Can agricultural lands and uses on Humboldt Bay adapt to sea level rise?

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"In order to adapt to future change in sea level rise, coastal [agricultural landowners and] *wildlife area managers need to understand vulnerability and risk, because adaptation to sea level rise is a risk management strategy against an uncertain future" (Sullivan 2013).*

Climate change adaptation planning broadly speaking, involves assessing vulnerability and developing adaptation strategies. Specifically, this paper starts with the climate change impact from sea level rise (SLR) to agricultural land use and then discusses, how: (1) SLR might manifest; (2) where SLR will likely occur; (3) when SLR is expected to happen; (4) what would be placed at risk; (5) how sensitive and important are prioritized assets at risk; and (6) development of strategies and recommendations for applied adaptation to anticipated (modeled) SLR impacts.

Background

Sea level rise, is one aspect of climate change that will affect low lying coastal areas around Humboldt Bay, including its agricultural lands. For the purpose of assessing vulnerability of coastal agricultural lands to SLR, it is important to segregate these lands based on their origin: (1) alluvial bottom lands and (2) diked former tidelands (Figure 1). Alluvial bottom lands are generally higher in elevation than the current tidal regime, which may become vulnerable to rising sea levels and extreme tidal events. From 1880 to 1910, approximately 8,000 acres of salt marsh (tidelands) on Humboldt Bay were diked off and drained for agricultural use (Figure 2, Laird 2013).

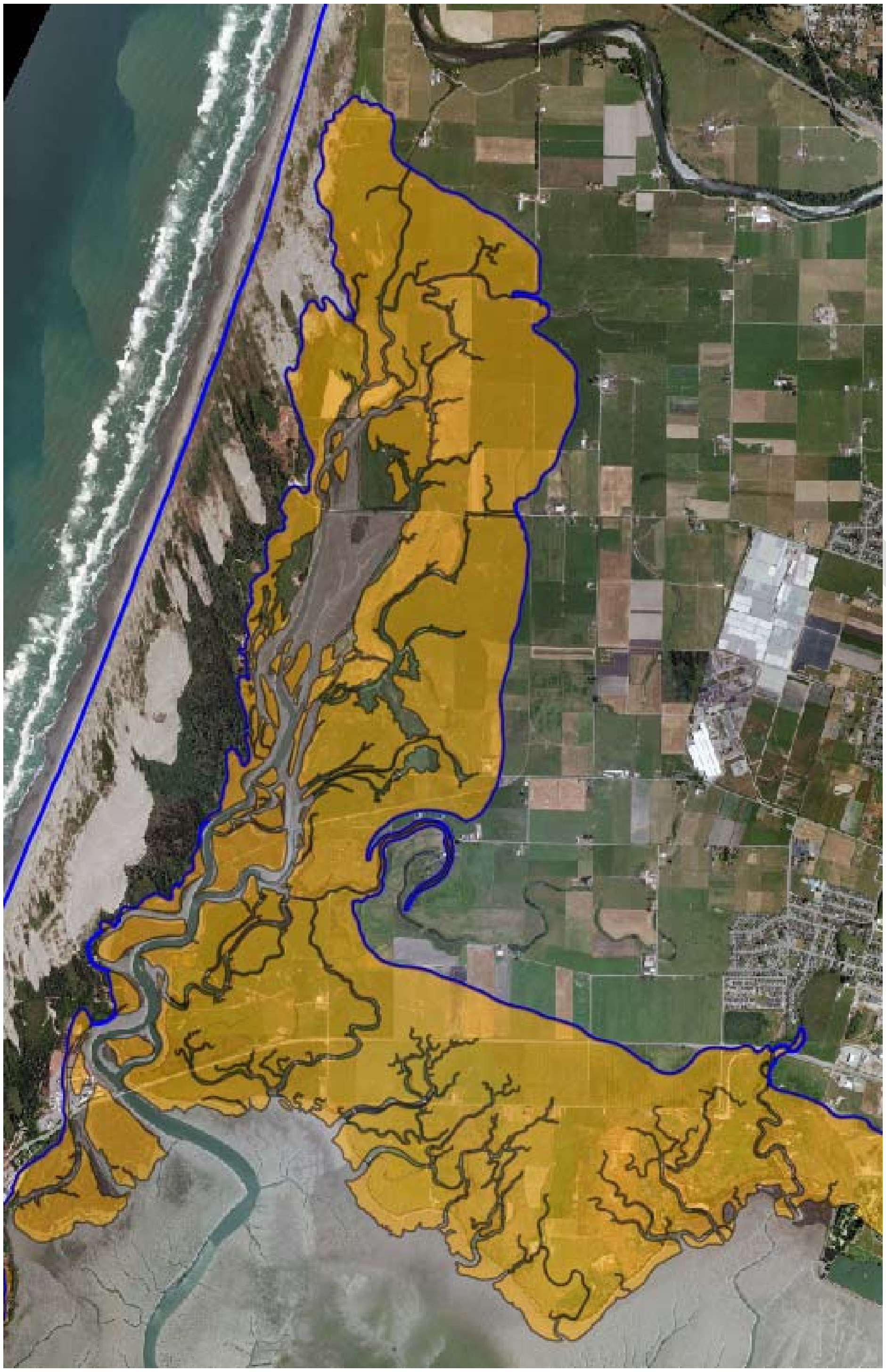


Figure 1. There are two types of agricultural lands on Humboldt Bay: (1) former tidelands (yellow shading) and (2) alluvial bottom lands (outside of blue tidal boundary of 1870).

