HUMBOLDT BAY

Shoreline Inventory, Mapping and Sea Level Rise Vulnerability Assessment

Aldaron Laird
Trinity Associates

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Prepared for

State Coastal Conservancy
1330 Broadway, 13th Floor
Oakland, CA 94612-2530

Prepared by

Aldaron Laird
Trinity Associates
980 7th Street, Suite K
Arcata, CA 95521

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Humboldt Bay Sea Level Rise Adaptation Planning Project:

Phase 1
Shoreline Inventory, Mapping, and Vulnerability Assessment

By:

Aldaron Laird
Senior Environmental Planner
Trinity Associates

Brian Powell
GIS Specialist
McBain and Trush

Jeff Anderson
Professional Engineer
Northern Hydrology and Engineering

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Cover photograph of Wiyot Tribe's world renewal ceremonial site, Tuluwat, during a King Tide.

The Birth and Growth of Humboldt Bay
in
Indian Lore of the North California Coast
by
Austen D. Warburton and Joseph F. Endert

1966

A long time ago there was a small grassy pool located where Humboldt Bay [Wigi] now lies. In this pool there were many frogs, so many that there was not food enough for all of them. They became very hungry and talked loud and long at night, calling to their friends, the Indians, for help. In those days there was great friendship between the two peoples.

There was an old man commonly known as May-wee-Mur. May-wee-Mur went to the see what was troubling the frogs after hearing them talk so much at night. The frogs told him that they wanted a bigger pool where there would be more food. May-wee-Mur told them that he would try to find such a pool, and in return the frogs said that they would help him. They told the old man that a deer had passed that way going to the ocean to lick salt off the rocks. The old man had his bow and quiver full of arrows with him, and headed for the ocean.

When the old man came near the ocean he saw the deer licking the rocks, and the old man was able to kill it with his first arrow. While May-wee-Mur was dressing the deer, Ka-Ha-mis, the Water Spirit, came close to shore in the breakers near where the old man was. Ka-ha-mis said: "I am very hungry. The sea has been so rough I have not been able to get any food. If you will give me the deer I will do much for you in your life time."

The old man was sorry for Ka-ha-mis as he, too, knew what hunger was in his younger life, and he gave the deer to the Water Spirit.

In those days the Indians used to hunt sea lions for food on the rocks toward Trinidad, and when one would be killed the carcass of the animal would be towed in the water behind the Indian's sea going canoe to the place where the entrance to Humboldt Bay now is. The carcass was there dragged across the sand and over swampy land to the place where the Indian village was located. This required a great deal of effort and consumed a great deal of time. When Ka-ha-mis saw how hard the Indians had to work to get their food, he was sorry for them. He also wanted to show his appreciation to May-wee-Mur, and decided to help the Indians.

Kah-ha-mis went to the little pond and thrashed around with his great strong body many times, until it grew to its present size. He then had to connect it with the ocean. To do this he had to thrash his way back and forth between the bay and the ocean many times before he had a channel wide and deep enough for ocean going canoes to travel freely. A great earthquake occurred and a tidal wave came which further widened the entrance to the bay now known as Humboldt. Ever since the Indians had no trouble in bringing the sea lions and their canoes right up to their village. Thus, for the old man's kindness to Kah-ha-mis he was repaid many times. "It is always that way," say the Indian grandmothers.

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Chapter 1 Introduction

In 2008, Governor Schwarzenegger issued Executive Order S-13-08 which identified the necessity to plan for and adapt to sea level rise. In response, the State Coastal Conservancy (SCC) authorized funding for a multi-phase sea level rise adaptation planning effort for Humboldt Bay. The Humboldt Bay Inventory, Mapping, and Sea Level Rise Vulnerability Assessment Project is the first phase of this effort.

The purpose of this project is to:

- inventory and map existing shoreline conditions on Humboldt Bay,
- assess existing shoreline vulnerability to breaching or overtopping, under current tidal and climatic conditions,
- assess existing shoreline vulnerability to sea level rise,
- identify land uses and infrastructure that could be affected if the existing shoreline fails to retain the tides.

This project is needed because:

- a comprehensive inventory and mapping of artificial shoreline structure, cover, and elevation, does not exist for Humboldt Bay,
- in the last decade, state declarations of emergency and shoreline breaching and overtopping illustrate the vulnerability of existing shoreline structures which has resulted in salt water flooding of lands behind these structures,
- during this century, global sea levels are predicted to rise at an increasing rate; conservative estimates are 6 inches by 2030, 12 inches by 2050, and 36 inches by 2100 (Griggs 2012),
- relative sea level rise rates may be greater on Humboldt Bay because of tectonic subsidence of the land and compaction of former tidelands.

This project will create a GIS database containing geo-spatial data of Humboldt Bay's shoreline. The database will build upon existing inventories of water control structures such as tide gates and culverts, and distribution of salt marsh. Chapter 2 will describe the methods employed to inventory and map the shoreline. Chapter 3, based upon the results of the inventory and mapping, will describe existing shoreline conditions of structure, cover, and elevation. Chapter 4 contains a vulnerability assessment of existing shoreline conditions under current tidal and climatic conditions as well as to rising sea levels. Chapter 5 summarizes the project's findings and vulnerability assessment along with recommendations on subsequent phases of the sea level rise adaptation planning for Humboldt Bay.

a) Humboldt Bay Shoreline Changes/Historical Context

Historically, the original U.S. Surveyor General Township Plats of 1854 depicted Humboldt Bay as occupying approximately 25,800 acres, of which 15,300 acres (59.3 percent) were tidal channels and inter-tidal mudflats, and 10,500 acres (40.7 percent) were inter-tidal wetlands, salt marsh (Laird 2007). Today, salt marsh occupies just 4 percent of Humboldt Bay (Barnhart 1992). Between 1890 and 1910, Humboldt Bay underwent a dramatic change on the scale that we perhaps now face with sea level rise. A comparison of the 2009 shoreline location with that depicted in the 1870 US Coast and Geodetic Survey (USCGS) of Humboldt Bay, serves to illustrate the magnitude of change to the Bay (Figure 1). Nearly 90 percent of the salt marsh (8,100 acres) was diked and drained for agricultural uses or walled off from tidal inundation with the construction of the Northwest Pacific Railroad (Pickart 2006). Over the last century, with the loss of sediment accretion from daily tidal inundation, these former tidelands have compacted as organic material has decomposed. Also, subsidence is occurring and has been recorded at the North Spit tidal station. Humboldt Bay has the highest rate of sea level rise (18.6 inches per century) in California (Russell 2012). Today, the result of compaction and subsidence is that former tidelands behind dikes are lower in elevation than the Bay and high tides. Absent a tide water flood model based on existing conditions, the former tideland footprint surveyed in 1870 will be considered, at a minimum, the potential inundation zone for this project vulnerability assessment.

Figure 1, 1870 USCGS survey of Humboldt Bay, with 1870 shoreline (blue) and 2009 shoreline (red for artificial and green for natural) serves to illustrate the magnitude of change to the Bay.

b) Humboldt Bay Shoreline Survey

For purposes of this vulnerability assessment, because rising tides do not recognize property boundaries; Humboldt Bay has been segregated into six individual hydrologic units: Arcata Bay, Eureka Bay, South Bay, Mad River Slough, Eureka Slough, and Elk River Slough (Figure 2). The shoreline of Humboldt Bay is defined as the boundary between the upper reach of the tidal zone and adjacent upland, often visible as the boundary between salt tolerant vegetation versus freshwater vegetation. On natural shorelines the tidal boundary was found to be closely associated with the mean monthly maximum water (MMMW) surface elevation in Humboldt Bay, which is the average of the maximum measured tide levels each month. The MMMW tide elevation is 7.74 feet (all elevations used in this report are referenced to the North American Vertical Datum of 1988 (NAVD 88) at the North Spit tide gage (National Oceanic and Atmospheric Agency (NOAA) Station 9418767). Utilizing geographic information system (GIS) software, the shoreline was first digitized and segmented based upon physical attributes on 2009 aerial photography; then the entire shoreline of Humboldt Bay was ground truthed to verify shoreline location, attributes, and segment boundaries. The GIS shoreline layer has been updated to reflect field observations. Lastly, NOAA coastal light direction and ranging (LiDAR) data from 2010 and a three dimensional tidal grid of the MMMW surface elevation (Anderson 2012) were utilized to re-align the digitized natural shoreline, if needed, where the vegetative boundary was difficult to discern or non-existent.

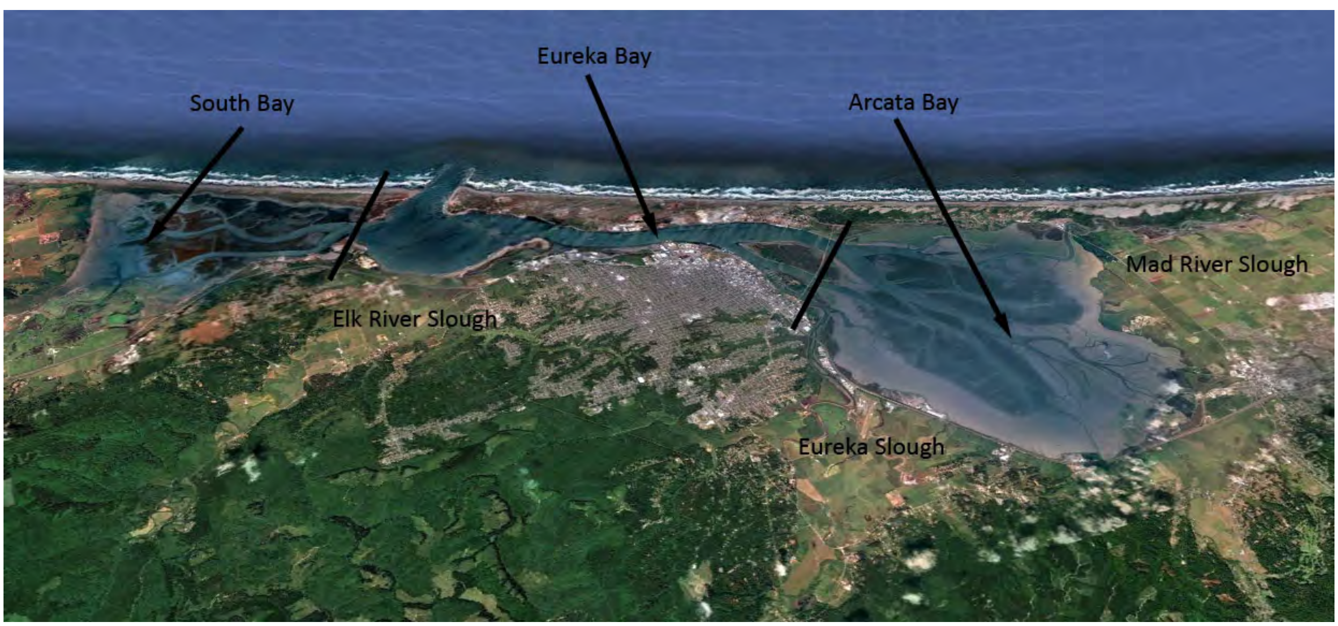

Figure 2, Humboldt Bay's hydrologic units (Google 2012).

