft. and 10.7 ft. elevation, miles that rated highly vulnerable, number of tide gates, dominate land use, and LCP jurisdiction).

DIKE UNIT	DIKE LENGTH	AREA	ELEVATION		HIGH V. RATING	TIDE GATES	LAND USE	LCP
			<9.7 FT	<10.7 FT				
MRS-1	4.75	911	0.77	1.31	1.74	5	AE	HBAP
MRS-2	2	349	0.55	0.51	1.1	2	AE	HBAP
MRS-3	1.13	72	0.12	0.22	0.25	2	AE	HBAP
AB-1	6.14	1218	0.71	1.27	1.26	8	AE	HBAP
AB-2	0.76	383	0.15	0.11	0.25	4	AE	COA
AB-3	0.55	139	0.55	0	0.55	2	AE	COA
AB-4	0.38	79	0.38	0	0.38	1	AE	HBAP
ES-1	3.32	775	0.29	0.55	0.68	8	COM/PF/AE	HBAP/COE
ES-1a	1.1	75	0.01	0.08	0.07	1	COM	HBAP
ES-2	5.26	799	0.71	1.68	2.41	4	AE	HABP
ES-3	1.75	174	0.41	0.78	1.24	2	AE	HBAP
ES-4	0.23	71	0.03	0.02	0.05	1	AE	HABP
ES-5	1.1	77	0	0.09	0.09	2	AE	HBAP
ES-6	0.64	32	0.08	0.24	0.32	1	AE	HBAP
ES-7	0.28	8	0.11	0.14	0.25	1	AE	HBAP
ES-8	0.57	29	0.02	0.21	0.22	1	AE	HBAP
ES-9	0.21	7	0.11	0.1	0.2	1	AE	HBAP
ES-10	0.61	15	0.07	0.18	0.25	1	AE	HBAP
ES-11	0.21	3	0.02	0.06	0.08	0	AE	HBAP
ERS-1	1.51	371	0.43	0.25	0.68	3	AE	HABP
ERS-2	0.79	40	0.7	0.06	0.76	1	AE	HABP
ERS-3	0.41	194	0.4	0.03	0.44	1	AE	HBAP/COE
SB-1	5.94	1583	2.69	2.53	3.87	10	AE	HABP
23	**39.64**	**7404**	**9.31**	**10.42**	**17.14**	**62**		

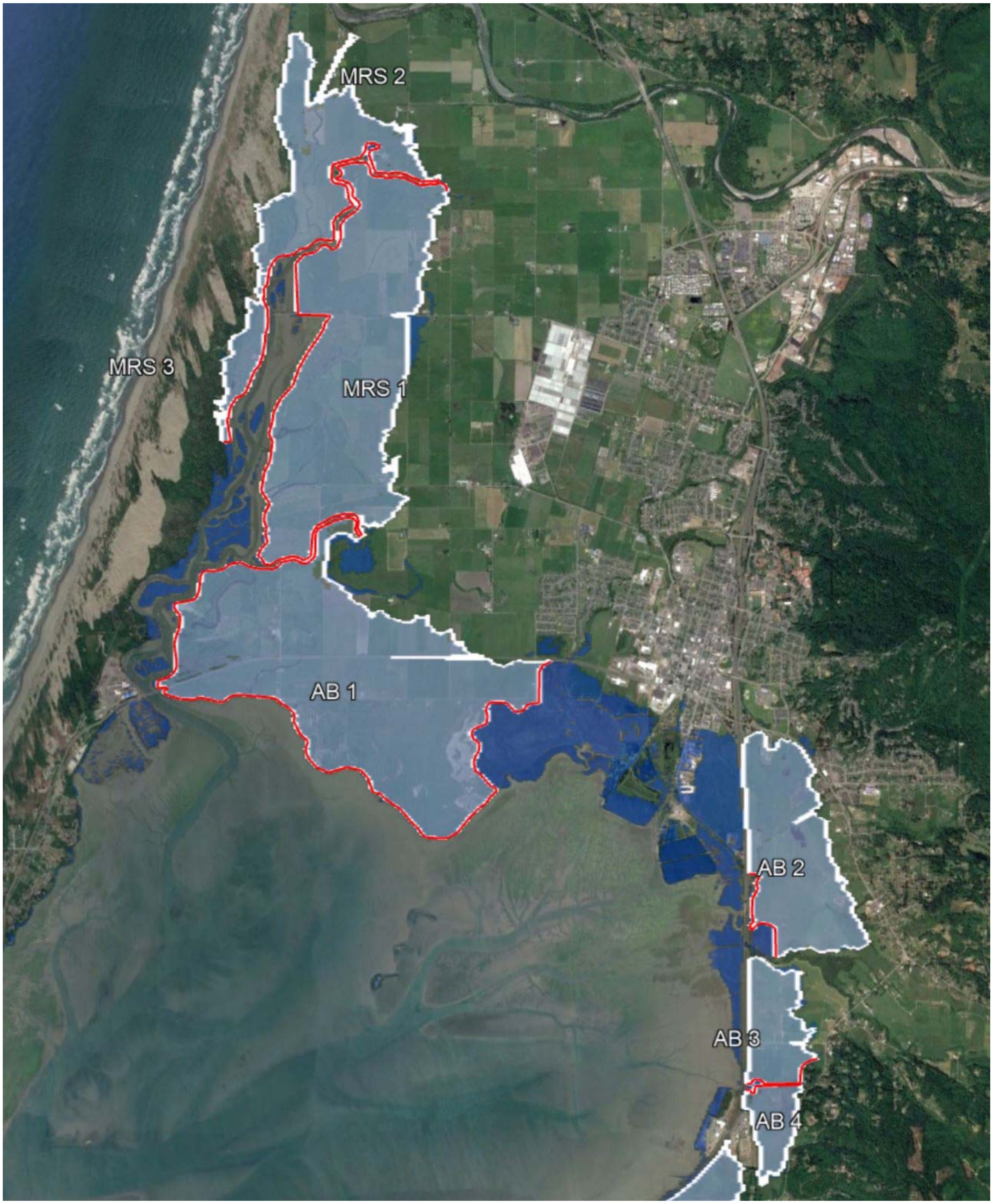

Figure 3. Diked shoreline hydrologic sub-units: Mad River Slough (MRS), Arcata Bay (AB), diked shoreline reaches (red), and potential MAMW inundation area (blue).

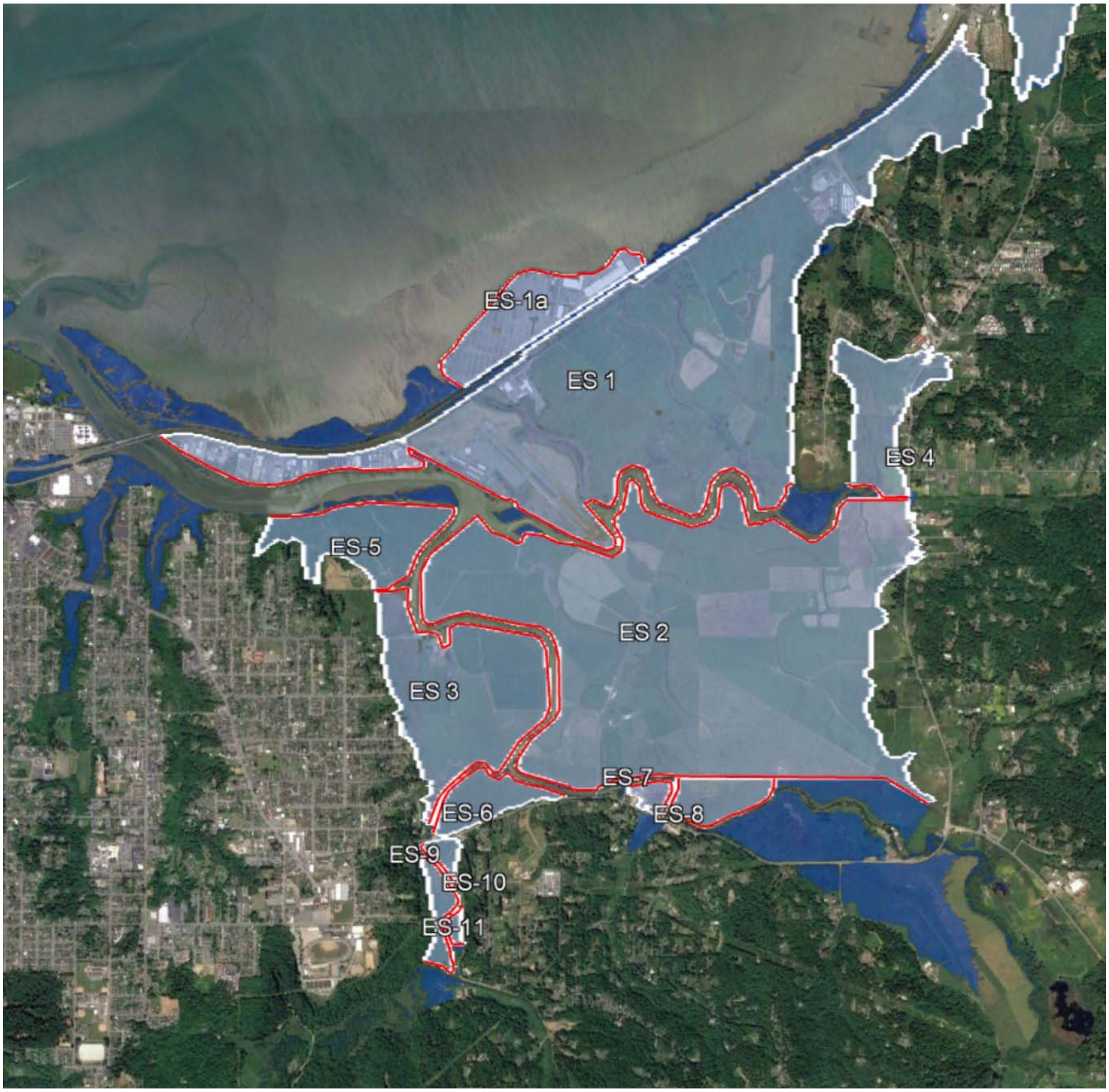

Figure 4. Diked shoreline hydrologic sub-units: Eureka Slough (ES), diked shoreline reaches (red), and potential MAMW inundation area (blue).

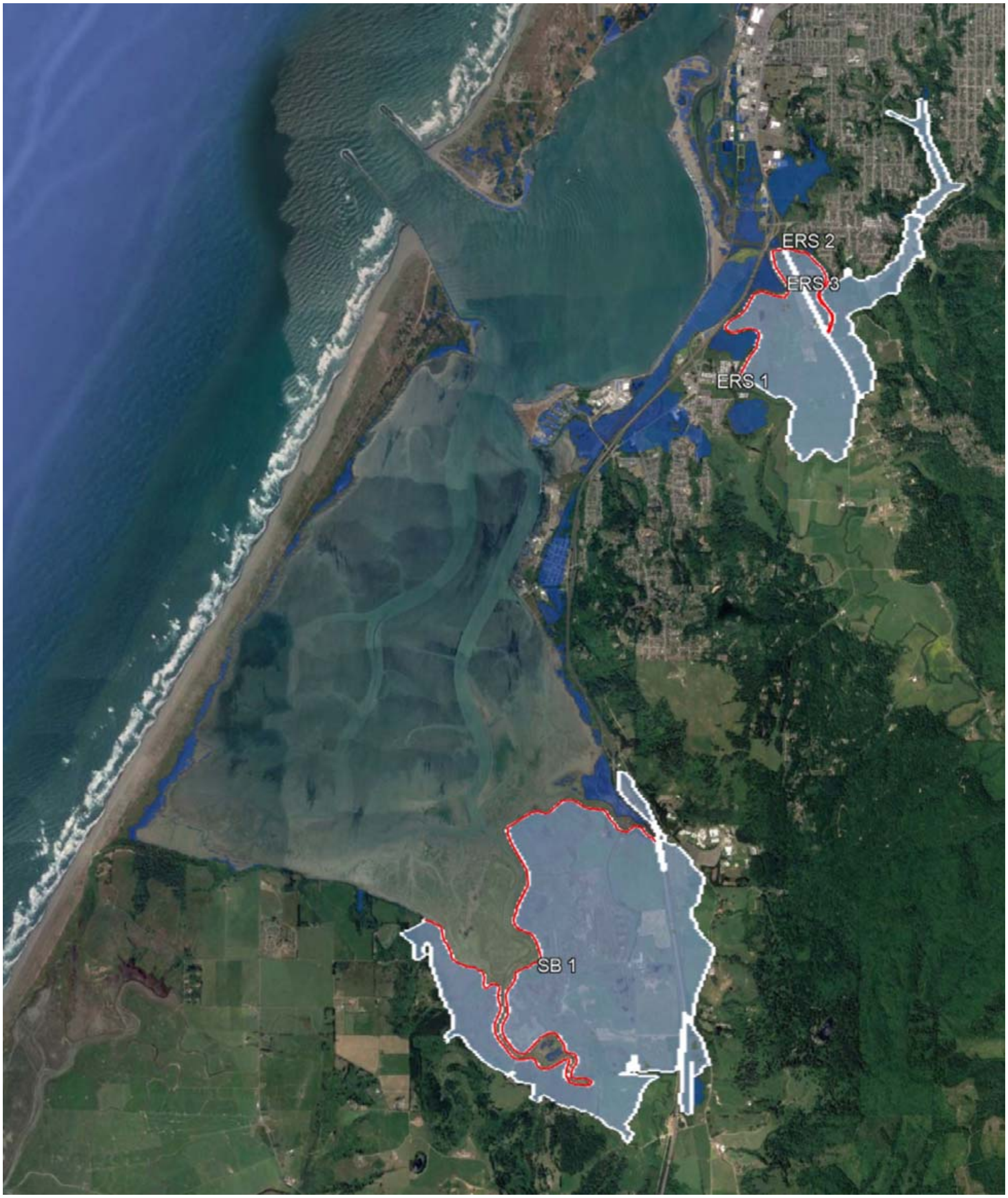

Figure 5. Diked shoreline hydrologic sub-units: Elk River Slough (ERS) and South Bay (SB), diked shoreline reaches (red), and potential MAMW inundation area (blue).