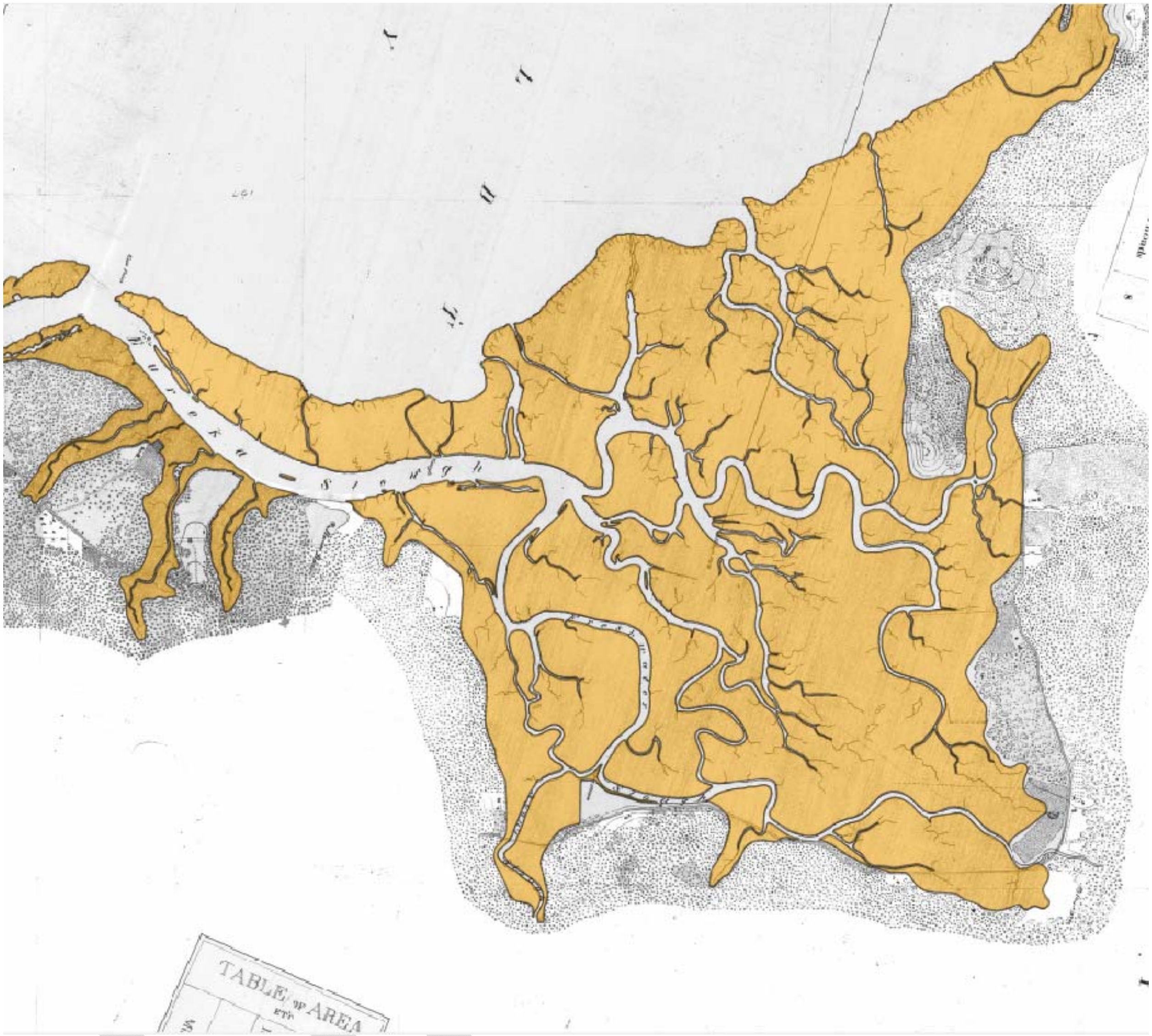


Figure 2. Historical inter-tidal lands on Eureka Slough, 1870 U.S. Coast and Geoditic Survey.

Over time, former tidelands have **<u>compacted</u>** by as much as 3 feet as organic material in salt marsh soils oxidized, and because sediment accretion from tides has been blocked by dikes and tide gates. In addition, vertical land movement associated with local tectonic activity is causing land in the Humboldt Bay region to **<u>subside</u>** (Cascadia Geosciences 2013). Combining subsidence on Humboldt Bay with SLR over the last 100 years, tidal elevations have increased approximately 18 inches – the most of any area on the west coast (Russell 2012). Humboldt Bay's agricultural lands are primarily protected by earthen dikes from salt water inundation during daily high tides. If these dikes were to be breached, flooding would cover a substantial area around Humboldt Bay (Figure 3). With time vulnerability of these agricultural lands is likely to increase; for example with just another 18 inches (0.5 meter) of SLR, it is projected that today's 100 year tidal event will become tomorrow's new annual King Tide (Figure 4, NHE 2013).