c) Humboldt Bay Shoreline Vulnerability Assessment

Sea level rise adaptation planning should begin with a vulnerability assessment (Griggs 2012). This project's vulnerability assessment focuses upon the shoreline of Humboldt Bay and its resiliency to coastal hazards such as erosion and flooding under current and future sea levels. The current shoreline of Humboldt Bay, especially its dikes, have never been comprehensively inventoried or mapped. Creation of a baseline of existing shoreline conditions will facilitate assessment of the current vulnerability of the shoreline and the flooding risk of lands, uses, and infrastructure on former tidelands, if nothing is done to rehabilitate or enhance the existing shoreline conditions.

As mentioned earlier, global or eustatic sea levels are predicted to rise at an increasing rate during this century; conservative estimates of sea level rise are 6 inches by 2030, 12 inches by 2050 and 36 inches by 2100 (Griggs 2012). However, relative sea level is subject to change if land levels fall (National Research Council (NRC) 2012). Based upon the North Spit tide gage record, since 1977, Humboldt Bay is subsiding and its average rate of relative sea level rise, 4.72 mm/yr (18.6 inches per century), is greater than anywhere else in California (Russell 2012).

El Nino events with elevated water temperatures can also increase sea levels for several winter months by as much as 1 foot. On Humboldt Bay during the El Nino events of 1983, the winter extreme high tide (EHT), known as King Tide, was 9.38 feet and in 1998, it was 9.07 feet. Since 2000, King Tides during seven of the last twelve years have exceeded the average EHT of 8.79 feet at the North Spit tidal station, with the highest tide reaching 9.55 feet. In 2003, the EHT combined with a storm surge reached 9.51 feet, breaching an un-fortified earthen dike on Mad River Slough flooding nearly six hundred acres of pasture (Figure 3). In 2006, the maximum high tide after a period of heavy rainfall reached 9.49 feet and Arcata Bay's northern diked shoreline and City of Arcata's wastewater treatment ponds and marsh dikes were over topped in multiple locations (Figure 4). In response to a combination of a storm surge and EHT shoreline damages, the Governor, in 2006, declared a state of emergency on Humboldt Bay. Emergency dike repairs were authorized at least five locations (Reclamation District 768-Mad River Slough & Arcata Bay, City of Arcata-Arcata Bay, California Redwood Company-Arcata Bay, North Coast Railroad Authority (NCRA)-Eureka Bay, and Humboldt Bay National Wildlife Refuge (HBNWR)-South Bay). In 2010, the maximum high tide reached 8.94 feet and a dike on Fay Slough, a tributary to Eureka Slough, was overtopped flooding 16 acres of state wildlife refuge (Figure 5). This project will identify shoreline areas that are currently in an eroded state and are vulnerable to breaching and shoreline areas of low elevation that are vulnerable to being overtopped by EHT with or without the effects of El Nino. This project will also identify shoreline areas that are vulnerable to overtopping at MMMW and EHT and with sea level rise if existing conditions persist.

Figure 3, 2003 breach on Mad River Slough, 9.51 foot tide and storm surge (Times Standard, Andrew Bird, January 26, 2004).

Figure 4, 2006, the maximum high tide after a period of heavy rainfall reached 9.49 feet and Arcata Bay's northern diked shoreline and City of Arcata's wastewater treatment ponds and marsh dikes were over topped in multiple locations.

Figure 5, 2010, the maximum high tide reached 8.94 feet and a dike on Fay Slough, a tributary to Eureka Slough, was overtopped flooding 16 acres of state wildlife refuge.

Chapter 2 Description of Shoreline Inventory and Mapping Methods

The intent of this shoreline inventory and mapping is to create a GIS database containing spatial data on the location of the tidal/upland boundary and distribution of shoreline attributes. As described previously, a unique aspect of this inventory and mapping effort is that the entire 102 miles of shoreline was ground truthed to verify shoreline location, attributes, and segment boundaries. In 2012, NOAA released a LiDAR dataset which was utilized to establish shoreline elevations. USFWS 2007 water control structure survey and NOAA's 2009 benthic habitat GIS databases for Humboldt Bay have been incorporated and expanded in this project's database. This project's database should be updated as new shorelines are created or existing shoreline conditions are modified.

The inventory and mapping of existing shoreline conditions on Humboldt Bay contains three elements: structure, cover, and elevation. The presence of water control structures and salt marsh are also included. A GIS database containing spatial data of existing shoreline conditions has been created for these five attributes. These attributes were selected to quantify existing conditions and to support a vulnerability assessment of existing shoreline conditions and various sea level scenarios.

This project utilized 2009 color aerial photography that has been orthorectified and geo-referenced to real word coordinates (UTM Nad 83 meters). Through photographic interpretation, the tidal/upland shoreline was digitized on the 2009 aerial photography. Aerial photograph/map sheets, 11x17 at a scale of 1" = 200', covering the entire perimeter of each hydrologic unit, were printed and used in the field to ground truth the computer based shoreline delineation and photographic interpretations of shoreline attributes and segment boundaries (Figure 6). Changes to shoreline location, segment attributes, or unit boundaries, were corrected directly on the map sheets. Following ground truthing, GIS databases were updated. Digital photographs were taken to record conditions at each shoreline unit and the boundary between units.

Historical maps (1854, 1870, 1890, 1916, 1921, 1933, and 1942) and aerial photography (1948, 54, 58, 65, 70, 81, and 88) from the 2007 Digital Historical Atlas of Humboldt Bay and Eel River Delta (Laird 2007) were incorporated into this project's GIS database to facilitate interpretations of historical changes in shoreline conditions and location such as placement of fill (Figure 7).

The shoreline was segmented; individual units were delineated based upon changes in physical attributes of type, structure, cover, and whether salt marsh habitat is present (Table 1). Initial attributes of structure and cover, developed during interpretation of aerial photographs, were augmented as new attributes where encountered during ground truthing. The list of attributes below is represented by at least one shoreline segment.

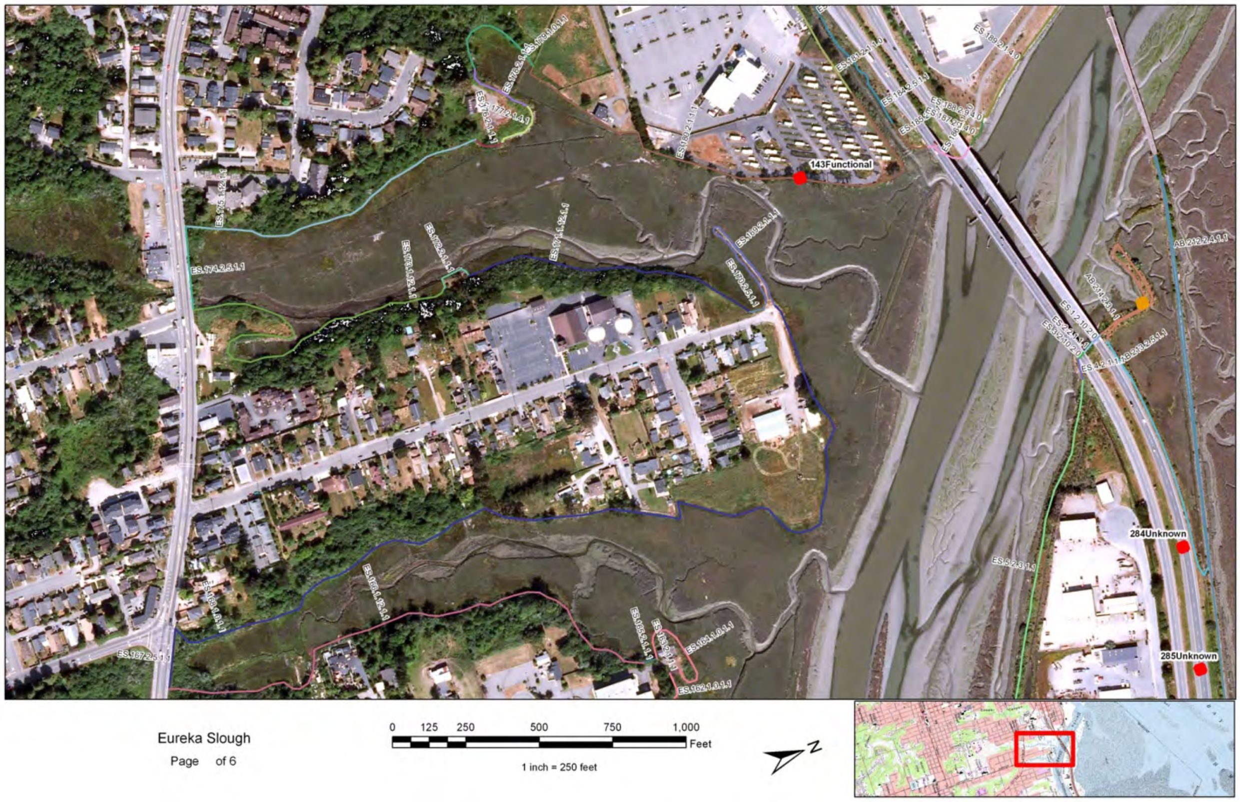

Figure 6. Example of aerial photograph/map sheets used during ground truthing the computer based shoreline delineation and photographic interpretations of shoreline attributes and segment boundaries.

Figure 7. Comparison of 1948 and 2009 aerial photographs documents the placement of fill in Mad River Slough, current shoreline depicting artificial (red) and natural (green) segments.