The *Humboldt Bay Shoreline, Inventory, Mapping, and Sea Level Rise Vulnerability Assessment* (Laird 2013) described the conditions of the diked shoreline: structure, cover, elevation and presence of salt marsh, and its exposure and susceptibility to sea level rise. Due to deferred maintenance, there are approximately 3.3 miles (8.1%) of diked shoreline actively eroding and susceptible to breaching during king tides (Figure 6).

Figure 6. Dike breaching during a king tide, inundating low-lying former tide lands.

Of the 41 miles of dikes around Humboldt Bay, approximately 11.7 miles (28.7%) are fortified and 25.7 miles (63.1%) are unfortified. Salt marsh plains, often referred to as natural shoreline infrastructure, can attenuate wave energy and height, thus offering protection to shoreline structures such as dikes. There 18.1 miles (44.5%) of diked shoreline with attached salt marsh on Humboldt Bay.

The number of days that current MAMW elevation of 8.8 ft is equaled or exceeded is four days per year. 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).

There are approximately 11.4 miles (28%) of the 41 miles of diked shoreline that are vulnerable to being overtopped by 2.0 ft of sea level rise, which would increase to 23.4 miles (57%) with 3.0 ft. of sea level rise. This would affect all 23 diked hydrologic units (Figure 7 - Figure 9). The high projection for relative sea level rise on Humboldt Bay for 2030 is 0.9 feet. The 2030 MAMW elevation could rise to 9.7 ft. By 2050, the high projection is 1.9 ft. The MAMW elevation in 2050 could reach 10.7 ft, which crosses a tipping point to 3.0 ft. Before 2100, when the high projection reaches 5.0 ft. approximately 38.4 miles (94.6%) of dikes at their current elevation would likely be overtopped MAMW of 13.7 ft, or by 2100 when MMMW reaches 13.2 ft.

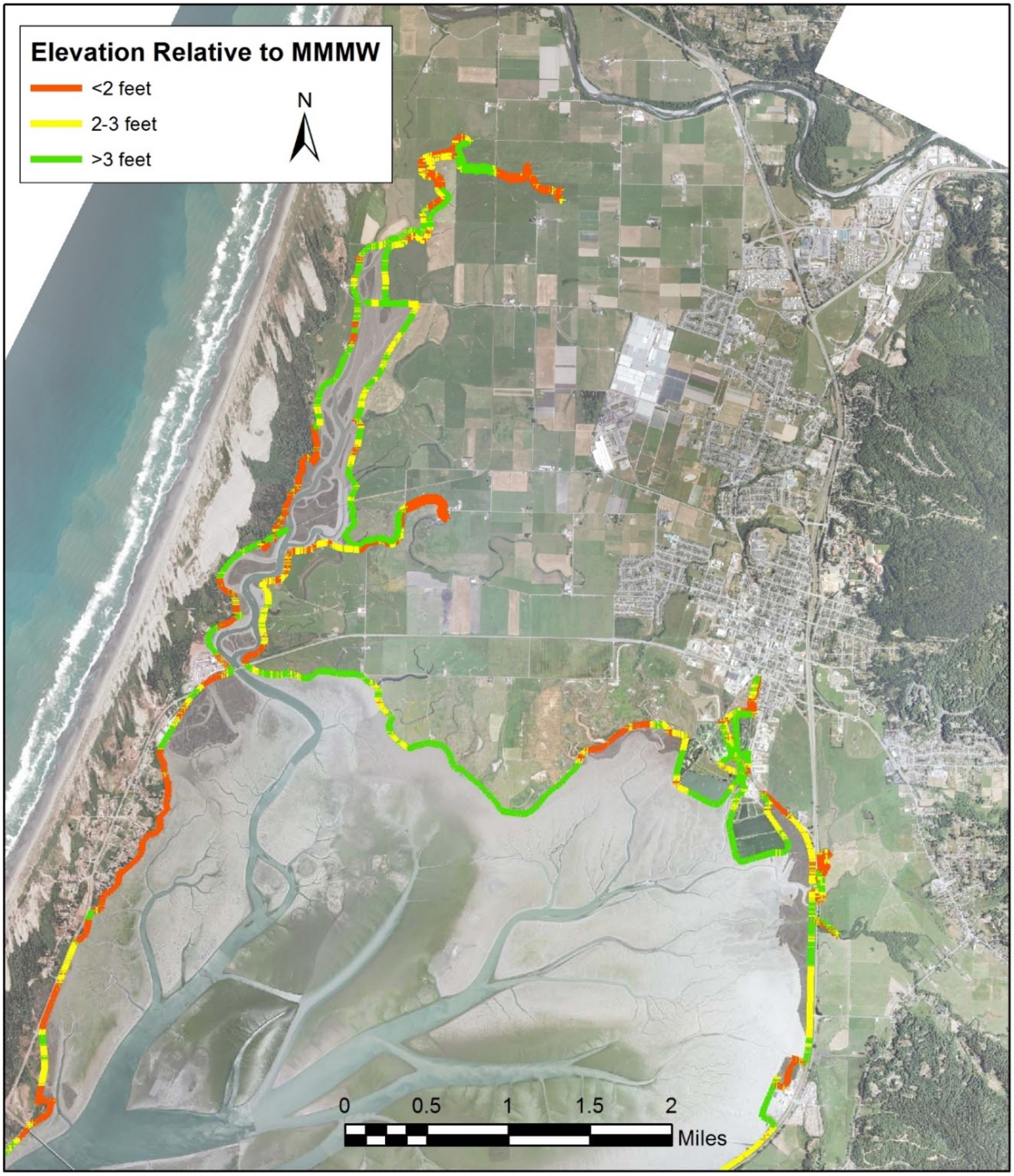

Figure 7. Shoreline elevation above the MMMW elevation of 7.7 ft (NAVD 88): red <2 ft, yellow = 2-3 ft, and green > 3 ft, on Mad River Slough and Arcata Bay (Laird 2013).

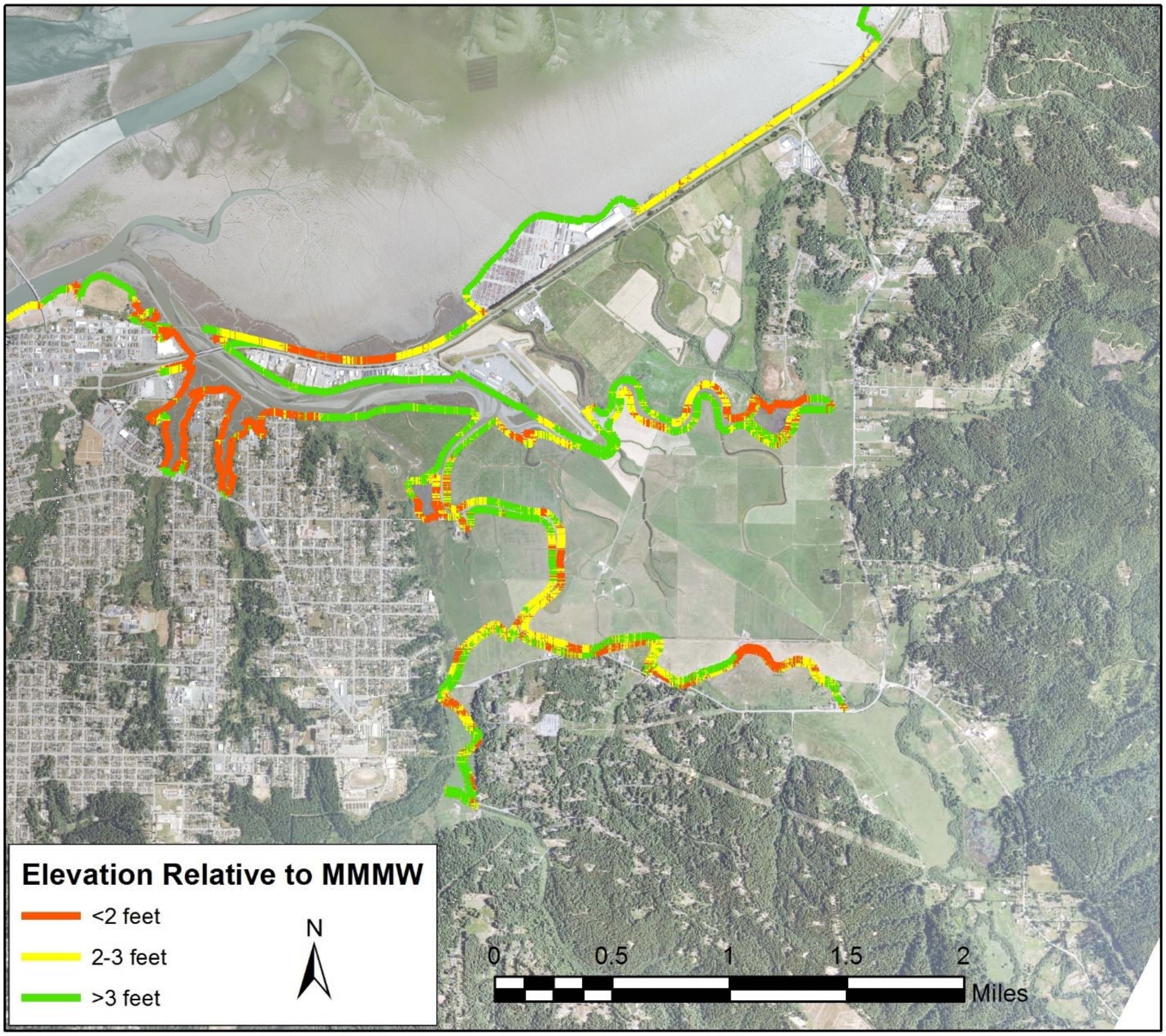

Figure 8. . Shoreline elevation above the MMMW elevation of 7.7 ft (NAVD 88): red <2 ft, yellow = 2-3 ft, and green > 3 ft, on Eureka Slough and Arcata Bay (Laird 2013).