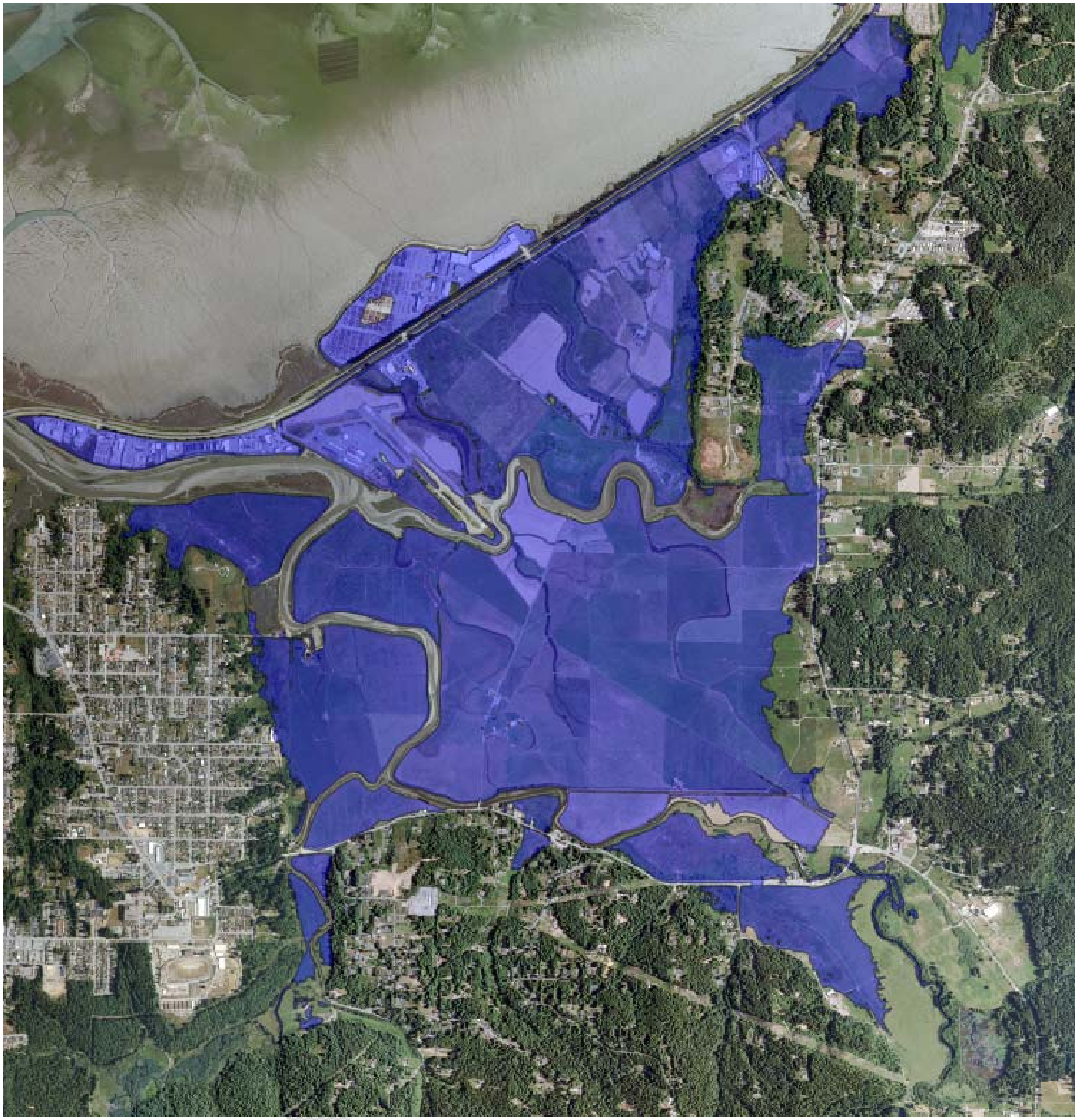


Figure 3. Potential inundation area on Eureka Slough, if existing diked shoreline were to be breached, based on preliminary data released by NHE 2014.