ATTRIBUTES					
Level 1	Level 2	Level 3	Level 4	Level 5	Level 6
Area	Segment	Type	Structure	Cover	Salt Marsh
MRS	Unit #	Natural-1	None-0	None-0	None-0
AB		Artificial-2	Fill-1	Vegetated-1	Salt Marsh-1
ES			Fortified-2	Exposed-2	Brackish Marsh-2
EB			Dike-3	Rock-3	
ERS			Railroad-4	Concrete-4	
SB			Road-5	Wood-5	
			Bulwark-6	Steel-6	
			Building-7	Rock/Concrete-7	
			Pond-8	Asphalt-8	
			Boat Ramp-9		
			Bridge Abutment-10		
			Tidegate-11		
			Cliff/Bluff-12		
			Fore Dune-13		
			Jetty-14		

Table 1. Hydrologic unit codes and attributes used to delineate and identify individual shoreline units.

The following is an example of shoreline segment identification code, which is unique to that unit.

- MRS.8.2.3.3.0
  - MRS = Mad River Slough hydrologic unit
  - 8 = Sequential segment number
  - 2 = Artificial shoreline type
  - 3 = Dike structure
  - 3 = Rock cover
  - 0 = Salt marsh not present

a) Shoreline Structure

Shorelines are either natural or artificial. Artificial shorelines are composed of man-made structures that, without maintenance, may fail to serve the function that they were constructed to serve. Shoreline structures can either armor or harden an existing natural shoreline or create a new shoreline where none existed previously. The following definitions were utilized to describe the types of shoreline structures encountered:

Type:

- Natural

A shoreline that appears natural and when there is no historical evidence of the shoreline having been artificially manipulated (Figure 8).

Figure 8. West side of South Bay is an example of a natural shoreline.

- Artificial.

A shoreline that is composed of a man-made structure, or in the case of *fill,* where there is historical evidence of the Bay having been artificially filled (Figure 9).

Figure 9. West side of Eureka Bay, the Coast Guard station is an example of a man-made or artificial shoreline.

Structure:

- None.

A shoreline with no structure is a natural shore or slough bank that is neither a cliff/bluff nor a fore dune (Figure 10).

Figure 10. Eureka Bay is an example of a shoreline with no structure eroding on Humboldt Bay.

- Fill.

A new shoreline created by filling the Bay or former inter-tidal wetlands with soil or other materials; placement of fill is established by reviewing historical maps or aerial photographs.

- Fortified.

A natural shoreline structure, which has been armored with revetment, is a fortified shoreline.

- Dike.

An earthen wall-like structure constructed to prevent tides from inundating land behind the dike (Figure 11). Most dikes on Humboldt Bay were constructed at the inter-tidal boundary between mudflats and salt marsh; lands behind the dikes were drained and converted to agricultural uses.

Figure 11. Hookton Slough on South Bay is an example of an earthen dike with rock revetment and roadway that is being maintained.

- Railroad.

Generally a trapezoidal fill prism constructed to support rails for use by trains to transport materials and people (Figure 12). Most of the railroad grade traverses former inter-tidal areas and railroad grades provide similar protection to landward areas as do dikes on Humboldt Bay. At this time the railroad has not been used commercially for more than a decade and much of the railroad grade has not been maintained.

Figure 12. West-side of Arcata Bay is an example of the railroad grade on Humboldt Bay with rock revetment.

- Road.

A road is a transportation corridor generally surfaced with asphalt; most often publicly owned and maintained (Figure 13).

Figure 13. Arcata Bay, State Highway 255 is an example of a roadway forming the shoreline on Humboldt Bay.

- Bulwark.

A bulwark is a solid wall generally constructed of wood, concrete, or steel to protect the land behind from wave induced erosion (Figure 14).

Figure 14. Eureka Bay is an example of a concrete bulwark forming the shoreline of Humboldt Bay.

- Building.

A structure forms the shore which is made up of a building or its foundation (Figure 15).

Figure 15. Eureka Bay is an example of a building and its foundation forming the shoreline of Humboldt Bay.

- Pond.

A pond is a type of dike that is constructed to enclose and protect an aquatic environment such as in a waste water treatment facility rather than former inter-tidal lands (Figure 16).

Figure 16. Arcata Bay is an example of a wastewater treatment pond forming the current shoreline of Humboldt Bay.

- Boat Ramp.

A boat ramp is a structure traversing the shore to allow boats to enter or exit the water (Figure 17).

Figure 17. City of Eureka marina is an example of a boat ramp forming the shoreline of Humboldt Bay.

- Bridge Abutment.

An abutment is a footing structure that supports one end of a bridge spanning a water body (Figure 18).

Figure 18. Eureka Slough is an example of a bridge abutment forming the shoreline of Humboldt Bay.

- Tidegate.

A tidegate is a water control structure, often set in a concrete wall-like structure, which enables the land behind a dike to drain on an ebbing tide but closes to prevent tidal inundation on a rising tide (Figure 19).

Figure 19. Elk River Slough is an example of a tidegate forming the shoreline of Humboldt Bay.

- Cliff/Bluff.

A cliff or bluff is a type of natural shoreline structure which is nearly vertical, formed by wave induced erosion or tectonic activity (Figure 20).

Figure 20. Table Bluff on South Bay is an example of a cliff/bluff forming the shoreline of Humboldt Bay.

- Fore dune.

A fore dune is a type of natural shoreline structure made up of a ridge of sand parallel to the shoreline that rises above mean high water elevation and is generally vegetated with plants tolerant of sand and salt spray (Figure 21).

Figure 21. Elk River Spit on Eureka Bay is an example of a fore dune forming the shoreline of Humboldt Bay.

- Jetty.

A structure, generally made of rock, that extends out into a body of water to influence the current or tide to protect the shore (Figure 22).

Figure 22. King Salmon on Eureka Bay is an example of a jetty forming the shoreline of Humboldt Bay.

b) Shoreline Cover

The following definitions were utilized to describe shoreline cover:

- None.

An absence of shore cover generally associated with a natural shoreline with no structure or an area of fill, without vegetation, that is not fortified or eroding (Figure 23).

Figure 23. Elk River Spit on Eureka Bay is an example of a shoreline with no cover on Humboldt Bay.

- Vegetated.

A vegetated shore is predominately covered with vegetation (Figure 24 a and b).

Figure 24a. Mad River Slough is an example of a shoreline with vegetated cover that is gazed on Humboldt Bay.

Figure 24b. Fay Slough is an example of a shoreline with vegetated cover that is not grazed on Humboldt Bay.

- Exposed.

An exposed shore is one that is generally vertical and eroding and is without vegetation or armorment (Figure 25).

Figure 25. Mad River Slough is an example of contrasting shorelines one that is exposed and the other with concrete revetment on Humboldt Bay.

- Rock.

A shore fortified with rock revetment (Figure 26).

Figure 26. Eureka Bay is an example of a shoreline with rock revetment on Humboldt Bay.

- Concrete.

A shore fortified with broken concrete revetment or a structure constructed of concrete (Figure 27).

Figure 27. Arcata Bay is an example of a shoreline that is covered with concrete revetment on Humboldt Bay.

- Wood.

A shoreline structure constructed of wood (Figure 28).

Figure 28. Eureka Bay is an example of a shoreline that is covered by a wood bulwark on Humboldt Bay.

- Steel.

A shoreline structure constructed of steel (Figure 29).

Figure 29. Mad River Slough is an example of a shoreline that is covered by a steel bulwark on Humboldt Bay.

- Rock/Concrete.

A shore fortified with rock and broken concrete revetment (Figure 30).

Figure 30. Arcata Bay is an example of a shoreline that is covered by a rock and concrete revetment on Humboldt Bay.

- Asphalt.

A shoreline covered in asphalt such as along a roadway.

c) Shoreline Elevation

In early 2012, the NOAA Coastal LiDAR dataset became available as a “hydro-flattened bare earth” digital elevation model (DEM). The LiDAR dataset reflects field conditions of 2010. Metadata provided with the DEM reported a vertical accuracy RMSE less than or equal to 18 centimeter (cm) and a horizontal accuracy of 50 cm RMSE or better. Brian Powell, GIS Specialist with McBain and Trush took a subset of the LiDAR DEM that included all portions of the Humboldt Bay shoreline (Figure 31). A contour layer was derived from the DEM and the DEM was color coded in 0.5 meter elevation increments. Digitized artificial shoreline segments were realigned with the contours and color coded DEM to ensure that the segments were aligned with the structures which they represent.

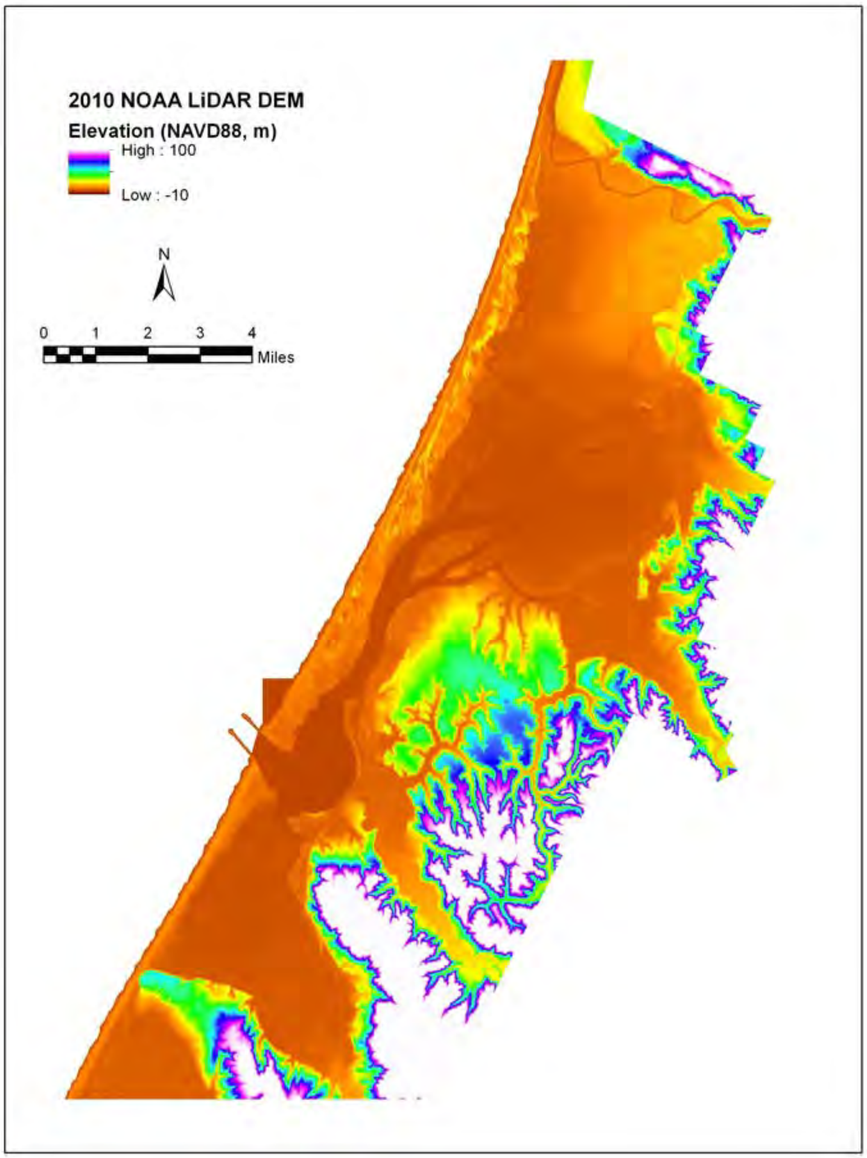

Figure 31. Humboldt Bay Lidar digital elevation model used in this project, NOAA 2012.