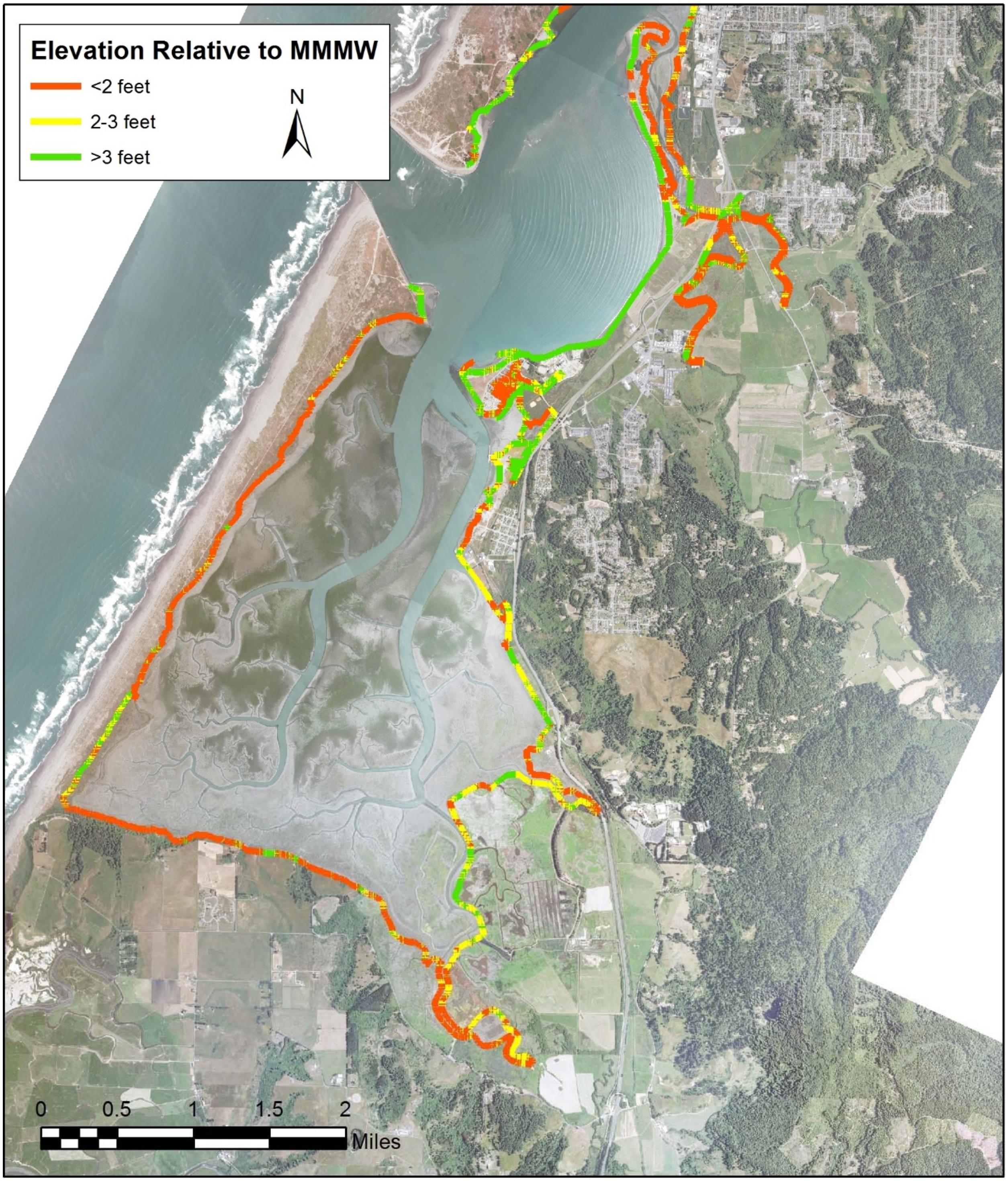

Figure 9. Shoreline elevation above the MMMW elevation of 7.7 ft (NAVD 88): red <2 ft, yellow = 2-3 ft, and green > 3 ft, on Elk River Slough and South Bay (Laird 2013).

The 2013 shoreline assessment also rated vulnerability, which is a quantitative measure that applies a combination of shoreline attributes (cover type and relative elevation to modeled MMMW elevation) to rank a shoreline segment's vulnerability to erosion and/or overtopping due to extreme tides, storm surges, and sea level rise. Approximately 21 miles of diked shoreline are rated highly vulnerable to breaching or being overtopped (Figure 10 - Figure 12). All the diked sub-units have shoreline segments that are rated highly vulnerable based on the presence of actively eroding dike slope and/or a dike crest elevation less than 9.7 ft (within 2.0 ft of current MMMW elevation).

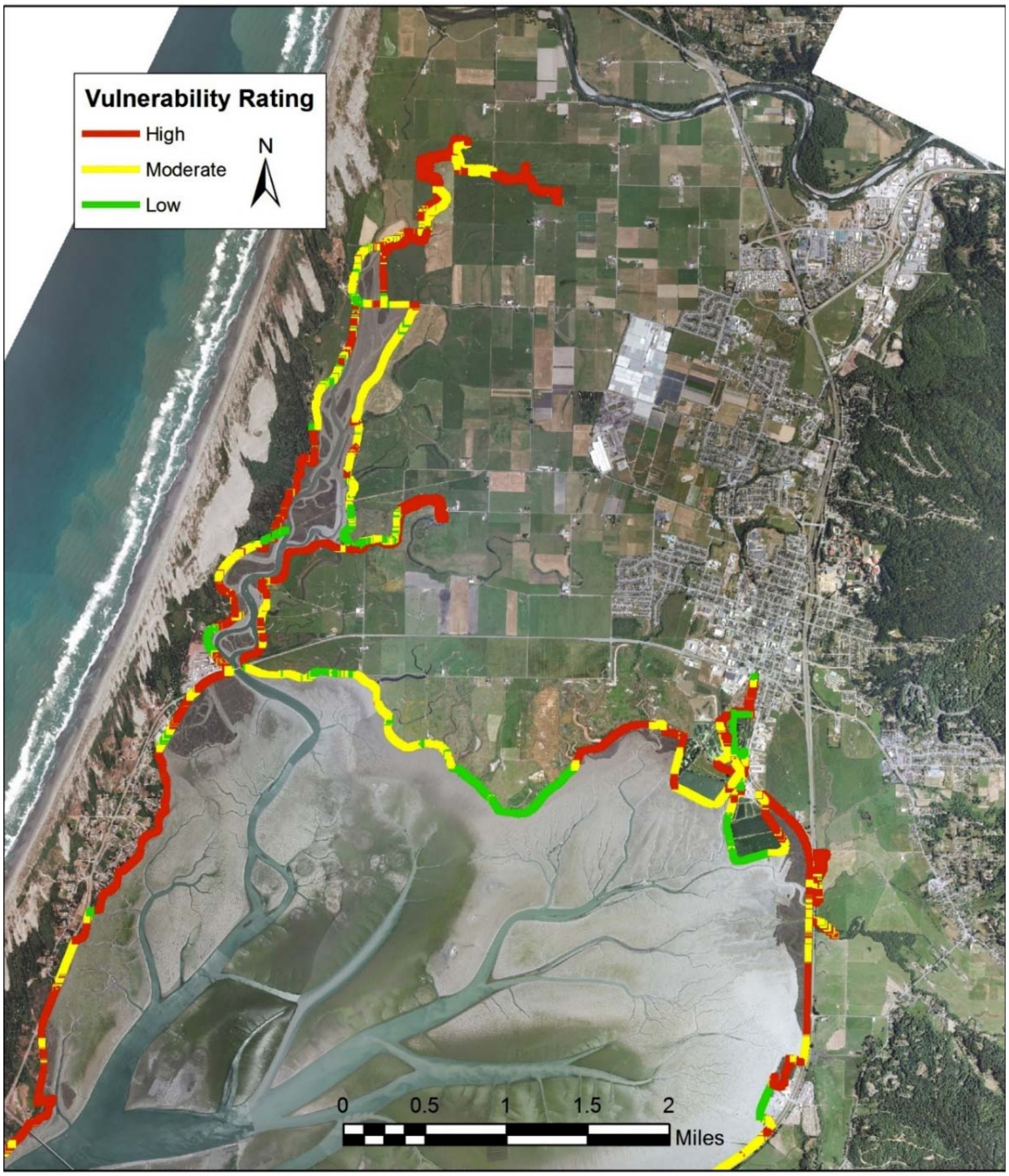

Figure 10. Shoreline vulnerability ratings: red = high, yellow = moderate, and green = low, on Mad River Slough and Arcata Bay (Laird 2013).

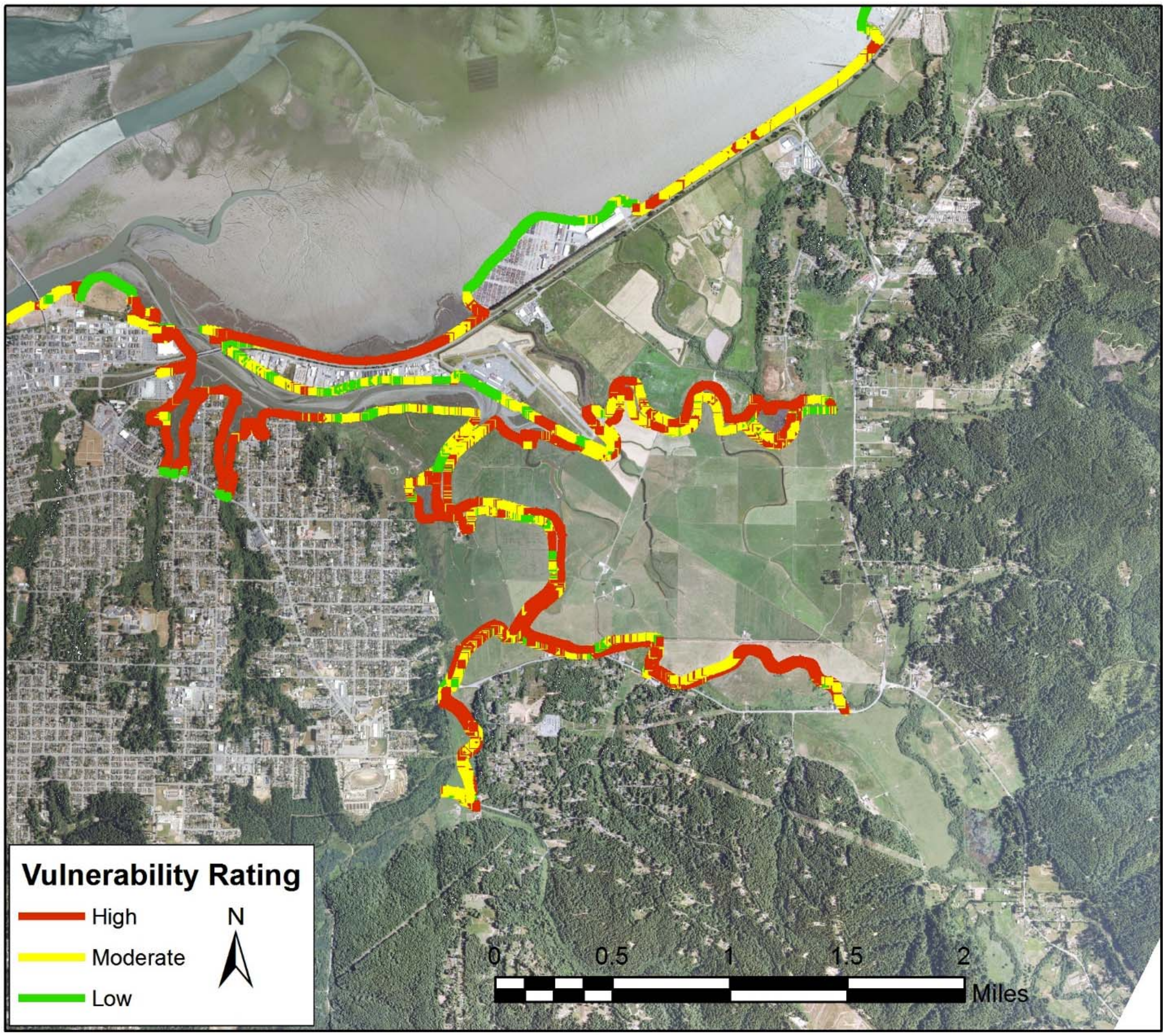

Figure 11. Shoreline vulnerability ratings: red = high, yellow = moderate, and green = low, on Eureka Slough (Laird 2013).