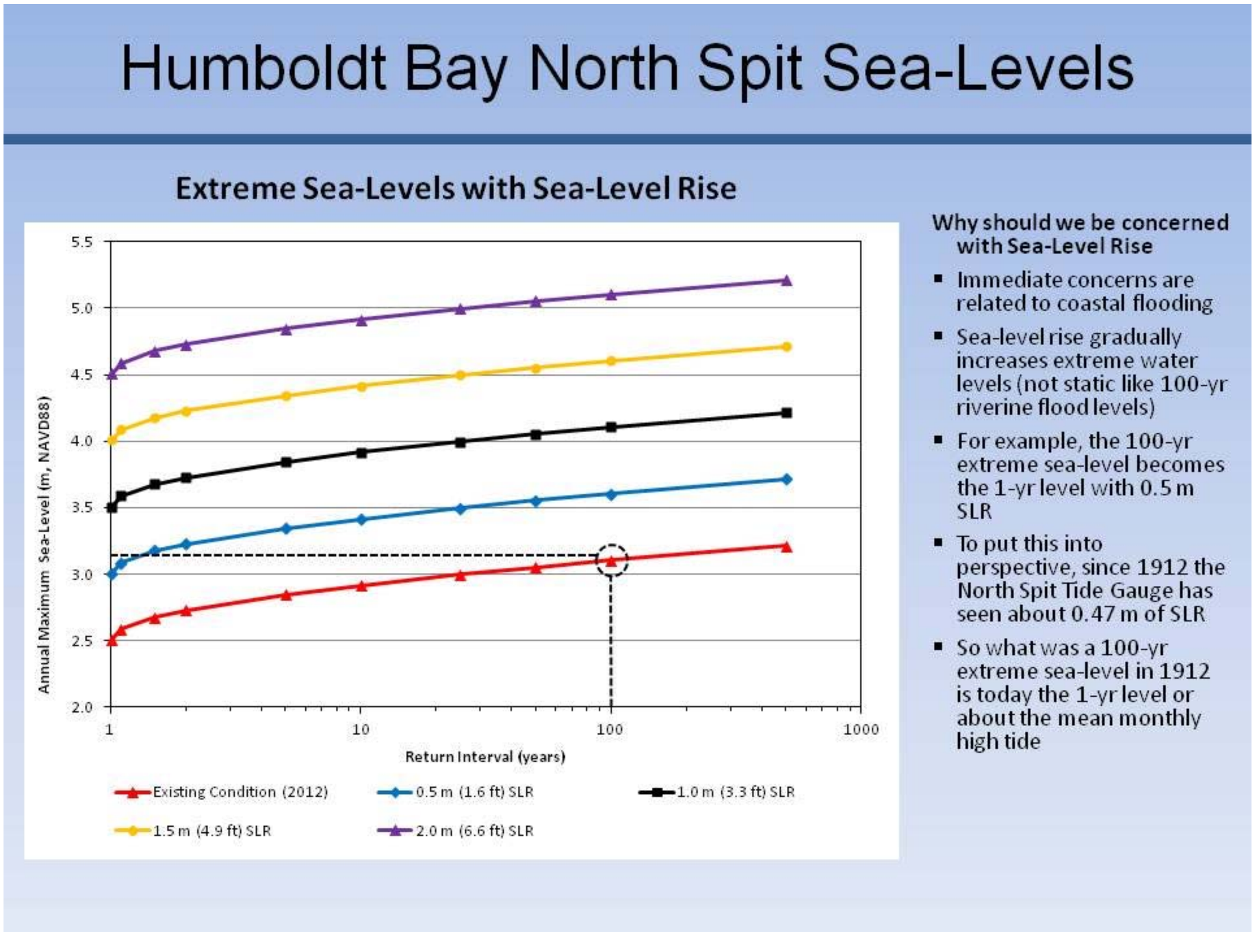


Figure 4. With just 0.5 meters of SLR the 100 event today will become the annual King Tide event, NHE 2013.

Relative Sea Level Rise Projections and Impacts

California's Ocean Protection Council and Coastal Commission SLR guidance documents recommend incorporating SLR projections for: 2030, 2050, and 2100, into planning and decision making for projects in California (CO-CAT 2013, CCC 2013).

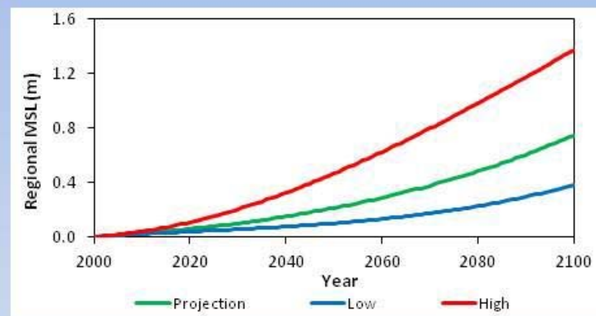
Based on Humboldt Bay's North Spit tide gage, relative sea level rise (RSLR), the combination of regional SLR rates and local vertical land motion rates, is estimated to be in: 2030 approximately 7 inches, 2050 13 inches, and by 2100 39 inches (Figure 5, NHE 2014). On Humboldt Bay, SLR may affect agricultural land uses by shoreline erosion, flooding, rising groundwater, and salt water intrusion. As SLR affects low lying agricultural land on Humboldt Bay, it also has the potential to impact valuable waterfowl and shorebird habitats, on these same lands that from January through April, support most of North America's Aleutian goose population.

Sea-Level Rise Projections for Humboldt Bay Region

Sea-Level Rise Projections Based on National Research Council (2012) Study

Regional mean sea-level rise (ReSLR) projections for different scenarios in Humboldt Bay Region without vertical land motion effect

	ReSLR Projections Relative to Year 2000 (cm (in))		
Year	Low	Projection	High
2030	3.9 (1.5)	9.9 (3.9)	21.3 (8.4)
2050	10.9 (4.3)	21.4 (8.4)	46.2 (18.2)
2100	38.6 (15.2)	75.1 (29.6)	137.9 (54.3)



Relative mean sea level rise (RSLR) projections for different scenarios in Humboldt Bay with vertical land motion effect (VLM at North Spit gage = -2.30 mm yr^{-1} downward)

	RSLR Projections Relative to Year 2000 (cm (in))		
Year	Low	Projection	High
2030	12.5 (4.9)	16.8 (6.6)	27.3 (10.7)
2050	21.4 (8.4)	32.8 (12.9)	58.1 (22.9)
2100	61.2 (24.1)	97.7 (38.5)	160.4 (63.2)

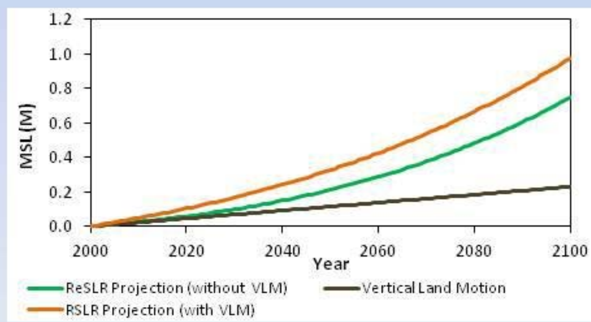


Figure 5. Regional and RSLR level rise projections for Humboldt Bay (NHE 2013).