Generally twice a month, the Sun, Moon, and Earth align at the new moon and full moon phases. At these phases, the tidal force of the Sun and Moon is at its maximum, and the higher tides are known as spring tides, as in a rising spring, not the season. The average of the monthly maximum high tide, MMMW, was selected as the baseline water surface elevation to describe existing shoreline elevations and to assess the vulnerability of the shoreline.

Jeff Anderson, P.E. of Northern Hydrology and Engineering, prepared a DEM of Humboldt Bay representing water surface elevations of the present day MMMW surface (Figure 32). The MMMW surface was subtracted from the LiDAR DEM to produce a third DEM of relative elevations to the MMMW. These relative elevations were assigned to the shoreline segments at one meter spacing as the DEM is comprised of a one meter pixel resolution. The 1 meter spaced vertices of the shoreline segments were exported to a 3D point feature class. The shoreline segments were then broken at each vertex to produce 170,666 1 meter shoreline segments which all contained the original unique segment identifier, shoreline attributes, and start and end relative elevation values in the attribute table. An average relative elevation was calculated for each one meter shoreline segment and used as the basis for analysis. Identifying the location of the MMMW elevation for those reaches with natural shoreline segments verified or adjusted shoreline locations that relied on a demarcation between salt marsh and upland or freshwater wetland vegetation.

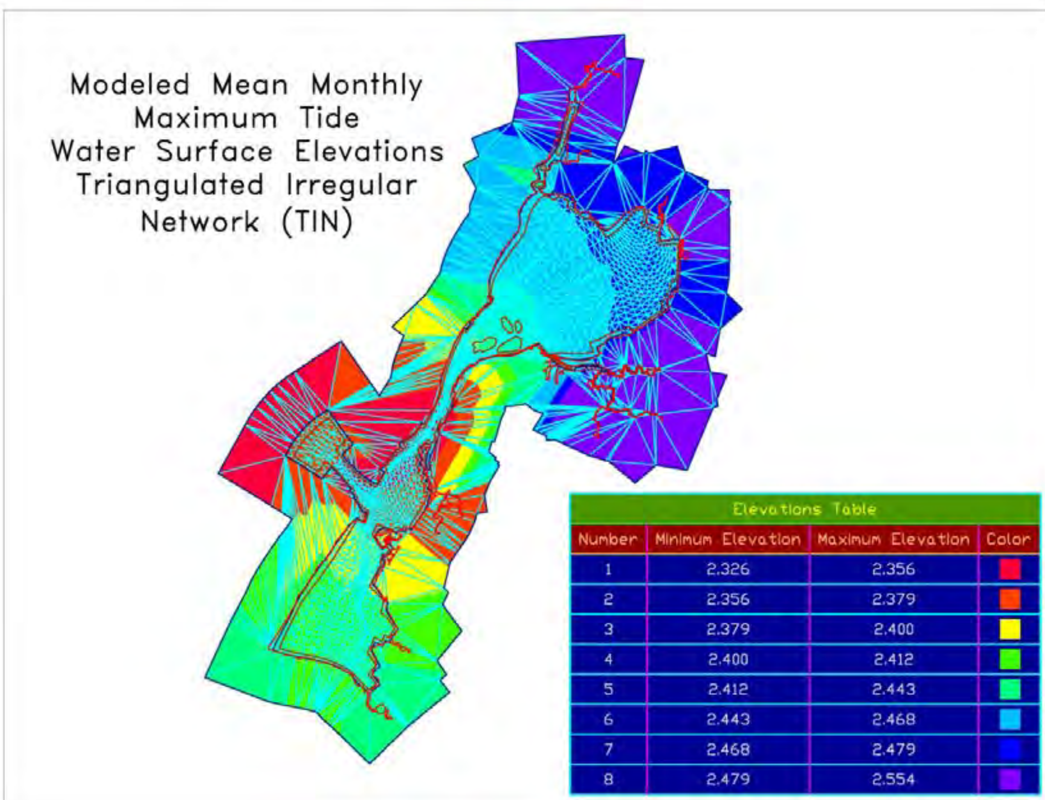

Figure 32. A DEM of Humboldt Bay representing water surface elevations of the present day MMMW surface.

d) Salt Marsh

In 2006, the SCC and its partners conducted the "Northern California Coastal Conservation Needs Assessment," which highlighted the need for coastal and marine spatial data to protect resources and support ecosystem-based management (EBM). EBM program partners described and evaluated the inter-tidal and sub-tidal habitats of Humboldt Bay. Their work was greatly aided by acquiring high-resolution multispectral imagery in 2009, from which they generated a benthic habitat data set of the Bay and Estuary. Salt marsh was one of seven benthic habitats that were mapped (Figure 33).

Figure 33. NOAA's Coastal Services Center's, Humboldt Bay 2009 GIS database of salt marsh habitat distribution on Humboldt Bay.

NOAA's Coastal Services Center's Humboldt Bay, California Benthic Habitats 2009 GIS database of salt marsh habitat distribution was incorporated into this project's GIS database. The area of coverage for the 2009 salt marsh survey was up to mean high water elevation on the shoreline of Humboldt Bay. Salt marshes behind dikes or water control structures were not included in the 2009 survey. Areas of salt marsh habitat that were not mapped by NOAA in 2009 but were located during the ground truthing phase of the shoreline inventory and mapping effort have been identified on a separate GIS layer. The extent of salt marsh habitat in these previously un-mapped areas has not been delineated.

Whether salt marsh habitat was present and attached to the shoreline was one of the attributes used to stratify shoreline segments. Narrow benches on earthen dikes are a common feature that has formed as result of cattle traversing dikes; these benches are often occupied by salt marsh vegetation. An arbitrary threshold was established of a minimum width of four feet of salt marsh for shoreline mapping purposes (Pickart pers. comm. 2011).

e) Water Control Structures

The USFWS conducted a comprehensive water control structure inventory, assessment, and mapping, of Humboldt Bay (Goldsmith 2007). The survey of culverts and tidegates controlling drainage to Humboldt Bay identified the location and function of these water control structures. The original diking and draining of former tidelands around Humboldt Bay, for agricultural purposes, required the installation of tide gates. The construction of railroads, highways, and streets, required the installation of culverts or bridges at the numerous streams or slough crossings around the Bay. These structures are owned and maintained by a multitude of private, local, state, and federal, agencies. The USFWs created a GIS database containing spatial data for all tidegates, culverts, and other water control structures, surrounding Humboldt Bay (Figure 34). The USFWS incorporated existing datasets and also conducted site visits to locate and assess water control structures. The USFWS water control database includes a total of 371 structures; 164 structures were field inventoried by USFWS, and the remaining 207 structures were imported from existing datasets. A total of 79 tidegates and 282 culverts were identified, as well as 10 other structures, principally splash board weir structures. The USFWS water control GIS database has been incorporated into this project's database.

While delineating the shoreline on the 2009 aerial photography, potential water control structures not previously mapped in 2007 were identified where drainage channels emanated from shoreline structures such as dikes into the Bay (Figure 35). During ground truthing of the shoreline, inventory and mapping the existence of these potential water control structures was either confirmed or denied. Confirmed water control structures location and type were identified on the field aerial photo sheets, photographed, and measurements taken, when possible, of the structure. A new layer in the GIS database contains the location and attributes of these newly located water control structures.

Figure 34. USFWS's 2007 GIS database, distribution of water control structures on Humboldt Bay.

3. Description of Existing Shoreline Conditions

The shoreline inventory and mapping has produced a comprehensive geo-spatial baseline of existing conditions: structure, cover, and elevation. This baseline also updates USFWS' 2007 database of the distribution of water control structures and NOAA's 2009 database of the distribution of salt marsh habitat. It is now possible to quantify shoreline conditions on Humboldt Bay as well as for each of the six hydrologic units that make up Humboldt Bay. With this database it is possible to locate shoreline units with specific characteristics such as the type of structure, cover, and elevation. The inventory and mapping data of shoreline attributes of structure, cover, and elevation will be summarized for Humboldt Bay in its entirety, and for the six hydrologic units.

a) Shoreline Structure

Humboldt Bay:

The perimeter of Humboldt Bay in 1870, as surveyed by the USCGS, was 60 miles, and today it is 102 miles in length. The two basic structural types are natural and artificial. The variety of shoreline structures on Humboldt Bay is impressive; dune and forest ecosystems, natural bluffs that form the linear southern boundary of the Bay, Elk River Spit and its fore dunes and salt marsh extending out into the shipping channel, miles of earthen dikes protecting vast areas of agricultural lands and wildlife refuges, a neglected railroad grade along much of the east shore of South, Eureka, and Arcata Bays and the west shore of Arcata Bay, working docks and fortified waterfront on Eureka Bay, two marinas, an imposing rock rip rap wall facing the harbor entrance and protecting the PG&E power plant, abandoned waterfronts at Fields Landing, Fairhaven, and Samoa, waste water treatment ponds, wildlife marshes, dense residential areas along the canals of King Salmon and First and Second Sloughs in Eureka, and the new boardwalk in Eureka.