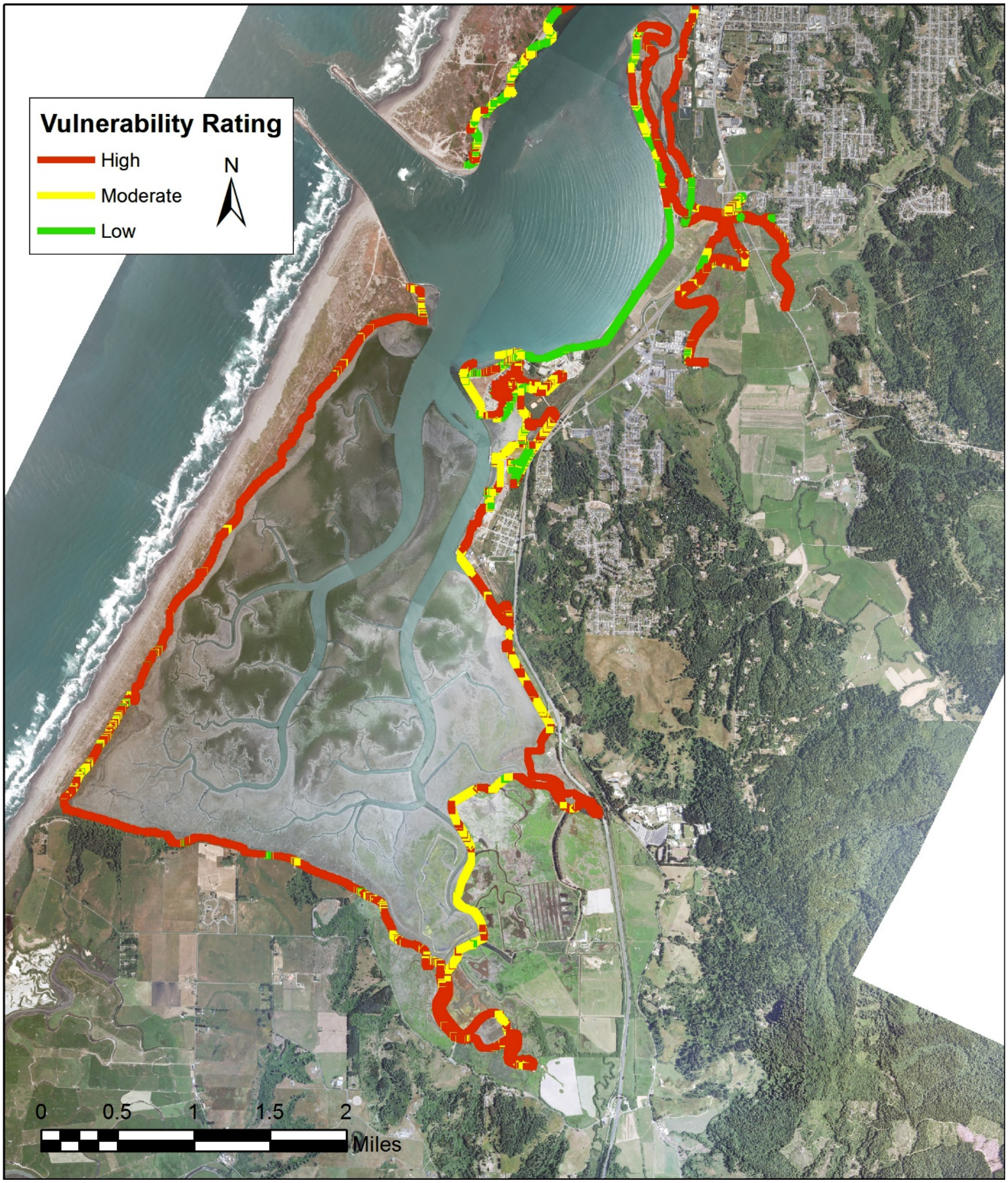

Figure 12. Shoreline vulnerability ratings: red = high, yellow = moderate, and green = low, on Elk River Slough and South Bay (Laird 2013).

In the 23 diked hydrologic sub-units, there are 62 tide gates that drain the former tidelands. Drainage impairment can occur as low tides rise higher in elevation in response to sea level rise. Rising low tide elevations could reduce tide gate effectiveness in draining stormwater, resulting in flooding of the diked lands and critical infrastructure. Eventually, regardless of the condition of dike structures and the protection they afford, low-lying areas are vulnerable to flooding from emerging groundwater and saltwater intrusion in response to sea level rise. With sea level rise, these modes of flooding would begin as nuisance flooding during winter/spring storms and king tides, increasing in frequency over time until they become chronic flooding. Ultimately, low-lying areas will become continuously inundated.

The average elevation of groundwater on land adjacent to the shoreline is generally above mean sea level (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. These areas have compacted as organic material in the original salt marsh soil has oxidized and are now from 1 to 3 ft. lower in elevation. Groundwater elevations depend on surface elevations and fluctuate seasonally. For example, groundwater elevation near Mad River Slough on diked former tidelands can vary between ground surface down to three feet below the ground surface (Hoover 2015) (Figure 13). As sea level rises, the denser saltwater will push fresh groundwater to higher elevations until the groundwater eventually emerges and floods the surface of the diked former tidelands with 3.3 ft (1.0 m) of sea level rise (Figure 15).

Rising groundwater flooding will cause vegetative conversions, adversely affecting agricultural lands and natural resource areas. Rising groundwater can also affect foundations of structures, as well as permanently flood low-lying areas. Emergent groundwater will likely make access and maintenance of utility infrastructure difficult (e.g., water transmission line, sewer lines, gas lines, and electrical transmission towers).

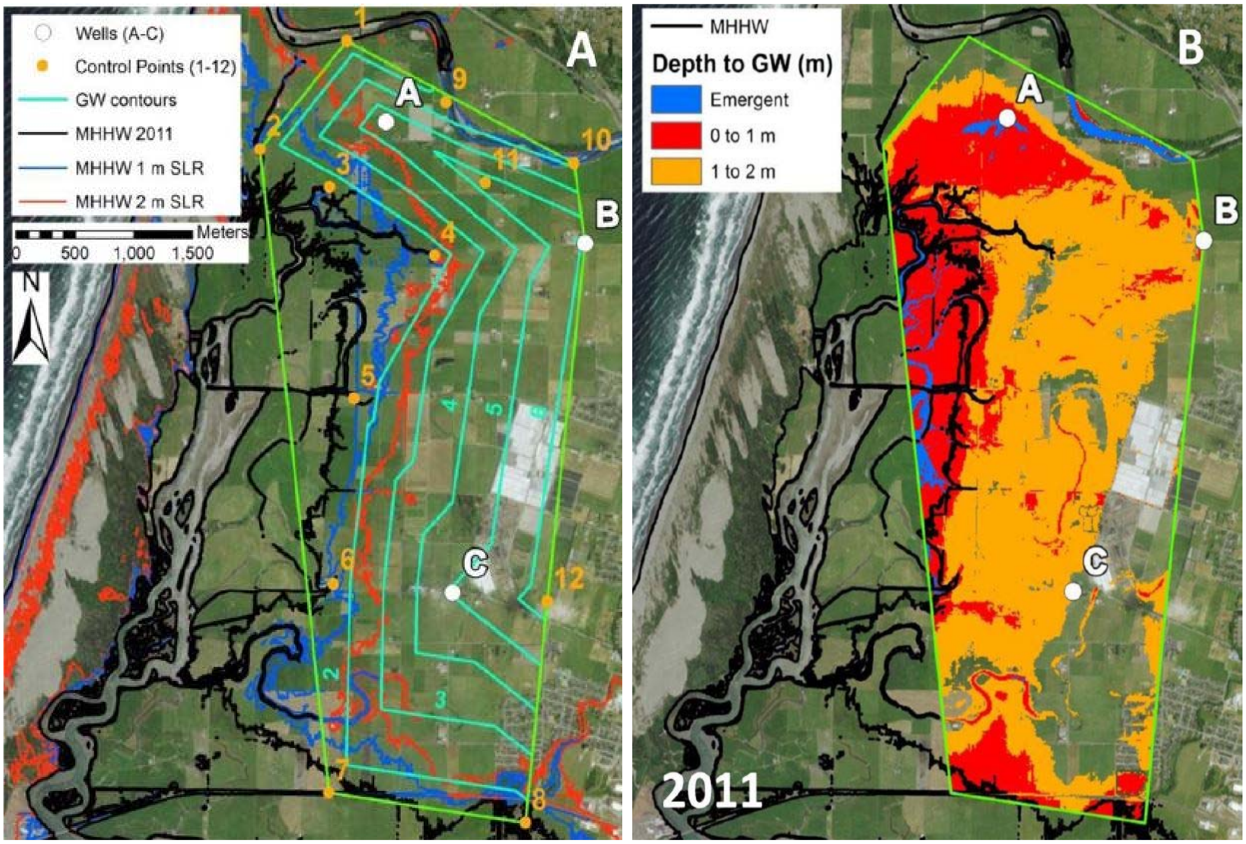

Figure 13.. From Hoover 2015, as based on Willis 2014. Fresh groundwater floats on higher-density seawater, and the average elevation of the water table would be above MSL 3.4 ft. MHHW is 6.5 ft.

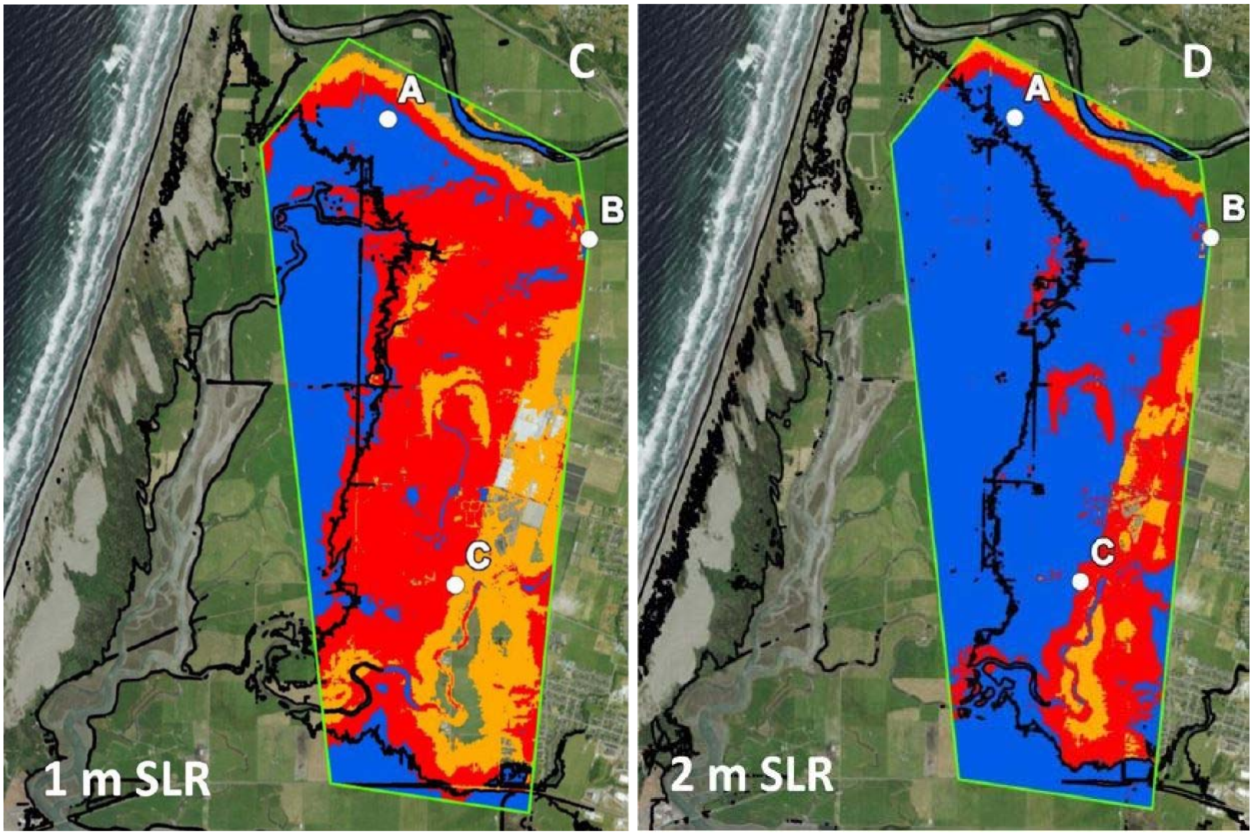

Figure 14. From Hoover 2015, based on Willis 2014, illustrating the difference of 1 m (3.3 ft) of sea level rise. Blue = emergent, Red = 0 to 1 M, and Orange = 1 to 2 m (6.6 ft).

Assets Protected by Diked Shorelines

Humboldt County's HBAP Sea Level Rise Vulnerability Assessment (Laird 2018) and the vulnerability assessments for the City of Eureka (Laird 2016) and City of Arcata (Laird 2018) describe assets that are currently protected by earthen dikes, and are consequently at risk from tidal inundation should a breach occur. Dikes currently protect land uses and developments, transportation infrastructure, utility infrastructure, environmentally sensitive habitat areas (ESHA), and wildlife refuges.

The dominant land use on diked lands is agriculture, with a significant portion of these lands (9 sub-units) also being managed as wildlife refuges and open space (AB-1-3, ES-1, 3, and 8, ERS-1-2, and SB-1). A few diked units in Eureka Slough also support commercial, residential, and public facility uses (ES-1, 1a, 2, and 7).

The construction of dikes pre-dated the construction of surface and air transportation infrastructure, which led to locating critical Highway 101 and airport infrastructure behind dikes on low-lying diked former tidelands. Highway 101 traverses six diked sub-units (AB-2-4, ES-1 and 1a, and SB-1). Highway 255 is locally important to the communities on the North Spit and to critical coastal-dependent Industrial bulk cargo shipping facilities. Highway 255 traverses one dike hydrologic sub-unit, AB-1. These highways are owned and maintained by Caltrans but do not form the shoreline on Humboldt Bay. Caltrans does not maintain the diked shorelines that protect its highways from tidal inundation now, and from future sea level rise impacts.