It is estimated that RSLR on Humboldt Bay will reach 0.5 feet by 2030, 1 foot by 2050, 2 feet by 2075, and 3 feet by 2095 (NHE 2014). Although projecting RSLR is theoretically valid in reality, it will likely be annual extreme high tides, King tides, or extreme 10 or 100 year events that breach these dikes in multiple locations before we reach the 2 foot (1 foot RSLR plus 1 foot King tide) threshold in 2050. Average King tides on Humboldt Bay reach 8.78 feet (NAVD88) at the North Spit tide gage. Essentially we experience 1.04 feet of SLR each year for several days during the winter months. On Humboldt Bay, with 1 foot of SLR, 11 miles of the dikes could be overtopped during King tides, with 2 feet of SLR, King tides could overtop 23 miles of the dikes, but with 3 feet of SLR King tides could overtop 38 miles, 93 percent of the dikes (Figure 6, Laird 2013). If the elevation of these dikes is not raised, a significant threshold will be reached when RSLR is greater than 2.0 feet, which will likely be reached between 2050 and 2075 and 57 percent of the dikes could be overtopped during annual King Tides.

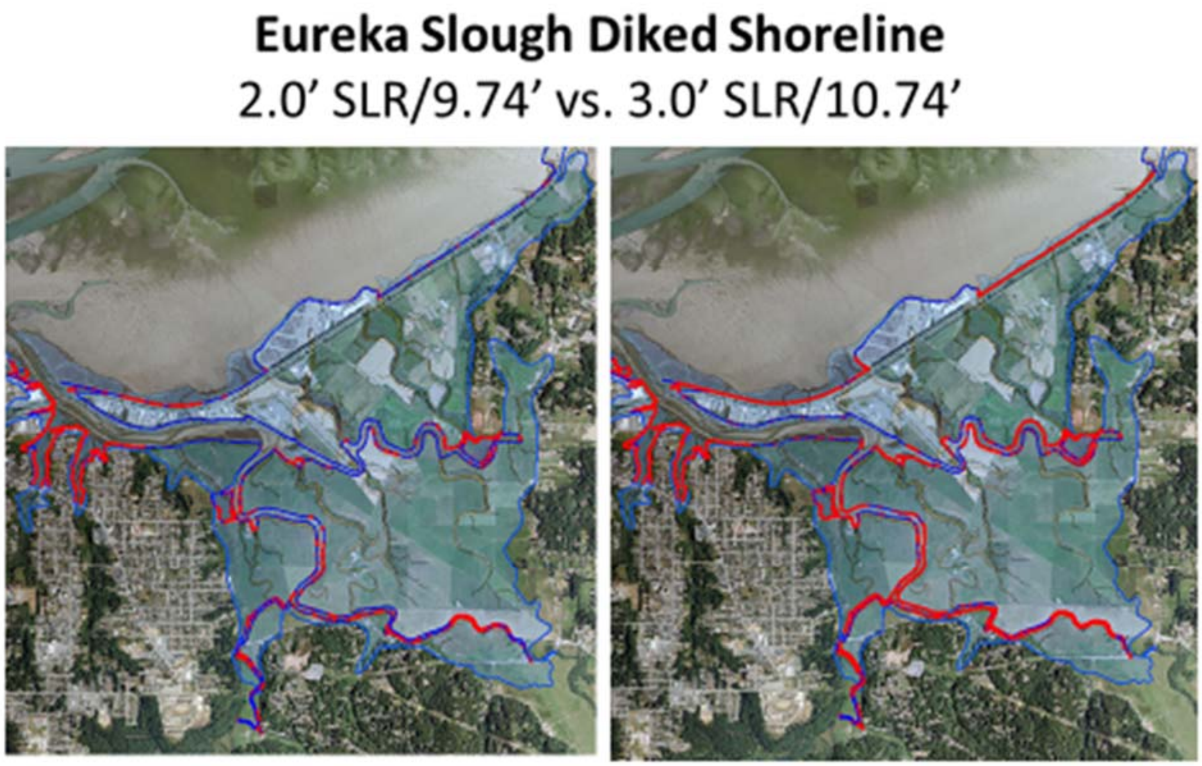


Figure 6. Diked shoreline on Eureka Slough overtopped (red shorelines) with 2.0 feet of SLR versus 3.0 feet (Laird 2013).

Vulnerability of Agricultural Lands

There are 41 miles of earthen dikes on Humboldt Bay, protecting approximately 8,000 acres of agricultural land and wildlife habitat (Figure 7, Laird 2013). Based on **current** shoreline conditions, extreme high tides and storm surges can overtop low elevation dikes, and wind waves can erode un-fortified dikes causing them to breach, resulting in flooding of former tidelands now agricultural lands with salt water.

Currently, 21 miles of diked shoreline is rated highly vulnerable due to an eroding shoreline and/or dike elevation within 2 feet of the base mean monthly maximum water (MMMW) elevation of 7.74 feet, as measured at the North Spit tide gage (Figure 8, Powell 2013). On Humboldt Bay, King Tides average 8.78 feet, and storm surges or El Nino can add another foot in water elevation above MMMW elevation; essentially 2 feet of SLR is possible under current conditions for a short duration. These conditions occurred on New Year’s eve 2005, resulting in the highest water elevation, of 9.55 feet, at the North Spit tide gage for this epoch. As a result, the Governor declared a state of emergency on Humboldt Bay and in response several miles of diked shoreline were fortified. The 21 miles of highly vulnerable diked shoreline puts thousands of acres of low lying agricultural lands at immediate risk from shoreline breaching and flooding with saltwater (Figure 9). Agricultural lands, primarily pasture, that are protected by dikes are very sensitive to saltwater flooding.