Individual hydrologic units ranked by percent of Humboldt Bay's shoreline length:

- South Bay 21.3%
- Eureka Slough 20.3%
- Arcata Bay 20.0%
- Eureka Bay 15.5%
- Mad River Slough 13.4%
- Elk River Slough 9.5%

The shoreline is composed of 959 discrete segments; 75% of the shoreline is made up of artificial structures (76.7 miles) and 25% is natural (25.7 miles) (Figure 35) (Table 2). It is significant that 75% of the shoreline is artificial. Much of the artificial shoreline is over 100 years old. Artificial structures need to be maintained in order to retain their integrity and protect land uses and infrastructure behind these structures; particularly in the case of dikes, where lands reclaimed from the Bay are now lower in elevation than the daily high tides.

Figure 35. Humboldt Bay shoreline structure: 75% is artificial (red) and 25% is natural (green).

SHORELINE TYPE		ARCATA BAY	EUREKA BAY	SOUTH BAY	MAD RIVER SLOUGH	EUREKA SLOUGH	ELK RIVER SLOUGH	TOTAL FEET	TOTAL MILES	TOTAL PERCENT
Artificial	**Length (ft)**	98,619	59,772	78,132	57,623	87,834	22,829	**404,810**	**77**	**75%**
	Percent	91.2%	71.2%	67.8%	79.9%	80.1%	44.6%			
Natural	**Length (ft)**	9,486	24,131	37,122	14,508	21,854	28,396	**135,498**	**26**	**25%**
	Percent	8.8%	28.8%	32.2%	20.1%	19.9%	55.4%			
Total	**Length (ft)**	108,104	83,903	115,255	72,131	109,688	51,226	**540,307**	**102**	
	Percent	20.0%	15.5%	21.3%	13.4%	20.3%	9.5%			

Table 2. Humboldt Bay, artificial and natural shoreline length and percentage by hydrologic unit.

A significant portion of the shorelines in all of the hydrologic units are artificial (67.8-91.2%), except for Elk River Slough (44.6%). Arcata Bay contains the greatest amount of the artificial shoreline (98,619 feet) and South Bay has the greatest amount of the natural shoreline (37,122 feet). While there are 15 different types of shoreline structures, 95% of the shoreline is made up of just 6 types (Chart 1) (Figure 36). The dominant structural types are dikes occupying 40.7 miles of shoreline, natural 26.0 miles, railroad grade 10.5 miles, fill 7.7 miles, fortified 7.6 miles, and roadway 5.0 miles.

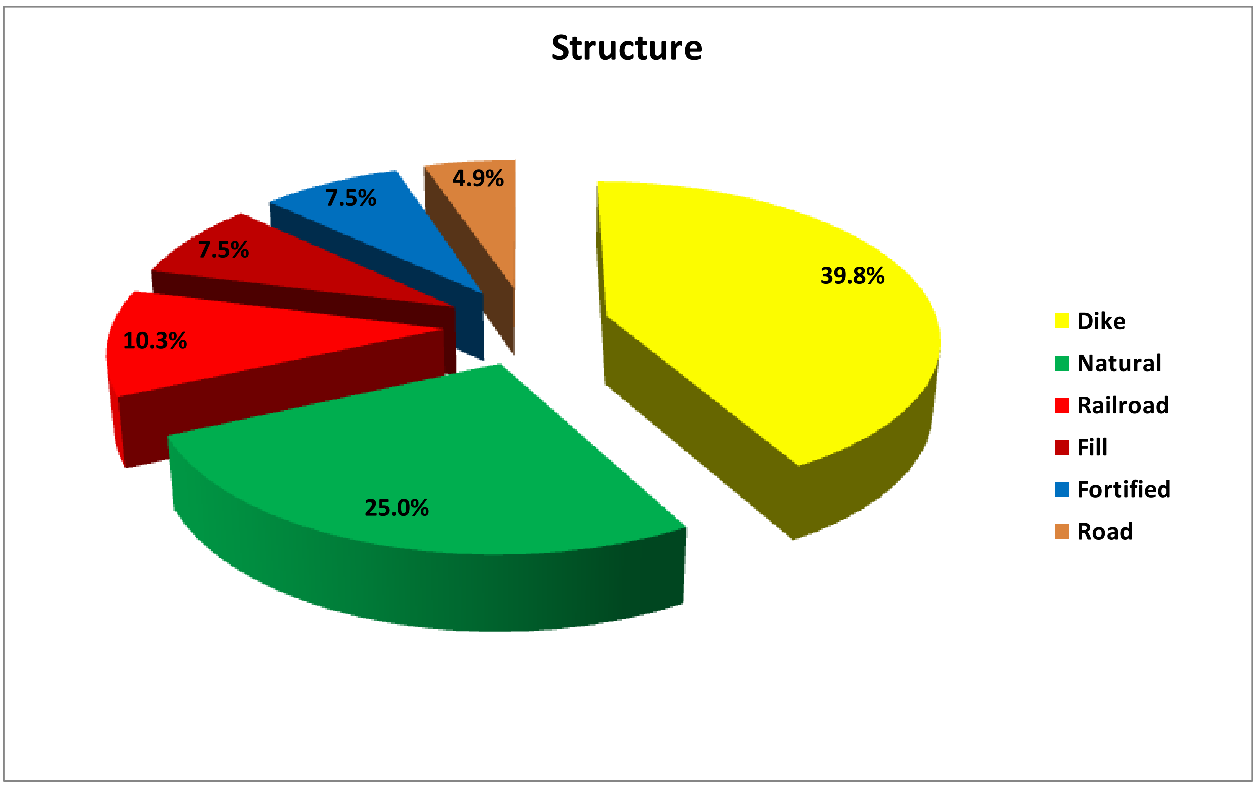

Chart 1. Percentage of Humboldt Bay shoreline occupied by the six most prevalent structures.

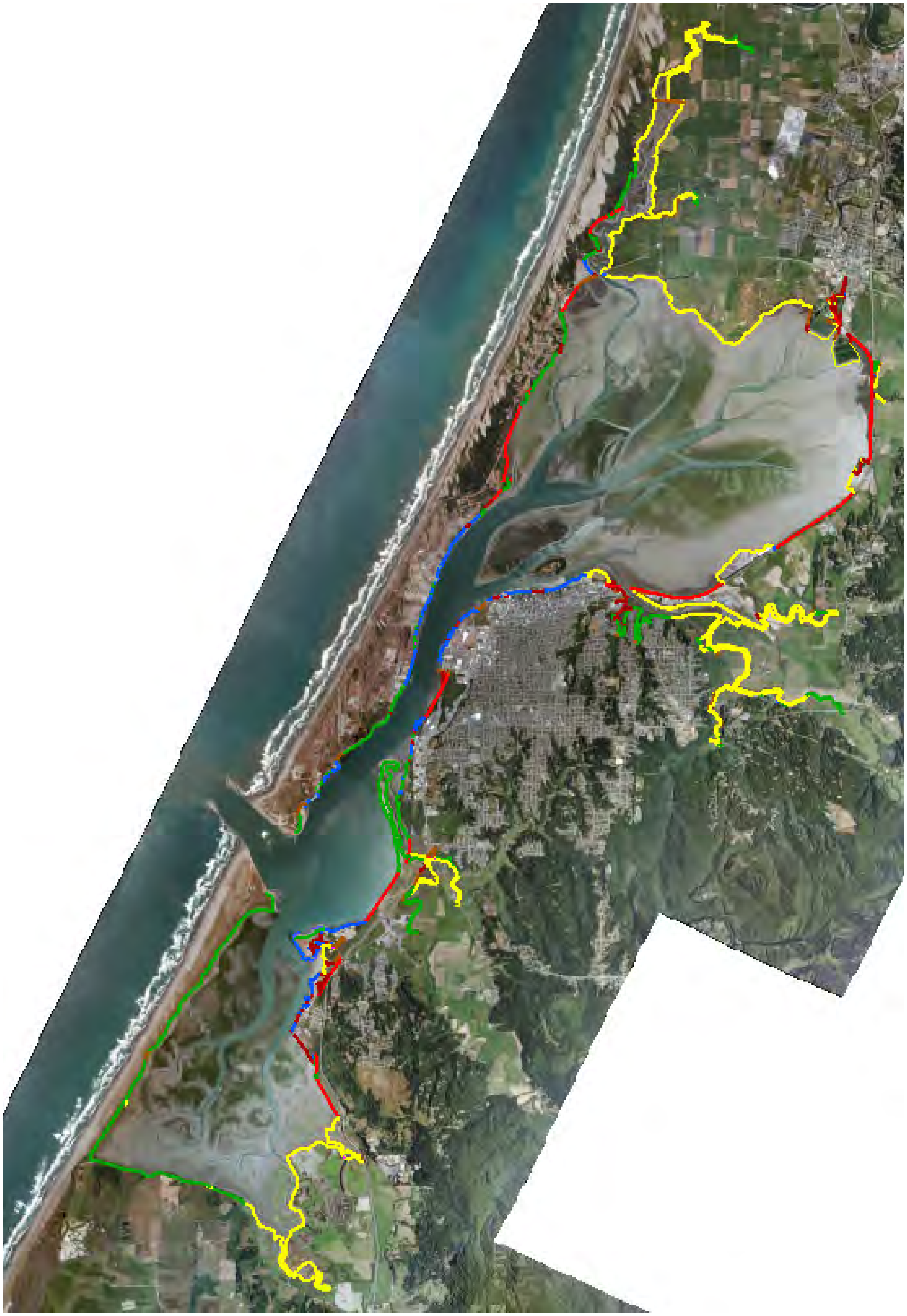

Figure 36. Distribution of shoreline structure types on Humboldt Bay: dike (yellow), natural (green), railroad (red), fill (maroon), fortified (blue), and roadway (brown).

Of the five dominant artificial shoreline structures found on Humboldt Bay: Eureka Slough contains 35.2% of the diked shoreline on Humboldt Bay, Arcata Bay has 61.9% of the rail road, South Bay 24.1% of the fill, Eureka Bay 73.7% of the fortified shoreline, and Arcata Bay 25.7% of the roadway shoreline (Table 3).