Humboldt County's Murray Field Airport is located on land that is lower in elevation than MHW (5.8 ft.) The area is protected from tidal inundation by dikes on sub-units ES-1 and ES-1a. The County does not own or maintain these entire diked shorelines.

The diked shoreline on more than half of the diked hydrologic sub-units (AB-1-4, ES-1, 2-11, ERS-1-3, and SB-1) protect regionally critical utilities, including municipal water transmission lines and pump stations, wastewater lines and lift stations, gas lines, electrical transmission towers/distribution poles, and optical fiber lines. All these utilities are located on low-lying diked former tidelands, which would be tidally inundated daily if not for the protection afforded by dikes. The utility providers do not own or maintain these dikes.

Sea Level Rise Impacts

Sea level rise is an effect of climate change, specifically from the warming of the atmosphere and oceans. Going forward, 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 (Griggs 2017). Sea levels can also increase or decrease because of vertical land movement, from tectonic forces (Patton 2017). Rising sea levels will directly affect the shoreline of Humboldt Bay, including diked shorelines and consequently adjacent lands, developments, infrastructure and coastal resources.

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

Rising sea level effects that could adversely affect diked shoreline structures include:

- Increase in elevation of monthly high tides, extreme annual high tides, and 100-year storm flood elevations that could overtop and breach dikes.
- Higher daily and monthly tide elevations, which could increase shoreline slumping, erosion, and breaching.
- Increase in daily and monthly high tides that could drown salt marsh plains protecting dikes by attenuating wave energy and heights.

- Increase in elevation of low tides, which would increase flooding of low-lying former tideland areas by delaying drainage through tide gates, and impeding stormwater runoff.
- Increase in groundwater elevation, resulting in emerging and flooding of low-lying former tideland areas.
- Saltwater intrusion of low-lying former tideland areas affecting freshwater vegetation, agricultural uses, adjacent aquifers, and underground structures, such as saltwater inflow to sewer lines and potentially wastewater treatment facilities.

Under the current tidal regime, shoreline erosion without additional sea level rise could have significant consequences on Humboldt Bay. Dike shoreline structures were constructed between 1890 and 1930. More than a century later, these structures are approximately 1.5 ft lower relative to current sea levels due to tectonic subsidence and global sea level rise (Griggs 2012 and Patton 2017). These dikes are a historical legacy that could have a profound negative effect on critical infrastructure when tidal inundation of thousands of acres of land occurs. Breaching is occurring with increasing frequency on Humboldt Bay. Adaptation measures are needed to increase the resiliency of these dikes, to protect agricultural use, utility and transportation infrastructure, seasonal freshwater wetlands and wildlife areas.

Susceptibility of Dikes to Sea Level Rise Impacts

Even a single breach of a dike can lead to saltwater inundation of all lands behind the diked shoreline (Figure 15). The protective function of a dike as a tidal barrier is highly susceptible to being compromised by breaching. Breaches can occur from shoreline erosion due to wind waves and extreme tides or water elevations. Unfortified dike faces are also susceptible to slumping on ebbing tides as water drains from the dike. Low elevation dikes, within 2 ft. of MMMW elevation, are now more susceptible to being overtopped than when they were first built a century ago due to the relative sea level increase of 1.5 ft. Overtopping of a dike can lead to breaching, if the backside of the dike is eroded. Rising groundwater will likely flood the diked former tidelands, but may not adversely affect dike structures.

Figure 15.. An earthen dike breached during king tide and high waves in 2003 resulted in hundreds of acres flooded by saltwater, with a temporary water cofferdam (Times-Standard Andrew Bird photograph January 26, 2004).

There are approximately 41 miles of dikes that traverse 170 individual parcels around Humboldt Bay, with multiple landowners and no centralized dike management district. To effectively address sea level rise impacts, the vulnerability of dike shoreline structures, and the critical assets residing behind these dikes, it is desirable to maintain the entire length of shoreline in a hydrologic sub-unit, regardless of shoreline ownership (Figure 16). Management of Humboldt Bay's diked shoreline would benefit greatly if a Dike Reclamation District was formed to maintain the dike shoreline. Alternatively, the Humboldt Bay Harbor, Recreation and Conservation District, which has development authority over the shoreline up to MHHW, could also serve as the Dike Reclamation District on Humboldt Bay. In the next five decades with rising sea levels of 0.9 ft. by 2030, 1.9 ft. by 2050 and 3.2 ft. by 2070, coordinated and comprehensive management and maintenance of diked shoreline will become imperative if these structures are to continue to protect the assets that are risk.

Figure 16. Protection and maintenance of dikes must encompass the entire hydrologic unit shoreline and not be based on property ownership.

Diked Hydrologic Units and Protected Assets

Diked hydrologic sub-units are physical land units defined by a common diked shoreline. Many of the diked sub-units contain critical utility and transportation infrastructure assets, and local and national wildlife refuges. A simple rating scheme has been employed to rank sub-units based on the number and type of assets being protected by the diked shoreline (Table 2). All assets have a value of 1 except for state transportation, Highway 101 and 255, which were given a higher value of 2 due to their regional importance. There are six diked sub-units where a majority of the critical utility and transportation infrastructure assets are located: ES-1, AB-1-4, and SB 1. For the benefit of the Humboldt Bay region, building resiliency in the dikes on these sub-units is a priority.

Table 2. Summary of assets located in diked shoreline hydrologic sub-units: Mad River Slough (MRS), Arcata Bay (AB), Eureka Slough (ES), Elk River Slough (ERS), and South Bay (SB). Diked shoreline hydrologic sub-unit, LCP jurisdiction, presence of critical utility and transportation infrastructure, and wildlife refuges.

DIKE	LCP	UTILITIES					TRANSPORTATION				WILDLIFE	RATING
UNIT		Muni Water	Wastewater	Gas	Electrical	Commun.	Local	State	Air	Trail/Rail	REFUGE	
MRS-1	HBAP						X					1
MRS-2	HBAP											0
MRS-3	HBAP						X					1
AB-1	HBAP	X			X		X	**X**		X	X	7
AB-2	COA	X		X	X	X	X	**X**			X	8
AB-3	COA	X		X	X	X	X	**X**			X	8
AB-4	HBAP	X		X	X	X	X	**X**				7
ES-1	HBAP/COE		X	X		X	X	**X**	X	X	X	9
ES-1a	HBAP							**X**		X		3
ES-2	HABP	X		X	X		X					4
ES-3	HBAP	X		X			X					3
ES-4	HABP	X		X	X		X					4
ES-5	HBAP											0
ES-6	HBAP	?					X					1
ES-7	HBAP	?					X					1
ES-8	HBAP											0
ES-9	HBAP			X			X					2
ES-10	HBAP											0
ES-11	HBAP						X					1
ERS-1	HABP	X		X	X		X				X	5
ERS-2	HABP	X		X			X					3
ERS-3	HBAP/COE	X	X	X	X		X					5
SB-1	HABP			X		X	X	**X**		X	X	7

All diked sub-units have at least one shoreline segment with a high vulnerability rating, and therefore presently at risk of breaching. Cumulatively, there are approximately 21 out 41 miles (41.5%) of diked shoreline rated highly vulnerable to breaching.

Because utility assets and the services they provide are critical to communities, identifying the diked sub-units protecting utility infrastructure is important. The Humboldt Bay Municipal Water District (HBMWD), City of Eureka, and Humboldt Community Services District (HCSD) have underground water transmission lines that traverse 10 diked sub-units (AB-1-4, ES-2-4, and ERS-1-3) and serve thousands of people and businesses. The City of Eureka and HCSD have underground wastewater collection/transmission lines and lift/pump stations that are located in two diked sub-units (ES-1 and ERS 3). Pacific Gas and Electric Company has underground gas transmission lines traversing 12 diked sub-units (AB-2-4, ES-1, 2-4, and 9, ERS-1-3, and SB-1) and 8 sub-units (AB-1-4, ES-2 and 4, ERS-1 and 3) where electrical transmission towers and distribution poles are located. The locations of these underground optical fiber lines generally parallel transportation infrastructure and are believed to be located in 5 diked sub-units (AB-2-4, ES-1, and SB-1). Segments of the defunct North Coast Railroad Authority's railroad on Humboldt Bay are protected from tidal inundation during MMMW and MAMW by three diked sub-units (AB-1, ES1 and 1a).

Transportation infrastructure, particularly U.S. Highway 101, is also a critical asset. Regionally, Highway 255 is an important asset to Humboldt Bay. Highway 101 is protected from tidal inundation by dike shoreline structures as it traverses 6 sub-units (AB-2-4, ES-1 and 1a, and SB-1). Highway 255 is protected by the diked shoreline in AB-1. If the diked shorelines were breached today, MMMW (8+ times/year) would tidally inundate Highway 101 in SB-1, and MAMW or king tides (4+ times/year) would inundate the highway in SB-1 and ES-1. Highway 255 would be tidally inundated under current MMMW if the diked shoreline in AB-1 were breached. The County's Murray Field airport in ES-1 is at risk of being tidally inundated by MHHW (182+ times/year) under current conditions if the diked shoreline is breached.

Wildlife refuges and reserves in the coastal zone protect valuable ESHA, particularly seasonal freshwater wetlands that are critical to thousands of migrating waterfowl and shorebirds. On Humboldt Bay, there are local, state, and federal wildlife refuges and reserves in 6 dike sub-units (AB-1-3, ES-1, ERS-1, and SB-1). There are 9 diked sub-units (MRS-1-3, ES5-8 and 10-11) containing freshwater wetlands that are primarily used for agriculture. While not officially designated as wildlife areas, waterfowl and shorebirds do utilize the seasonal freshwater wetlands (ESHA) that occur in these agricultural units.

Some diked former tidelands have compacted over the last century and are therefore more prone to flooding by stormwater runoff, rising ground water, and rising tides that reduce drainage capacity of water control structures such as dikes and culverts. Significant portions of 10 diked sub-units' (MRS-1-3, AB 1 and 4, ES-1-3 and 6, SB-1) have surface elevations less than MHW (5.8 feet). Because of compaction, these lands will have increased water depths from tidal inundation, should the dikes be breached or overtopped, making maintenance of utilities traversing these lands much more difficult.

Sub-unit ES-1 has the highest rating (9 out of a possible 11) based on the number and type of assets that are vulnerable and at risk to sea level rise. Two Local Coastal Programs (LCP) (the County's HBAP and the City of Eureka's LCP) cover this unit. Unit ES-1 has 3.3 miles of diked shoreline, with another 1.1 miles of diked shoreline in unit ES-1a. Together, a total of 4.4 miles of shoreline protect commercial (including a mobile home park), public facilities (County airport and Caltrans' Highway 101), and agricultural land uses (including a state wildlife refuge) and developments. Sub-unit ES-1 has 0.3 miles of dikes that are less than 9.7 ft and 0.55 miles less than 10.7 ft (the tipping point between 2.0 and 3.0 ft of sea level rise), and 0.68 miles of eroding and low elevation shoreline that were rated highly vulnerable. Consequently, under current conditions assets in this unit are at risk from tidal inundation should the shoreline be breached. This unit is the subject of a joint in-depth sea level rise vulnerability assessment to be conducted by Humboldt County and City of Eureka. These agencies will also be developing sea level rise adaptation strategies for the assets in this unit.

Sub-units AB-2 and AB-3 have a rating of 8, with 0.76 and 0.55 miles of dikes respectively, located in the City of Arcata's LCP jurisdiction. These units primarily support agricultural uses, including a wildlife refuge. The diked shoreline in AB-2 is owned and maintained by the City of Arcata. It has 0.15 miles of dikes that are less than 9.7 ft and 0.11 miles less than 10.7 ft (the tipping point between 2.0 and 3.0 ft of sea level rise) and 0.25 miles of eroding and low elevation shoreline that were rated highly vulnerable. Consequently, assets in this unit are at risk from tidal inundation should the shoreline be breached, under current conditions.

Sub-unit AB-3 has 0.55 miles of dike that are less than 9.7 ft in elevation and are rated highly vulnerable. Assets in this unit are at risk from tidal inundation should the shoreline be breached. These sub-units also have critical utility and transportation infrastructure assets and segments of eroding and low elevation shoreline that are rated highly vulnerable.

Sub-units AB-1 and SB-1 have a rating of 7 and are located entirely in Humboldt County's HBAP jurisdiction. These are the two largest sub-units (1,218 and 1,583 acres respectively) on Humboldt Bay, with 6.1 (AB-1) and 5.9 (SB-1) miles of diked shorelines, much of which is highly vulnerable to sea level rise. AB-1 has both privately and publicly owned diked shoreline and the only Dike Reclamation District on Humboldt Bay. SB-1 is entirely in the Humboldt Bay National Wildlife Refuge. Segments of the diked shoreline in these units have been fortified in the last 10 years, but there are still approximately 5 miles rated highly vulnerable.