Although there are other significant cattle grazing areas in Humboldt County that are not vulnerable to SLR, the majority of the agricultural lands on Humboldt Bay are also seasonal freshwater wetlands that are critical waterfowl and shore bird habitat. It is an over simplification to assess the importance of protecting agricultural lands from salt water inundation without considering critical infrastructure assets such as: water transmission pipelines, transportation corridors, natural gas lines, and electrical transmission towers; that are located on these agricultural lands and whose sole defense against RSLR are earthen dikes.

Figure 7. Shoreline structure on Eureka Slough is predominately made of dikes (yellow) built in the 1890s to convert fomer tidelands to agricultural uses.

Figure 8. Eroded and low elevation dike shorelines are vulnerable to breaching during King tides and/or storm surges.

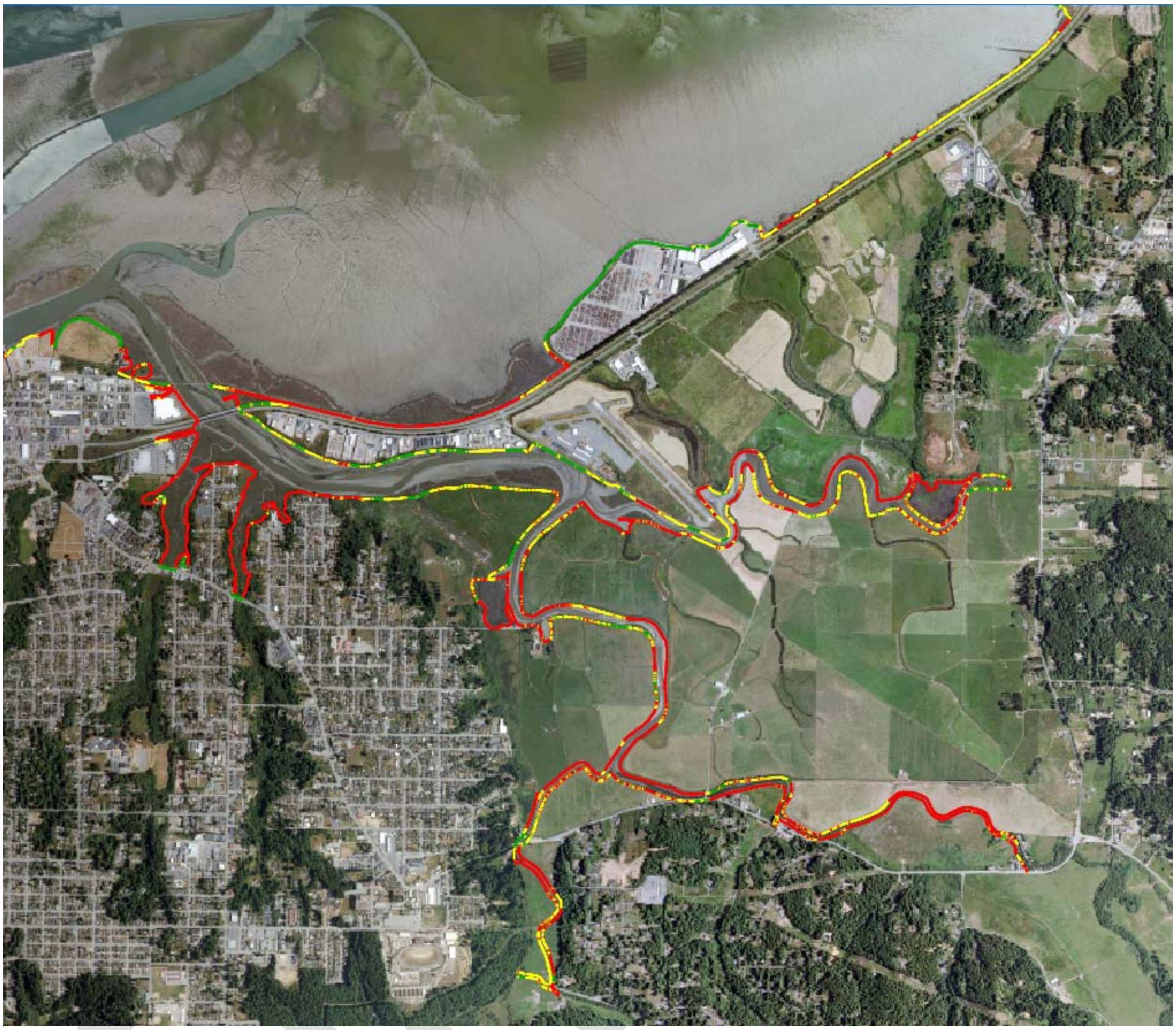


Figure 9. Shoreline vulnerability rating to erosion or overtopping on Eureka Slough: red is highly vulnerable, yellow-moderately, and green low.

With effects of up to 3 feet of compaction and 18.6 inches of RSLR over the last century, these low lying agricultural lands that are also underlain with former Bay mud, drain poorly. Surface elevation on most of these former tidelands is less than the mean high water (MHW) elevation of 5.8 feet. Draining storm water runoff from these diked former tidelands is challenging; there are 97 tide gates on Humboldt Bay (Laird 2013) and with intense rainfall these lands can become inundated for months at a time.

Diked agricultural lands are also seasonal freshwater wetlands and their pastures are important grazing areas not only for livestock but seasonally in the winter by Aleutian geese and these areas are important as waterfowl and shorebird habitat. If RSLR rates remain constant, then by 2050 the low water tidal datums could be: MLLW 1.33 feet and MLW 1.92 feet; the effectiveness of existing tide gates to drain these lands will be impaired because the percent of time that a tide gate is open and draining the land will be reduced.