ARTIFICIAL SHORELINE STRUCTURE		ARCATA BAY	EUREKA BAY	SOUTH BAY	MAD RIVER SLOUGH	EUREKA SLOUGH	ELK RIVER SLOUGH	TOTAL FEET	TOTAL MILES	TOTAL PERCENT
Dike	**Length (ft)**	33,107	3,077	40,215	47,471	75,588	15,334	**214,792**	**41**	**53.1%**
	Percent	15.4%	1.4%	18.7%	22.1%	35.2%	7.1%			
Fill	**Length (ft)**	12,935	6,309	13,816	469	6,059	955	**40,543**	**8**	**10.0%**
	Percent	31.9%	15.6%	34.1%	1.2%	14.9%	2.4%			
Fortified	**Length (ft)**	331	29,657	8,019	1,345	163	748	**40,263**	**8**	**9.9%**
	Percent	0.8%	73.7%	19.9%	3.3%	0.4%	1.9%			
Railroad	**Length (ft)**	34,431	8,794	7,197	2,968	551	1,714	**55,655**	**11**	**13.7%**
	Percent	61.9%	15.8%	12.9%	5.3%	1.0%	3.1%			
Road	**Length (ft)**	6,788	3,851	3,607	5,050	3,666	3,443	**26,405**	**5**	**6.5%**
	Percent	25.7%	14.6%	13.7%	19.1%	13.9%	13.0%			

Table 3. Humboldt Bay shoreline length and percentage by structure type for each hydrologic unit.

Based on shoreline length, earthen dikes are the most common shoreline structure on Humboldt Bay, 40.7 miles. Many of these dikes were built over 100 years ago. The shores of Eureka, Mad River, and Elk River Sloughs contain 64.4% of the dikes on Humboldt Bay. Dikes protect thousands of acres of former tide land (approximately 90% of the original salt marsh habitat) that would flood if these dikes were breached or overtopped. These dikes, besides protecting agricultural lands, also protect important regional infrastructure (power plant, water transmission lines, gas transmission lines, electrical transmission towers, interstate and state highways, county roads, city service streets, county airport, and wastewater treatment facilities) from tidal inundation. Dike and railroad shorelines cover 51.2 miles, 50% of the shoreline on Humboldt Bay, and they both share two common features that will be significant when the affect of sea level rise manifests; they are nearly flat and of uniform elevation.

Arcata Bay:

The shoreline of Arcata Bay is mostly developed; what natural shoreline remains fronts the community of Manila (Figure 37). Arcata Bay has an extensive inter-tidal area of mudflats at low tide and a few deep water channels draining the Bay. Most of Humboldt Bay's shell fish maricultural operations are located in Arcata Bay. Arcata Bay has two freshwater drainages without tide gates that have open-ended channels at the tidal-freshwater interface (Jolly Giant Creek, Jacoby Creek, and soon to be three when Janes Creek McDaniel's Slough restoration is completed in 2013). These streams provide valuable brackish water fish habitat.

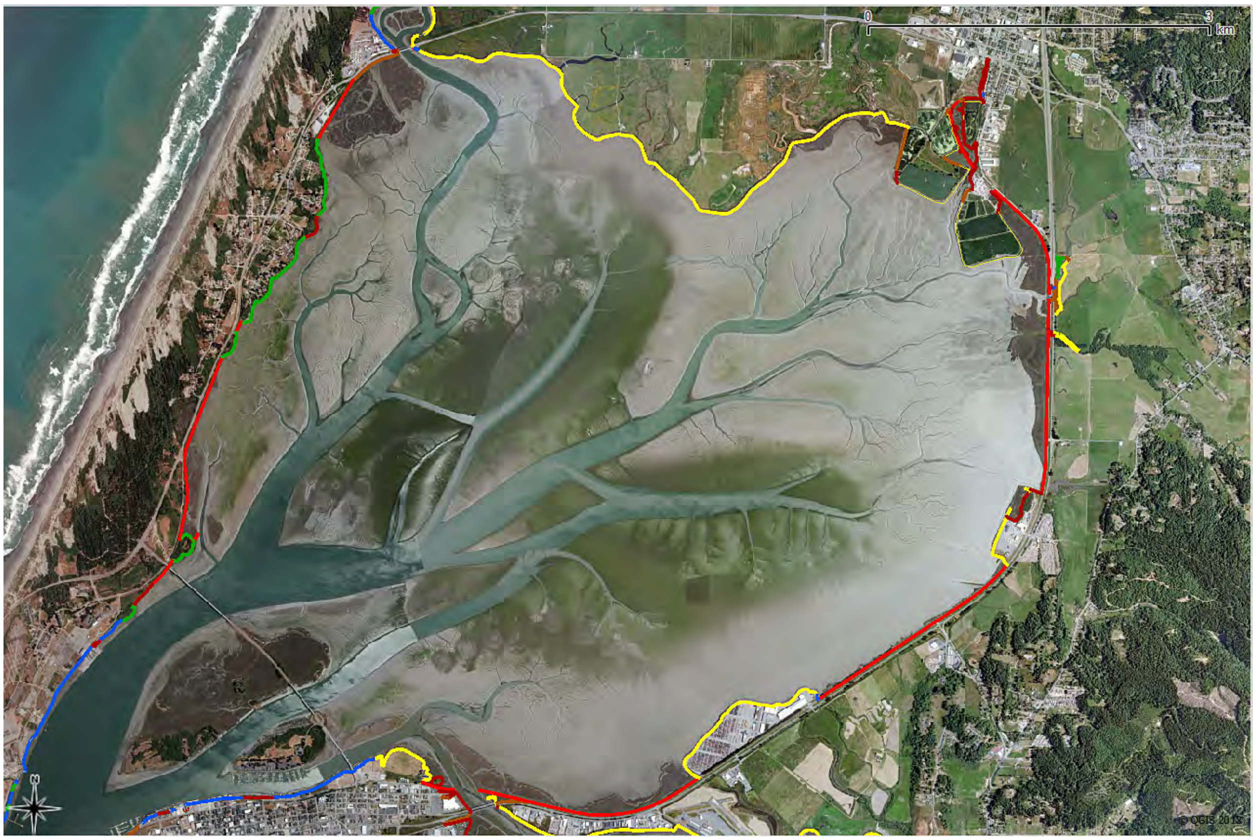

Figure 37. Distribution of shoreline structure types on Arcata Bay: dike (yellow), natural (green), railroad (red), fill (maroon), fortified (blue), and roadway (brown).

The shoreline of Arcata Bay is 20.5 miles long; 91% of the shoreline is composed of artificial structures and 9% of the shoreline is natural. The two dominate shoreline structures are the NCRA grade with 6.5 miles, 32% of the shoreline (Table 4) and Reclamation District's 768 dike of 6.3 miles, 31% of the shoreline, which was rehabilitated in 2008. Other types of shorelines on Arcata Bay are fill 2.5 miles (12%), the City of Arcata's waste water treatment and marsh ponds 1.9 miles (9%), which were also rehabilitated in 2008, and roadways 1.3 miles (6%).

Structure		
Arcata Bay	**Length (ft)**	**Percent (%)**
Boat Ramp	44.5	0%
Bridge Abutment	430.3	0%
Bulwark	327.0	0%
Dike	33,107.1	31%
Fill	12,934.9	12%
Fortified	330.0	0%
None	9,485.6	9%
Pond	10,225.8	9%
Railroad	34,431.2	32%
Road	6,787.8	6%
TOTAL	**108,104.1**	

Table 4. Arcata Bay shoreline structures by type, with length and percentage of total.

Eureka Bay:

Figure 38. Distribution of shoreline structure types on Eureka Bay: dike (yellow), natural (green), railroad (red), fill (maroon), fortified (blue), and roadway (brown).

Eureka Bay is a deep water harbor on Humboldt Bay. Its entrance is dredged annually to a depth of 40 feet and the shipping channel and turning basin are also dredged as are the two marinas periodically. There are several commercial docks still in operation and some which are not. While Eureka Bay is a working harbor, it has two and a half times as much natural shoreline as Arcata Bay; 4.6 miles versus 1.8 miles. Elk River Spit, one of the newest natural features on Humboldt Bay, protrudes out to the shipping channel and contains several unique shoreline environments: sandy beaches, foredunes, salt marsh and riparian-freshwater wetlands. Eureka Bay also has much of the historic (abandoned) waterfront on Humboldt Bay as well as the City of Eureka's newly re-developed waterfront and boardwalk.

The shoreline of Eureka Bay is 15.9 miles long; 71% of the shoreline is composed of artificial structures and 29% is natural. The dominant shoreline structures are fortified (5.6 miles, 35%) and foredunes (2.6 miles, 17%) (Table 5). Other types of shorelines are natural (2.0 miles, 12%), NCRA railroad (1.7 miles, 10%), fill (1.2 miles, 8%), and roadways (0.7 miles, 5%).

Structure		
Eureka Bay	**Length (ft)**	**Percent (%)**
Boat Ramp	417.4	0%
Building	293.3	0%
Bulwark	3,916.0	5%
Dike	3,077.0	4%
Fill	6,308.8	8%
Fore Dune	13,932.3	17%
Fortified	29,656.6	35%
Jetty	3,180.1	4%
None	10,446.6	12%
Railroad	8,794.1	10%
Road	3,851.5	5%
Tidegate	29.6	0%
TOTAL	**83,903.4**	

Table 5. Eureka Bay shorelines structure by type, with length and percentage of total.