AB-4, located in Humboldt County's HBAP jurisdiction, also has a rating of 7. Along with AB-3, it has unfortified low elevation dikes along Washington Gulch, a tributary to Humboldt Bay. The dikes in AB-4 are on private property, and protect agricultural uses, a restored salt marsh with a muted tide cycle, several types of utility infrastructure (municipal water transmission lines, gas transmission line, electrical transmission towers, and optical fibers), and transportation infrastructure (Highway 101 and Old Arcata Road).

The remaining 17 diked sub-units have a rating of 0 to 5 and are primarily privately owned and maintained. These sub-units are predominately used for agriculture and do not protect Highway 101, except for ES-1a, and have 5 or less assets being protected by diked shorelines.

Dike Shoreline Adaptation Strategies

The purpose of a dike is to create a barrier to prevent tidal inundation of lands interior of the structure. Sea level rise can increase erosion, slumping, over steepening of a dike slope, or overtopping of the dike crest and erosion of the back slope, with the result being a breach of the dike and tidal inundation of the interior lands. Dike breaching has occurred recently on a sub-unit known as White Slough slated for salt marsh restoration next to SB-1 in 2015 and on AB-1 in 2003. A dike can also be overtopped without breaching, resulting in the saltwater inundation of interior lands, which occurred in 2010 on another sub-unit just north Walker Point slated for salt marsh restoration next to ES-1. Tide gates are an integral component of a dike structure. Sea level rise can increase the frequency and duration of tide levels above current MLLW elevation which will reduce the amount of time that tide gates can drain interior lands that are flooded. Therefore, shoreline enhancement strategies must be able to address several types of impacts to dike structures: erosion, overtopping, breaching and backwater or rising groundwater flooding.

One of the first challenges to overcome in all diked sub-units, except SB-1 which is owned and maintained entirely by the Humboldt Bay National Wildlife Refuge, will be to bring together all the shoreline property owners. Together, these entities will need to agree on what sea level rise adaptation strategies and measures to employ in order to protect, accommodate, and/or relocate dikes, how they will be financed, and when they will be implemented.

Protection

Dikes protect transportation and utility infrastructure that are critical to the sustainability of the Humboldt Bay region. The economic value of the infrastructure that is at risk from tidal inundation should these dikes be compromised is significant, while the services they provide are essential to the ongoing wellbeing of the communities on Humboldt Bay and beyond. The highest priority sea level adaptation strategy to be considered and employed should be protection of the diked shorelines.

The length of the diked shoreline in each of the 23 sub-units ranges from 0.21 to 6.14 miles, with highly vulnerable shorelines accounting for 0.07 to 3.87 miles per unit. In some of the larger sub-units, it may be more cost effective to phase implementation of a protection strategy by addressing individual segments of a dike structure in a sub-unit at risk of breaching, rather than the entire length of the sub-unit’s diked shoreline. Consideration should be given to the expected longevity of existing dike segments, and rehabilitated or new dike segments. A 50-year design life with good maintenance practices is to be expected. Lastly, suitable sources of clean fill and rock materials will need to be identified.

Equipment access is another consideration in protecting a dike. Many dikes that are privately owned and located in primarily agricultural sub-units have a crest of insufficient width (10-12 ft) to allow equipment access. Dikes owned or maintained by public agencies (SB-1 and AB-1) generally have sufficient crest width to allow equipment access to maintain the dikes.

Protection as a sea level rise adaptation strategy generally would retain the dike structure in its present location. Two protection adaptation measures that could increase a dike’s resiliency to sea level rise include repairing a damaged segment or modifying an intact segment. Both measures could employ either hard and/or soft (natural) slope protection methods to protect the dike segment that is vulnerable to sea level rise.

Repair

Many unfortified dike reaches are eroded on the water side, either from wave action or slumping. These actions cause the dike face to over steepen and migrate inland, reducing the dike crest width (Figure 17). The loss of a significant portion of the original dike cross-section creates a vulnerable condition that is unacceptable. A reduced dike crest width will make access for heavy equipment problematic. Dikes that are overtopped, even for short duration, can erode from the land side, which is generally not fortified. At the extreme, an erosion point will migrate through the dike crest, resulting in a breach. Approximately 3.3 miles of dikes on Humboldt Bay are exposed and eroding.

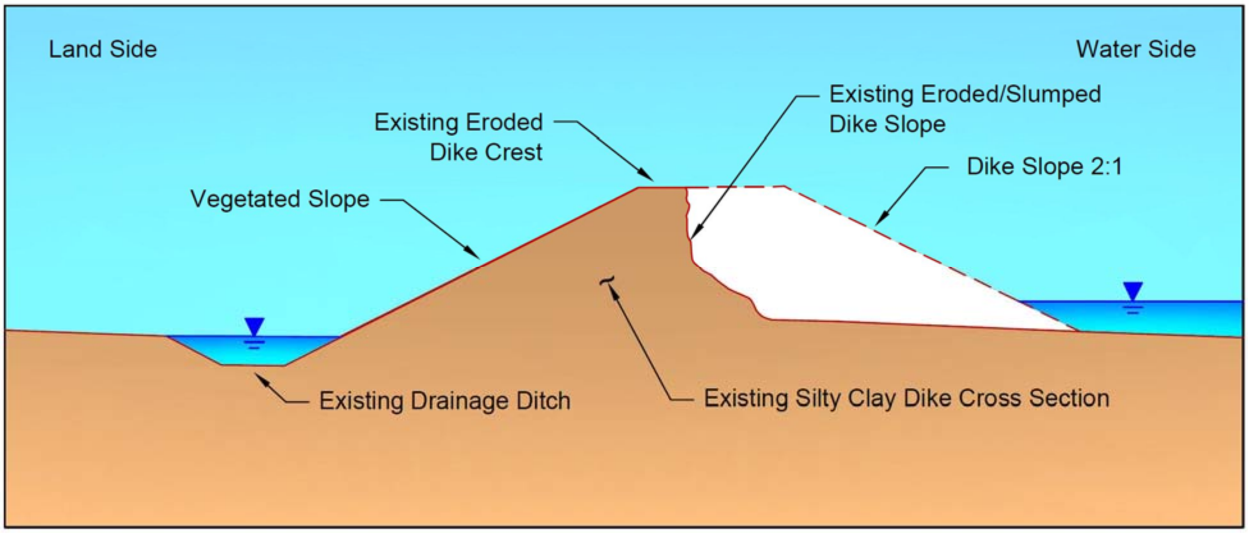

Figure 17. Eroded water side of an earthen dike illustrating typical dike features and the reduction in crest width.

Ancillary to repairing a dike, consideration must first be given to how to access the work area and isolate it from daily tidal inundation. Access can be very difficult once a dike is breached if the dike crest has eroded. Without a suitable crest width for equipment, land side access ramps will need to be constructed to enable equipment access to work on the water side of the dike. A temporary barrier, such as water filled cofferdam, will need to be installed to prevent tidal inundation. Access can be further compromised if there is an in-board ditch at the toe of the dike and mudflat on the water side.

The options for repairing a degraded dike include:

1. Reconstruction. Rebuilding a damaged structure can help recover the original dike cross section. This would rely on the same slope ratio (generally 2:1, horizontal to vertical) and reclaim the original footprint. This is essentially what most dike repair projects did in response to the Governor’s 2006 state of disaster declaration due to damage and threat from the 9.55-ft extreme water event. A taller dike can be achieved without expanding the dike footprint if a steeper slope such as a 1:1 slope can be constructed in the same base footprint. Expanding the original dike footprint to support a taller dike would allow a more desirable 2:1 slope ratio, but in many instances would require filling coastal wetland which can

be problematic in terms of compliance with the Coastal Act. This approach was not authorized by the CCC at the time of the 2006 disaster repairs.

2. Engineered Fortification. Protecting a dike structure from wave induced erosion with engineered fortification can be accomplished using rock, a bulwark, or sheet piling. Rock slope protection (RSP) is the most common engineered solution to wave induced erosion on Humboldt Bay. An alternative engineered solution is to build a bulwark, which is a wall-like embankment made of wood, rock filled gabions, or concrete that is employed on shorelines in deep-water or where space is limited or at a premium. Sheet pilings of steel or composite materials are a type of bulwark that is installed with a pile-driver. The advantage of these types of structures over RSP is that they occupy a much smaller footprint, and can be employed to increase the elevation of the dike and width of the crest while not exceeding the original footprint.

3. Natural Protection. Protecting the dike structure from wave induced erosion with natural shoreline infrastructure can also attenuate wave energy and height. Possible suitable natural shoreline infrastructure for Humboldt Bay include oyster reefs, salt marsh plain, and sill and cobble berms.

Modify

There are two options for the modification of an existing dike:

1. Reconstruct landward. Rebuilding the damaged dike segment's cross section on the land side avoids the complications of rebuilding on the water side. Reconstruction on the water side requires isolating the work area from daily tides, handling saturated soils, and equipment access over inter-tidal wetlands (Figure 18). Landward reconstruction of the dike would necessitate the relocation of the in-board drainage ditch, if one is present, and clearing vegetation from the land side of the dike. Rebuilding from the land side could create a suitable crest width and equipment working platform to facilitate fortification of the degraded water side of the dike with rock slope protection. As discussed above, reconstruction landward would likely require wetland fill, which has the potential to conflict with the Coastal Act.

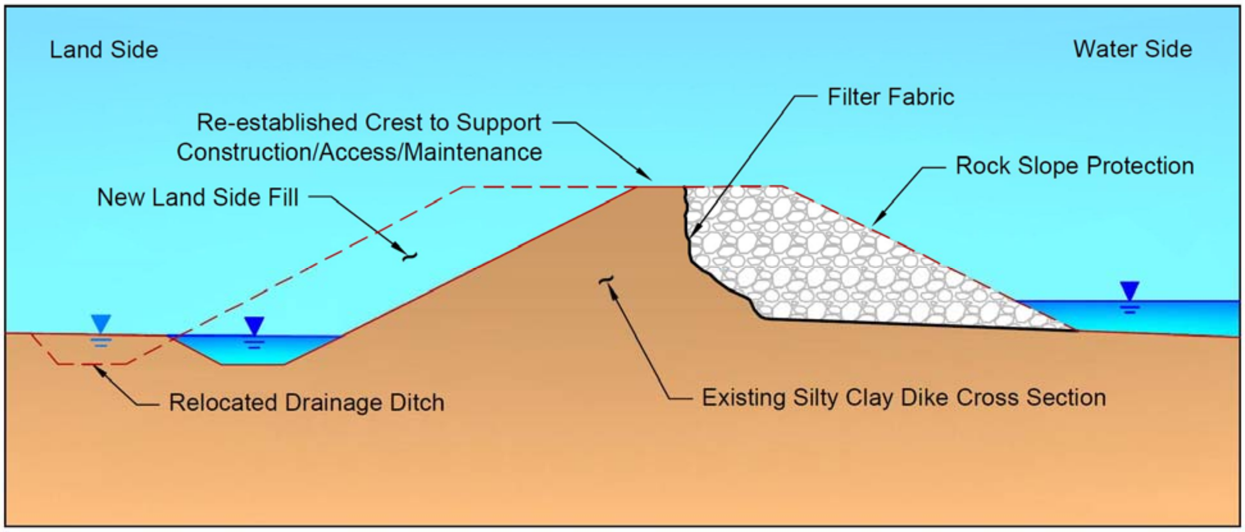

Figure 18. Modification of original dike design by rebuilding the dike on the landward side of the existing dike.

2. Increase dike height. Only 10.6 miles of dikes are fortified on Humboldt Bay, and roughly 29 miles of dikes need modification to increase their resiliency to wave induced erosion. Approximately 9.3 miles of diked shoreline is less than 2.0 ft higher (9.7 ft) than MMMW elevation and 10.4 miles are less than three feet higher (10.7 ft). To protect these 19.7 miles (49.7%) of the diked shoreline from being overtopped when water elevation crosses the tipping point between 9.7 to 10.7 ft, their crest elevation will need to be increased. Dike crests should be increased to 12 ft to protect the dike from overtopping from a MAMW of 11.7 ft in 2070 with 3.2 feet of sea level rise. Providing for 1 to 2 ft of free board would increase the dike crest to 13-14 ft.

   To build a dike taller than it is now will require a larger base, or footprint. On Humboldt Bay this would generally require placing fill in a coastal wetland. On the land side, this would place fill in a seasonal freshwater wetland known as farmed wetlands and/or in an in-board ditch. On the water side, this would place fill in salt marsh or mudflat. Alternatively, a taller dike structure could be constructed utilizing materials with greater strength (cohesive soils or aggregate/rock), and placement methods that afford greater stability to support a steeper slope than 2:1; thus, a higher elevation could be achieved in the same footprint. Engineered structures like bulwarks and sheet pilings could also be utilized to achieve a taller dike.