Rising groundwater and salt water intrusion are two additional impacts of SLR that will affect these low lying agricultural lands and use. Unfortunately, at this time there is insufficient data to develop a spatial or temporal correlation between either of these impacts and RSLR rates. It will be difficult to adapt to these impacts, which could make existing agricultural land use impacted by SLR unsustainable.

Adaptation Strategies

Adaptation strategies can involve: education, protection, relocation, and regulation.

Education

Education is important; the results of SLR vulnerability and risk assessments must be shared with government decision-makers and staff, property owners, stakeholders, and the public regarding SLR impacts. Education is the first adaptation strategy to employ, and on Humboldt Bay at minimum, needs to convey what areas are vulnerable under existing tidal conditions and extreme events. What property, infrastructures, or services are at risk in these areas is also important information to develop and share as soon as appropriate vulnerability data and maps are available.

Protection

Protecting agricultural lands from RSLR is a viable adaptation strategy, at least in the short to mid-term time frames (2030 and 2050). Protecting agricultural lands from flooding as result of shoreline failure is physically possible; dike elevations can be increased and eroding shorelines protected with fortifications or by constructing living shorelines, but these measures may not be feasible in all areas given economic considerations based on land values versus the cost of protection. However, it is important to also consider the value or criticality of protecting non-agricultural assets that may be located on agricultural lands or assets on adjacent lands that are afforded protection from SLR by the shoreline protection on agricultural lands. For example, the City of Eureka' water transmission lines traverse agricultural lands to the east of Arcata Bay and in Eureka Slough that are protected by dikes, as does PG&E's high pressure gas line, and the diked shoreline on the right bank of Fay Slough protects Highway 101 from being flooded from the east. While flooding caused by rising groundwater can also be addressed, by raising surface elevations of agricultural lands or pumping, it may not be an economically feasible treatment of extensive acreage. Flooding can also be caused by, stormwater runoff or rising MLW elevations, but inadequate drainage capacity can be expanded, particularly if grant assistance is available to help defray the cost of enhancing or adding additional drainage structures.

Relocation

Relocation of agricultural uses from vulnerable areas as an adaptation strategy is not an option, as nearly all arable land in Humboldt County, particularly in the coastal areas, is already in agricultural production. Relocation of critical assets located on or under agricultural lands is possible or alternatively can be elevated. Ultimately, with RSLR vulnerable agricultural lands will become inter-tidal wetlands. Updating LCPs to address RSLR should guide future land use decisions that would avoid placing infrastructure, land uses, property, or services at risk from coastal hazards.

Regulation

An important adaptation strategy for agricultural lands is realizing that diked former tidelands cannot be protected on a parcel by parcel basis; where landowners who share a common dike need to hold back the tides, they must join together to protect their lands from flooding (Figure 10).

The same holds true for land use and regulatory agencies; they must authorize adaptation projects that treat entire hydrologically connected areas, not individual parcels. Humboldt Bay has six major hydrologic units: Arcata, Eureka, and South Bay, and Mad River, Eureka, and Elk River Sloughs. Further stratification of these areas for adaptation planning yields approximately 25 sub-units (Figure 11). Although there is no single entity responsible for the maintenance of dikes, there are three land use authorities whose Local Coastal Program (LCP) jurisdictions cover these agricultural lands and their diked shorelines: (1) Humboldt County, (2) City of Eureka and (3) City of Arcata. Development of SLR adaptation strategies and measures that are applicable to agricultural lands around Humboldt Bay will encourage regional compatibility when updating LCPs. Several state and federal agencies: (1) California Department of Fish and Wildlife, (2) Humboldt Bay National Wildlife Refuge, (3) U.S. Fish and Wildlife Service (USFWS), and (4) the National Resources Conservation Service (NRCS), also actively manage thousands of acres of diked former tidelands that employ livestock grazing to maintain waterfowl and shorebird habitat.

In addition, there are three regulatory agencies with jurisdiction over development activities affecting the tidal shoreline: (1) at the local level the Humboldt Bay Harbor, Recreation and Conservation District, at the state level (2) the California Coastal Commission, and (3) at the federal level the Army Corps of Engineers (ACE). Land use, land management, and regulatory authorities should adopt the basic SLR adaptation strategy of treating hydrologically connected areas as a unit, irrespective of jurisdiction, and for planning and implementing adaptation measures.

Figure 10. Adaptation to SLR cannot be implemented parcel by parcel, strategies. Measures must be developed for entire individual hydrologic sub-units.