South Bay:

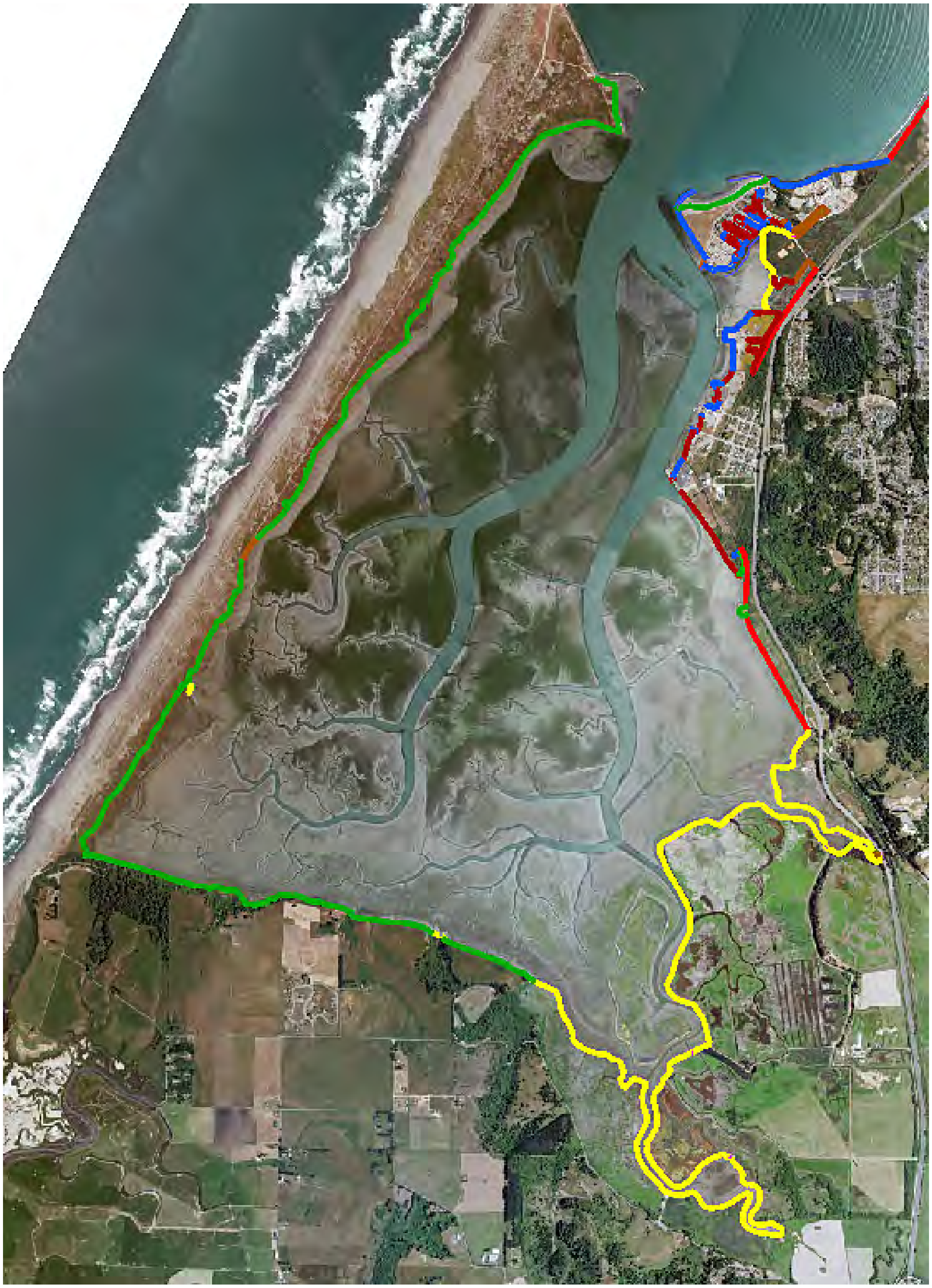

Figure 39. Distribution of shoreline structure types on South Bay: dike (yellow), natural (green), railroad (red), fill (maroon), fortified (blue), and roadway (brown).

South Bay has the greatest amount of natural shoreline and a relatively rare shoreline type along Table Bluff: cliffs. South Bay, like Arcata Bay, also has extensive inter-tidal mudflats at low tide, as well as a deep water channel to Fields Landing that is periodically dredged. South Bay also has a rather unique waterfront residential area at King Salmon: commercial waterfront in Fields Landing. There are two wildlife areas on South Bay, HBNWR and the Mike Thompson Wildlife Area on South Spit. Freshwater inflow from Salmon Creek provides valuable brackish water fish habitat at the HBNWR.

The shoreline of South Bay is 21.8 miles long; 68% of the shoreline is composed of artificial structures and 32% of the shoreline is natural. The two dominant shoreline structures are earthen dikes (7.6 miles, 35%) and natural (4.8 miles, 22%) (Table 6). Other types of shorelines are fill (2.6 miles, 12%), cliff/bluffs (2.0 miles, 9%), fortified (1.5 miles, 7%), and railroad (1.4 miles, 6%).

Structure		
South Bay	**Length (ft)**	**Percent (%)**
Boat Ramp	99.0	0%
Bridge Abutmen	193.4	0%
Bulwark	1,557.4	1%
Cliff/Bluff	10,389.9	9%
Dike	40,214.9	35%
Fill	13,816.0	12%
Fore Dune	1,531.8	1%
Fortified	8,019.1	7%
Jetty	2,959.0	3%
None	25,244.2	22%
Railroad	7,197.3	6%
Road	3,606.7	3%
Tidegate	426.0	0%
TOTAL	**115,254.7**	

Table 6. South Bay shoreline structures by type, with length and percentage of total.

Mad River Slough:

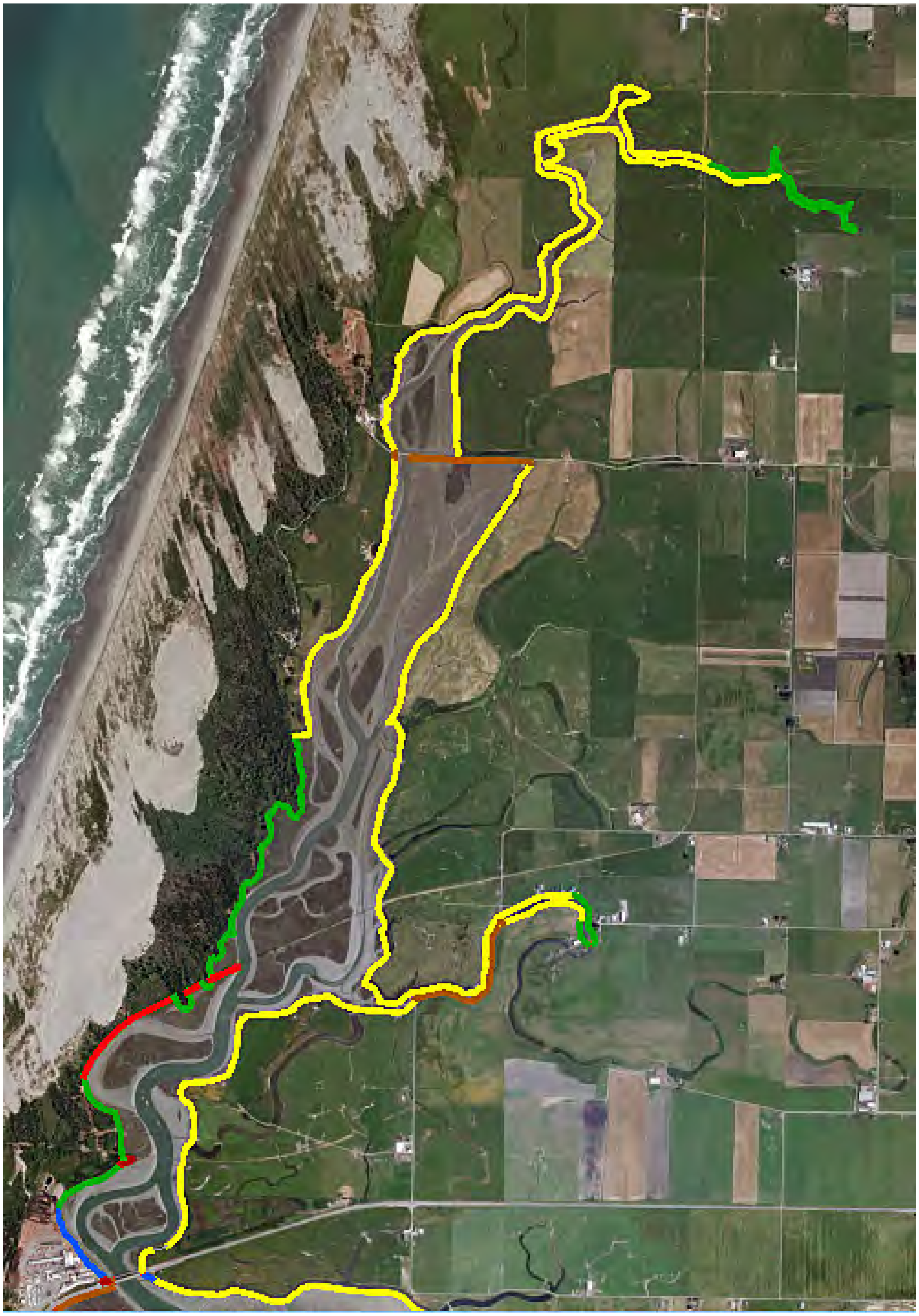

Figure 40. Distribution of shoreline structure types on Mad River Slough: dike (yellow), natural (green), railroad (red), fill (maroon), fortified (blue), and roadway (brown).

Mad River Slough has a unique dune and forest ecosystem on its western shore, mostly within the HBNWR, but its shores are predominant earthen dikes that protect agricultural uses on former tide lands. Occasionally, the Mad River, which is located to the north, floods, and its overbank flow drains across the Mad River bottomland to the dikes along the slough then impounds water for days, or breaches, releasing sediment to the downstream reaches of the slough and Humboldt Bay. The upper end of Mad River Slough is an open channel, with no freshwater inflow, and its banks are un-diked natural bottom land. Liscom Slough is a channel that historically drained a large area of the Mad River Bottom to Mad River Slough but its upper reaches are now blocked off by a road crossing.

The shoreline of Mad River Slough is 13.7 miles long; 80% of the shoreline is composed of artificial structures and 20% of the shoreline is natural. The two dominant shoreline structures are earthen dikes (9.0 miles, 66%) and natural (2.8 miles, 20%) (Table 7). Other types of shorelines are roadway (1.0 miles, 7%), and an abandoned historic Hammond Railroad Grade (0.6 miles, 4%).

Structure		
Mad River Slough	**Length (ft)**	**Percent (%)**
Boat Ramp	22.1	0%
Bulwark	297.3	0%
Dike	47,471.4	66%
Fill	469.1	1%
Fortified	1,345.0	2%
None/Natural	14,508.3	20%
Railroad	2,968.0	4%
Road	5,050.0	7%
TOTAL	**72,131.1**	

Table 7. Mad River Slough shoreline structures by type, with length and percentage of total.