Both dike modification options could employ protective measures to fortify the structure with RSP, bulwarks, sheet pilings, and/or creating natural shoreline infrastructure to attenuate wave energy and height.

Accommodation

Accommodation as a sea level rise adaptation strategy that, like protection as discussed above, would also retain the dike structure in its present location. Two accommodation adaptation measures may increase a dike's resiliency to sea level rise: constructing natural shoreline infrastructure waterward of a dike to provide a continuum of protection to the dike structure as sea levels rise, and increasing drainage capacity of low lying areas behind dikes as sea level rise reduces the efficiency of existing tide gates to drain these lands.

Construct Natural Shoreline Infrastructure

Constructing natural shoreline infrastructure is an alternative approach to armoring shoreline structures such as dikes to protect them from wave induced erosion and overtopping. Natural shoreline infrastructures known as a horizontal levees or eco-levees, constructed on a gradient from MLLW to MHHW or MMMW, can continue to afford a level of protection to shoreline structures with rising sea levels. Natural shoreline infrastructure can, depending on the wave energy setting, consist of oyster reefs, salt marsh sill and plain, and cobble berms (Figure 19) (Newkirk 2018). Constructing natural shoreline infrastructure provides a multitude of benefits, including shoreline stabilization, sub/inter-tidal habitats and sediment accretion, and avoids the adverse impacts of shoreline armoring to marine habitats. As with the placement of engineered RSP on the water side of a dike, the construction of natural shoreline infrastructure will need to address CCC regulatory constraints on the placement of fill in a coastal water or wetland. Natural shoreline infrastructure construction will need to demonstrate an overall net benefit to the inter-tidal habitats affected.

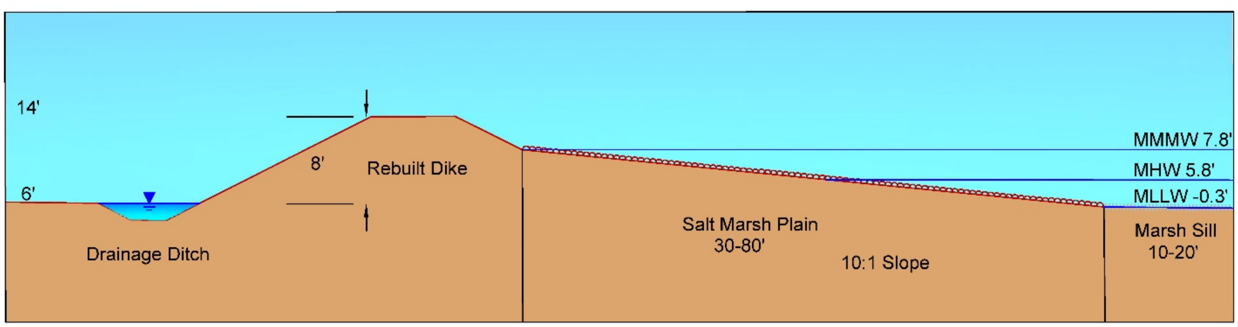

Figure 19. Natural shoreline infrastructure, a combination of a marsh sill and salt marsh plan.

1. An oyster reef can be employed to reduce wave energy generally from -2.3 ft to 1.7 ft (2ft +/- MLLW is -0.3 ft) elevation on Humboldt Bay, and to encourage sediment accretion. At these low elevations, native oyster reefs alone will not be able to attenuate wave energy sufficiently to protect the water side of dike structures. Oyster reefs, if feasible in combination with marsh sills and salt marsh plain can extend the continuum of tidal habitats to attenuate wave energy and height while increasing biodiversity.

2. The combination of a marsh sill (a stone structure) and salt marsh plain (a vegetated structure) may be more stable and successful on Humboldt Bay than either structure would be alone. The combination of the two structures can create continuum of habitats and a friction inducing wave environment from MMMW (7.7 ft) to below MLLW (-0.3 ft). A marsh sill is a low-profile (8 or 10:1) stone (cobble or rock) structure starting at an elevation just below MLLW to 4.3 ft. A marsh sill (10-20 ft wide) can provide a stable toe to a salt marsh plain that would extend towards the dike from MHW (5.8 ft) elevation to MHHW (6.5 ft). If it is feasible, additional fill could continue up to MMMW elevation, the boundary between salt marsh and upland vegetation. The width of the salt marsh plain should be at a minimum 30 ft for wave dissipation (Newkirk 2018) but maximized to the extent feasible. Both the marsh sill and salt marsh plain would encourage sediment accretion to occur and support eelgrass and salt marsh vegetation. They would also attenuate wave energy and height to protect the water side of dike structures. The salt marsh gradient should provide shoreline protection through a range of sea level rise elevations (0.9 ft/2030 to 1.9 ft/2050).

3. A cobble berm made of 6-inch diameter or greater cobble to create cobble bench/shelf at slopes of 5:1 to 10:1 could provide protection at the base of the water side of a dike by dissipating wave energy. The predominant wave approach angle should be less than 20 degrees (Newkirk 2018).

Increase Drainage Capacity

Rising sea levels will increase the elevation of low water datums (MLLW and MLW). Generally, the inlets to dikes on Humboldt Bay are placed at or near MLLW elevation of -0.3 ft. As MLLW rises in elevation, the base elevation that water on the interior of the dike will drain to will also rise, resulting in less cross-sectional area in the tide gate for discharge. Increased low tide elevations will also result in a longer duration of inundation of lands interior to the dike and tide gate. Existing tide gates could be elevated; however, that would result in the inundation of lands interior to the tide gate unless the elevation of those lands is also increased. Replacing top hinged tide gates with a larger diameter side hinged tide gates would increase drainage efficiency and capacity and therefore help alleviate the problem of delayed discharge and inundation. Side hinged tide gates open as soon as the tide begins to ebb, and are not dependent on a hydraulic head to open like a top hinged tide gate, which enables the side hinged gate to stay open longer. Adding additional tide gates would also increase drainage capacity.

Land Conversion

As rising groundwater and reduced drainage capacity degrade agricultural uses on diked former tidelands, they could be allowed to convert to submergent/emergent freshwater wetlands and/or riparian habitat. This adaptation measure may not be suitable in those sub-units where access to critical infrastructure for future maintenance will be required.

Relocation

Relocation or managed retreat (phased relocation) is a sea level rise adaptation strategy that involves moving a dike structure inland from its present location. The distance inland that a dike is relocated may be dependent on important variables such as the willingness of agricultural landowners to give up farm land, and the distance to the nearest critical infrastructure from existing dike shoreline.

Moving a dike inland within the footprint of diked former tidelands would enable the restoration of the former salt marsh behind the old structure to create natural shoreline infrastructure to protect the new dike structure. There are many design variations to consider when relocating a dike structure. For example, the existing dike structure could be re-purposed, rather than being removed, to form a string of barrier islands to intercept wind wave and storm run-up waves. They would protect the leading edge of a salt marsh plain, rather than constructing a marsh sill. This technique would also provide wildlife habitat (Figure 20).

When building a new dike inland, consideration should be given to length of time that the protected land uses, developments, and access to critical infrastructure will be sustainable due to rising groundwater becoming emergent water, duration and depth of backwater flooding, and salt water intrusion due to sea level rise. Based on the average elevation of compacted former salt marsh soils (less than 6 ft) the existing ground surface would become inundated by rising groundwater with 3.0 ft of sea level rise, which is projected to possibly occur by 2070. The crest elevation of the new dike would need to be 12 to 14 ft, which should be sufficient to provide protection from tidal inundation resulting from 3.0 ft of sea level rise by 2070. Constructing a taller dike could also be phased to off-set construction costs and provide sequential protection for 1.0 ft (2030), 2.0 ft (2050), and 3.0 ft (2070) of sea level rise. If natural shoreline infrastructure were employed, it may be possible to forgo RSP fortification of the new dike structure, significantly reducing the cost of construction. There may also be an opportunity reduce the length of the diked shoreline when relocating the structure by not following the sinuosity of the shoreline and cutting off meanders with a straighter dike structure. This would reduce impacts to coastal wetlands and construction costs. When relocating and building a new dike, there will also be an opportunity to install an adequate number of appropriately sized tide gates, based on the backwater drainage volume (acre-ft).

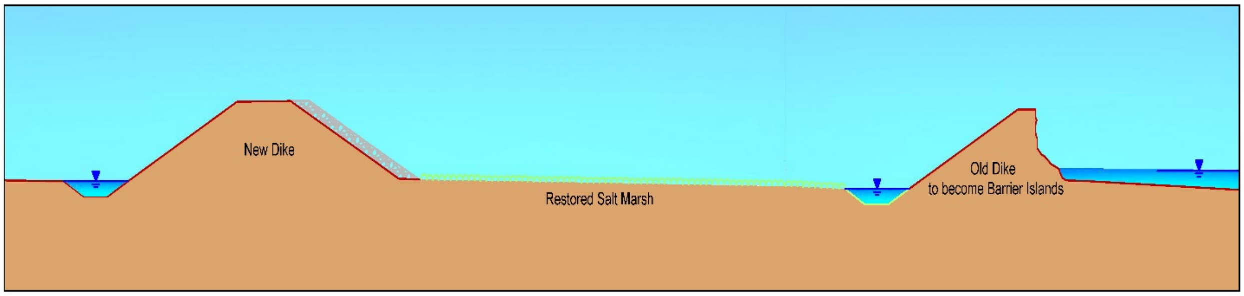

Figure 20. Relocated dike with former dike barrier island feature and restored salt marsh natural infrastructure for new dike.

Coastal Commission Authorization of Sea Level Rise Adaptation Measures for Dikes on Humboldt Bay

The diked shorelines on Humboldt Bay are in areas where the CCC has retained jurisdiction under the Coastal Act. Implementation of the proposed sea level rise adaptation strategies and measures will require approval of the CCC pursuant to Chapter 3 Coastal Resources Planning and Management Policies.

The Coastal Act's basic goals are to "protect, maintain, and, where feasible, enhance and restore the overall quality of the coastal zone environment and its natural and artificial resources" (PRC § 30001.5 (a)). The Coastal Act also contains several policies that could constrain the implementation of some otherwise feasible sea level rise adaptation measures:

1. Rebuilding an eroded dike should include protective measures to prevent the erosion of the repaired dike. On Humboldt Bay, diked former tidelands are considered seasonal freshwater wetlands by the CCC. The ability to place fill in a coastal wetland is very limited (PRC § 30233). Constructing natural infrastructure protection, like a cobble berm, at the toe of the water side of a dike is not an allowable fill as structure protection, and in addition, would likely entail converting mudflat habitat, a protected marine resource. Similarly, constructing an oyster reef or marsh sill of rock on mud flat habitat to anchor and protect the toe of a constructed salt marsh plain to protect a dike may not be allowed as a structure protection, but could potentially be allowed as restoration if salt marsh historically existed at this location. Restoring marine resources (habitats) is an allowable reason to place fill in a coastal wetland pursuant to PRC § 30233. However, converting mudflat habitat to salt marsh habitat if salt marsh did not historically occur at that location, may still not be an allowable fill because of the conversion of one marine habitat to another, even though 90% of the historical salt marsh on the Bay has been lost.

2. While raising the elevation of the crest of a dike is a viable way to protect a dike and assets inland of the dike from sea level rise, such action could require increasing the base footprint of the dike. Increasing a dike's footprint is not an allowable reason on its own to place fill in a wetland (PRC § 30233) but could be allowable if the increase in dike height is associated with an allowable wetland fill use, such as restoration. Alternatively, increasing the height of a dike could be achieved without expanding its footprint if the water side of the dike is hardened with RSP, bulwarks or sheet piling. However, the armoring of dikes is not an allowable wetland fill of salt marsh or mudflat on the water side, unless this type of armoring existed in the original dike footprint, in which case the armoring could be replaced on the dike as a repair and maintenance activity if it did not result in an enlargement or relocation of the dike pursuant to PRC § 30610.

3. Shoreline protection structures are allowed when required to serve coastal-dependent uses (any use which requires a site on, or adjacent to, the sea to function at all) or to protect existing structures from erosion (PRC § 30235). However, most of the diked sub-units are agricultural lands, and agriculture is not a coastal-dependent use. Diked sub-units that have wildlife refuges that protect coastal freshwater wetlands and coastal wildlife habitats which support populations of waterfowl and shorebirds may qualify as a coastal-dependent use, making fill placement for shoreline protection a possibility. Existing structures has been interpreted to mean structures in place as of 1976, when the Coastal Act was passed. Most of the diked sub-units (82%) have utility and transportation infrastructure that existed prior to 1976; only 4 have sub-units have no such assets. Installing RSP or constructing natural shoreline protection structures should be allowed if these structures will increase protection of the diked shoreline, which of course is what is protecting the existing inland structures from tidal inundation. However, experience has shown that the application of PRC § 30235 to determine when shoreline protection is allowable is extremely nuanced and limited.