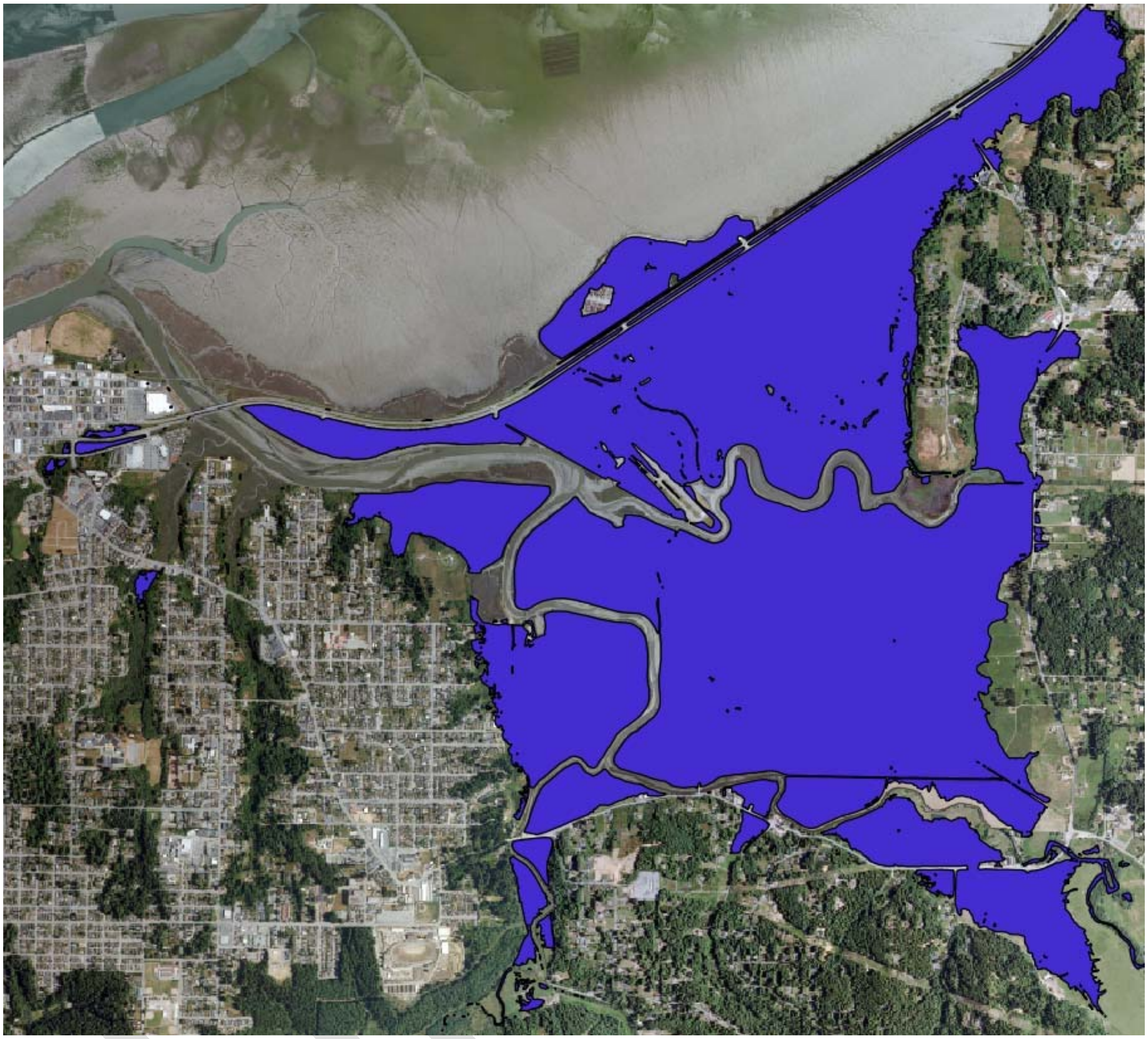


Figure 11, Areas of potential inundation, if diked shoreline were to be breached or overtopped, depicting (7) discrete hydrological sub-units within the larger Eureka Slough complex based on preliminary data from NHE 2014.

Adaptation Measures

Sustaining agricultural, wildlife, and other natural resource uses of these low lying lands will require development and implementation of adaptation measures. There are several adaptation measures that could increase the resiliency of these diked agricultural lands to SLR:

1. Dikes could be raised 2 or 3 more feet; however this may require expanding the footprint of the dike onto the agricultural lands, which are also seasonal freshwater wetlands, unless the dike faces can be steepened with fortification.

2. Where diked shoreline reaches are exposed to wind generated waves, the dike could be relocated inland and salt and freshwater marsh plains could be created in front; the living shoreline would provide protection for the dike.
3. Retrofitting top hinged tide gates with side hinged tide gates and enlarging the diameter of the inlet culvert can increase the efficiency of the water control structure to drain flooded agricultural lands through a greater range of tidal elevations. Adding more tide gates can also increase the amount of drainage during a tide cycle.
4. Importing clean fill material to raise the surface elevation of compacted and subsided agricultural lands would make these lands much more resilient to rising groundwater and rising MLW and MLLW elevations.
5. Because multiple landowners need to be involved in these sub-units, to successfully implement adaptation measures, regulatory integration will be necessary. The NRCS and USFWS have programs that assist local agricultural landowners to sustain agricultural practices and protect wildlife habitat. These federal agencies could develop a Memorandum of Agreement with the ACE to authorize activities sanctioned by the Services to increase the resiliency of agricultural lands facing the impacts of SLR. The agricultural areas that are vulnerable to RSLR on Humboldt Bay are subject to both the California Coastal Act and Federal Coastal Zone Management Act. Therefore, Services could also prepare a general consistency determination (CD) for the Coastal Commission's concurrence to authorize placement of fill on diked former tidelands as an adaptation measure for sustaining: agricultural practices and wildlife habitat in response to RSLR. The proposed CD and these physical adaptation measures would enable property owners to increase the adaptive capacity of their agricultural lands, possibly sustaining agricultural uses and wildlife habitat.

Given the current projected rate of RSLR on Humboldt Bay, if these adaptation measures were implemented, the sustainability of agricultural lands on former tidelands could be extended to support agricultural and wildlife uses to 2050 (1 foot RSLR) or even 2075 (2 feet RSLR). Ultimately, when the Bay reclaims these former tidelands, it will be much more likely that former agricultural lands with raised surfaces will convert to salt marsh rather than mud flat.

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