4. Where diked shoreline reaches are exposed to wind generated waves and are eroding, or in response to sea level rise, dikes can be relocated inland, but if their new location is still on diked former tidelands, this may also not be an allowable fill (PRC § 30233). Relocating a diked maybe an allowable fill if the former diked salt marsh plain could be restored at the same time, which would provide protection to the new dike. Relocating a dike would employ current engineering standards in rebuilding the dike to appropriate and stable slopes, which would likely result in expanding the footprint of the relocated dike. Increasing the base width of the new dike over the old dike may trigger the same regulatory constraint described above (PRC § 30233), but again, if

the new dike is necessary for the restoration of salt marsh, the expansion of the dike base fill may be allowable.

There are inherent conflicts within the Coastal Act between restoring former tidelands, a marine resource (PRC § 30230); restricting what constitutes an allowable placement of fill in a coastal wetland (PRC § 30233); prohibiting the construction of shoreline protection (PRC § 30235); and perpetuating agricultural uses pursuant to PRC § 30241 and 30242, which seek to protect and maintain agricultural lands from being converted to other uses. Many of the viable sea level rise adaptation measures for dike structures invoke these conflicts. The Coastal Act anticipated the need to balance policies that are brought into conflict under unique circumstances to protect coastal resources, such as agriculture, wetlands, wildlife habitat, and coastal infrastructure, and allows the Commission to weigh the net benefit derived to coastal resources from a proposed action (PRC § 30007.5).

On Humboldt Bay, diked agricultural lands are not single purpose use areas. Diked shorelines protect much more than agricultural uses such as dairies, livestock grazing, and feed production. These lands are regionally important as seasonal freshwater wetlands that support migrating waterfowl, shorebirds, and resident wildlife populations. They also protect critical utility and transportation infrastructure. Pursuant to PRC § 30233, enhancing and protecting wildlife habitat is an allowable reason to place fill in a coastal wetland, and should therefore allow the placement of fill to build resiliency in the shoreline structure that is protecting and maintaining these diked freshwater wetlands and wildlife from sea level rise.

Protecting diked agricultural lands conflicts with achieving the goal in PRC § 30230 to restore marine resources whenever feasible. Restoring marine resources is an achievable goal if there are no physical, economic, cultural, environmental, or political impediments. However, these impediments do exist at many sites where agricultural lands could be sustained for five or more decades, if the proposed dike shoreline sea level rise adaptation measures were applied.

By 2070, if MHHW rises to 9.5 ft, these diked former tidelands may not be able to support agricultural uses and will be “reclaimed” by Humboldt Bay by rising groundwater and salt water intrusion, even if the dikes are still in place. The diked shoreline structures on agricultural lands could be considered a temporary structure that will lose its function when rising groundwater converts the vegetation behind the dike. Building resiliency in diked shoreline structures will provide the Humboldt Bay region time to build resiliency into critical utility and transportation infrastructure, relocate assets to safer locations, and maintain important seasonal freshwater wetland wildlife habitat for another five decades or more. With more than 5.0 ft of sea level rise, it is likely that MAMW king tides (14.2 ft) by 2100 will have restored many of the marine resources that were lost when dikes were constructed more than a century ago.

Generalized Dike Construction Cost Estimates

On Humboldt Bay the basic engineered dike design can include: an in-board drainage ditch, tide gate, earthen core at 2:1 slopes, 10-12-foot crest width, filter fabric and RSP on the water side of the dike (Figure 21).

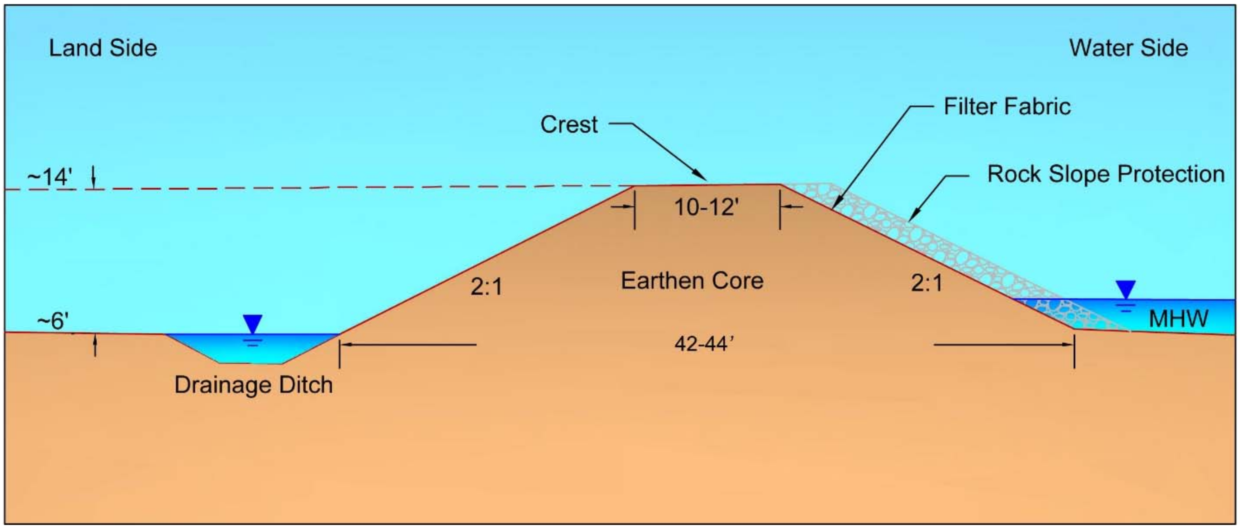

Figure 21. Typical dike features, drainage ditch, earthen core, 2:1 slopes, crest height equal of 14 feet (MAMW elevation by 2100) width for vehicular access, and rock slope protection.

Materials to build a dike with 2:1 slopes on ground with a 6 ft surface elevation, with a crest elevation of 14 ft (MAMW elevation for high projection by 2100), and a minimum 10 ft crest width for equipment access, which results in a 42-ft wide base:

- approximately 7.7 cubic yards of fill per linear ft = 40,656 cubic yards fill per mile
- approximately 18 ft slope with 0.66 sq. yd. filter fabric per linear ft = 3,520 sq. yd filter fabric per mile
- 1.5 ft diameter RSP = approximately 5,280 cy per mile.

General costs of material placement in constructing a dike, unit cost and cost per mile are listed below:

- Fill placement ~ $20.00/cy ~ $813,120.00/mile
- Filter fabric placement ~ $5.00/sq yd ~ $17,600.00/mile
- Rock placement ~ $50.00/cy ~ $264,000.00
  Sub-Total ~ $1,094,720.00/mile

If fill can be secured that needs to be removed from an offsite source, the cost of the fill would be contingent on the trucking distance from the source to the construction site. If fill is secured from a vendor, there will be a cost per cubic yard for the material in addition to trucking costs.

- Fill material ~ $20.00/cy ~ $813,120.00/mile
- Filter fabric ~ $0.50/sq yd ~ $20,328.00/mile
- <u>Rock material ~ $150.00/cy ~ $792,000.00/mile</u>
  Sub-Total ~ $1,625,448.00/mile

  TOTAL ~ $2,720,168.00/mile

If approximately half of the cross-section of an existing unfortified dike, based on the dimensions above, has eroded similar to what is illustrated in Figure 17, then the cost of rebuilding that dike with the addition of RSP could be approximately $1,907,048.00 per mile. To raise the crest elevation of an existing unfortified dike from approximately 10 ft to 14 ft elevation, based on the dimensions above, could cost approximately $1,063,304.00 per mile.

The cost of rebuilding, modifying or relocating a dike is subject to many variables, such as the availability of construction firms and equipment, mobilization costs, the availability and suitability of fill materials and source distance from the project site, land and water side surface elevations, the condition of the dike if rebuilding or modifying an existing dike, the adaptation measures to be employed (fortify water side with RSP, rebuild dike on the land side, raise the crest elevation, or relocate the dike), and whether to employ natural infrastructure such as cobble bench, marsh sill and salt marsh plain. Other important construction cost elements include planning, design, permitting, and construction management. As an example, the City of Arcata's construction costs for past work on an RSP dike ranged from $178/LF to $233/LF ($939,840.00/mile to $1,230,240.00/mile). If the City's non-construction components and contingency cost are included, the RSP dike could cost as high as $400/LF to $500/LF ($2,112,000.00/mile to $2,640.00.00/mile).

In general, older dikes on Humboldt Bay may not have a crest width sufficient for vehicular equipment. To increase the crest width of a dike may require a wider base and an increase in the amount of fill needed. The 11.7 miles of dike around the Bay that are fortified may have utilized broken concrete and other hard debris (old dikes) or engineered RSP (newer dikes). Non-RSP cover would likely need to be removed when rebuilding or modifying a dike, which would be an additional expense to enhancing a dike.

The construction costs for natural infrastructure such as oyster reefs, salt marsh sill, salt marsh plain, and cobble berms are dependent on the cost of materials, placement of materials, as well as associated project costs of design/engineering, permits, construction mobilization, and monitoring.

Given all the variables described above, it is difficult to accurately or completely forecast what it might cost to rebuild the 3.3 miles of eroding dikes or modify the 23.4 miles of existing dikes that are less than 14 ft in elevation.

Since the 2005 high water event, there have been several dike repair projects completed by public agencies on Humboldt Bay. Below are examples that provide some insight into costs of repairing a dike on Arcata Bay:

- Reclamation District 768, 2007 to 2011

  Included placing fill on the water side to rebuild the dike cross section, removing broken concrete slope protection, and installing RSP on 4.9 miles of dike; approximately $1,631,809.00/mile

- City of Arcata, 2008 and 2013

  2008 dike repair work included placing fill to raise crest elevation, removing broken concrete slope protection and installing filter fabric and RSP on approximately 0.9 miles of dike; approximately $900,000.00/mile.

  2013 new construction of two miles of eco-levee, with a dike crest elevation of 12 ft and 10 ft wide crest, a 10:1 water side slope, and no RSP; approximately $2,250,000.00/mile.

To facilitate the work necessary on Humboldt Bay to build resiliency in existing dikes or relocate dikes inland, it would be helpful and cost effective if programmatic permits to cover these actions could be developed with the CCC, Humboldt County, Cities of Eureka and Arcata, Humboldt Bay Harbor, Recreation and Conservation District, North Coast Regional Water Quality Control Board, and US Army Corps of Engineers. Maintaining up to date regional LiDAR coverage will also be a great assistance to engineers, planners and regulatory agencies in developing and approving dike resiliency projects.

Potential Dike Construction Funding Sources

As mentioned earlier, there is no one agency that maintains the diked shorelines, which traverse 170 parcels on Humboldt Bay. Reclamation Districts to manage and maintain levees have been organized in California's Bay-Delta and Central Valley regions. A Reclamation District could be formed on Humboldt Bay to manage and maintain dikes if the property owners who would benefit from the diked shoreline agreed to be taxed to operate such a special district. Besides relying on tax revenues, a Dike District could apply for grant funds from the following agencies or programs.

- <u>Sea level rise adaptation funds</u>: SCC (Climate Ready Grants and Prop 1 Water quality, Supply, and Infrastructure Improvement Act of 2014 Grants); OPC (Prop 84 Safe Drinking Water, Water Quality and Supply, Flood Control, River and Coastal Protection Bond Act of 2006); Caltrans (SB 1 Road Repair and Accountability Act of 2017 and, Sustainable Transportation and Adaptation Planning Grants); and NOAA-National Fish and Wildlife Foundation Coastal Resiliency grant program.

- Hazard mitigation funds, FEMA (Hazard mitigation assistance grants) and California Office of Emergency Services.

- Coastal wetlands enhancement funds: SCC, OPC and CDFW (Prop 68 California Clean Water and Safe Parks Act of 2018); USFWS (National Coastal Wetlands Conservation Grants) and North Pacific Landscape Cooperative.

Another potential mechanism to secure funds to rebuild, modify, or relocate diked shorelines would be for the owners of utility and transportation assets protected by these dikes to join with the property owners and help fund building sea level rise resiliency into these dike shorelines. Entities who own and maintain critical assets, but do not own the diked shorelines that protects their assets include:

- Caltrans (Highway 101 and 255),
- Humboldt County (airport and roads),
- City of Eureka (municipal water lines, pump station, wastewater line and lift stations, and streets),
- HBMWD (municipal water lines),
- HCSD (municipal water lines, pump station, wastewater line and lift stations,),
- PG&E (gas lines, electrical transmission towers and distribution poles), and
- Optical fiber companies

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