Eureka Slough:

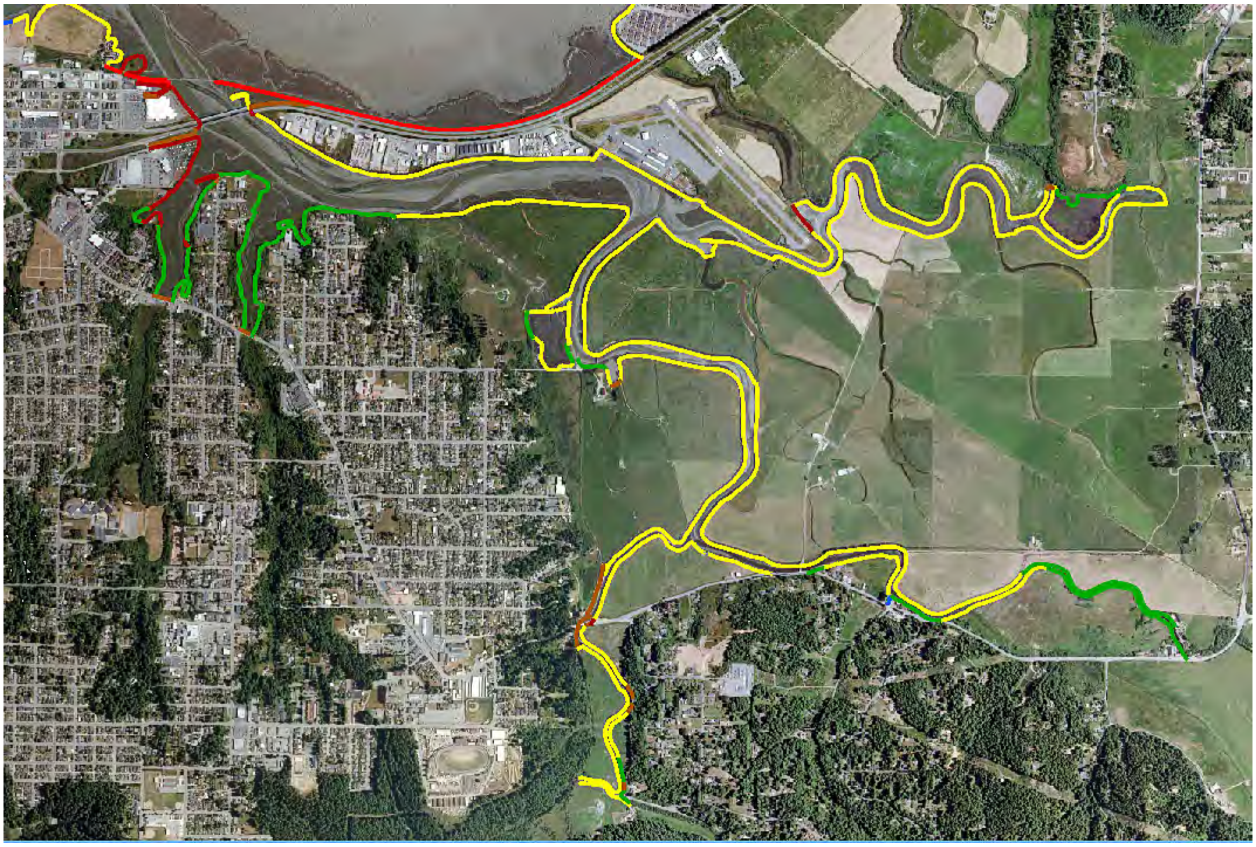

Figure 41. Distribution of shoreline structure types on Eureka Slough: dike (yellow), natural (green), railroad (red), fill (maroon), fortified (blue), and roadway (brown).

Eureka Slough has three major tidal branches; Fay Slough, Freshwater Slough and Ryan Slough. Freshwater inflow from the upper watersheds of these Sloughs provides valuable brackish water fishery habitat. Eureka Slough has the greatest amount of diked shore on Humboldt Bay; many of these dikes were first constructed in 1894 (Susie Van Kirk 2007). The upper end of Freshwater Slough is an open channel and its banks are un-diked natural bottom land. The upper end of Fay Slough has unique brackish marsh habitat. There is a county airport along the shores of Fay and Eureka Sloughs.

The shoreline of Eureka Slough is 20.8 miles long; 80% of the shoreline is composed of artificial structures and 20% of the shoreline is natural. The two dominant shoreline structures are earthen dikes (14.3 miles, 69%) and natural (2.9 miles, 14%)(Table 8). Other types of shorelines are cliff/bluffs (1.3 miles, 6%), fill (1.2 miles, 6%), and roadway (0.7 miles, 3%).

Structure		
Eureka Slough	**Length (ft)**	**Percent (%)**
Boat Ramp	23.2	0%
Bridge Abutment	355.2	0%
Bulwark	1,334.2	1%
Cliff/Bluff	6,687.4	6%
Dike	75,588.1	69%
Fill	6,058.6	6%
Fortified	162.9	0%
None	15,166.8	14%
Railroad	551.5	1%
Road	3,666.1	3%
Tidegate	94.2	0%
TOTAL	**109,688.4**	

Table 8. Eureka Slough shoreline structures by type, with length and percentage of total.

Elk River Slough:

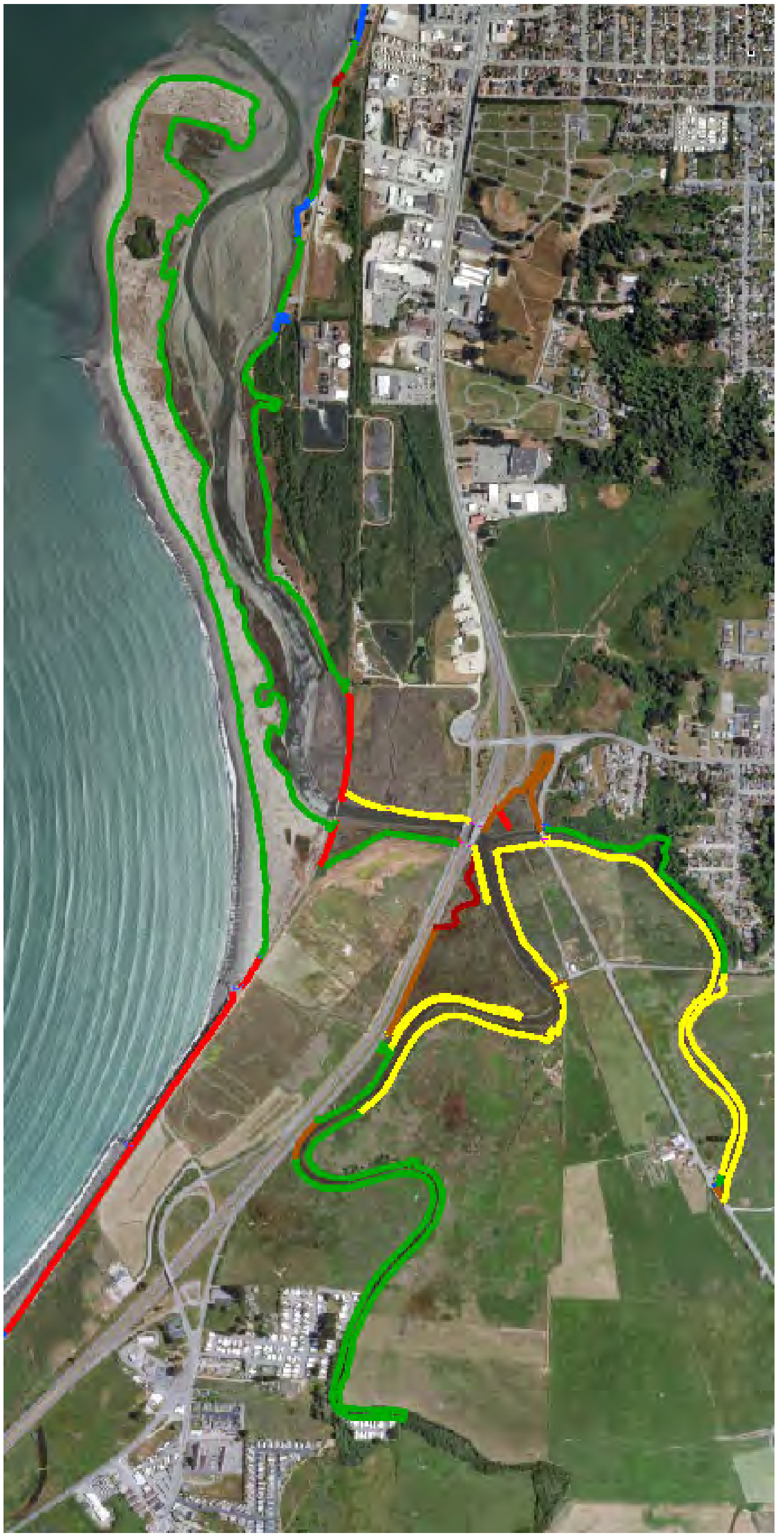

Figure 42. Distribution of shoreline structure types on Elk River Slough: dike (yellow), natural (green), railroad (red), fill (maroon), fortified (blue), and roadway (brown).

Elk River Slough is unique in that historical maps do not depict extensive areas of salt marsh and tidal channel networks (Laird 2007) (Figure 43). However, the 1921 soil survey of Humboldt Bay does indicate that Elk River Slough and its valleys was a zone of tidal and freshwater interface, with salt marsh to the south and north of Elk River Slough and up the valley reaches on Elk River and Ryan Slough (Watson 1925). Salt marsh and windblown soils were overlain with overbank deposits of freshwater sediments (Figure 44). A significant portion of the shoreline along Elk River Slough is not diked, approximately 4,500 feet; it is natural bottom land. The upper end of the Slough is an open channel that traverses the floodplain until riparian forest closes in on Elk River at the upper tidal limits. Another unique landscape feature of Elk River Slough is the spit that has accreted and extended out into the shipping channel of Eureka Bay. The spit is apparently a result of the construction of the Harbor entrance jetties and dredging that caused the erosion of historic Buhne Point, whose sediments then formed Elk River's spit (pers. comm. John Winzler 2012).

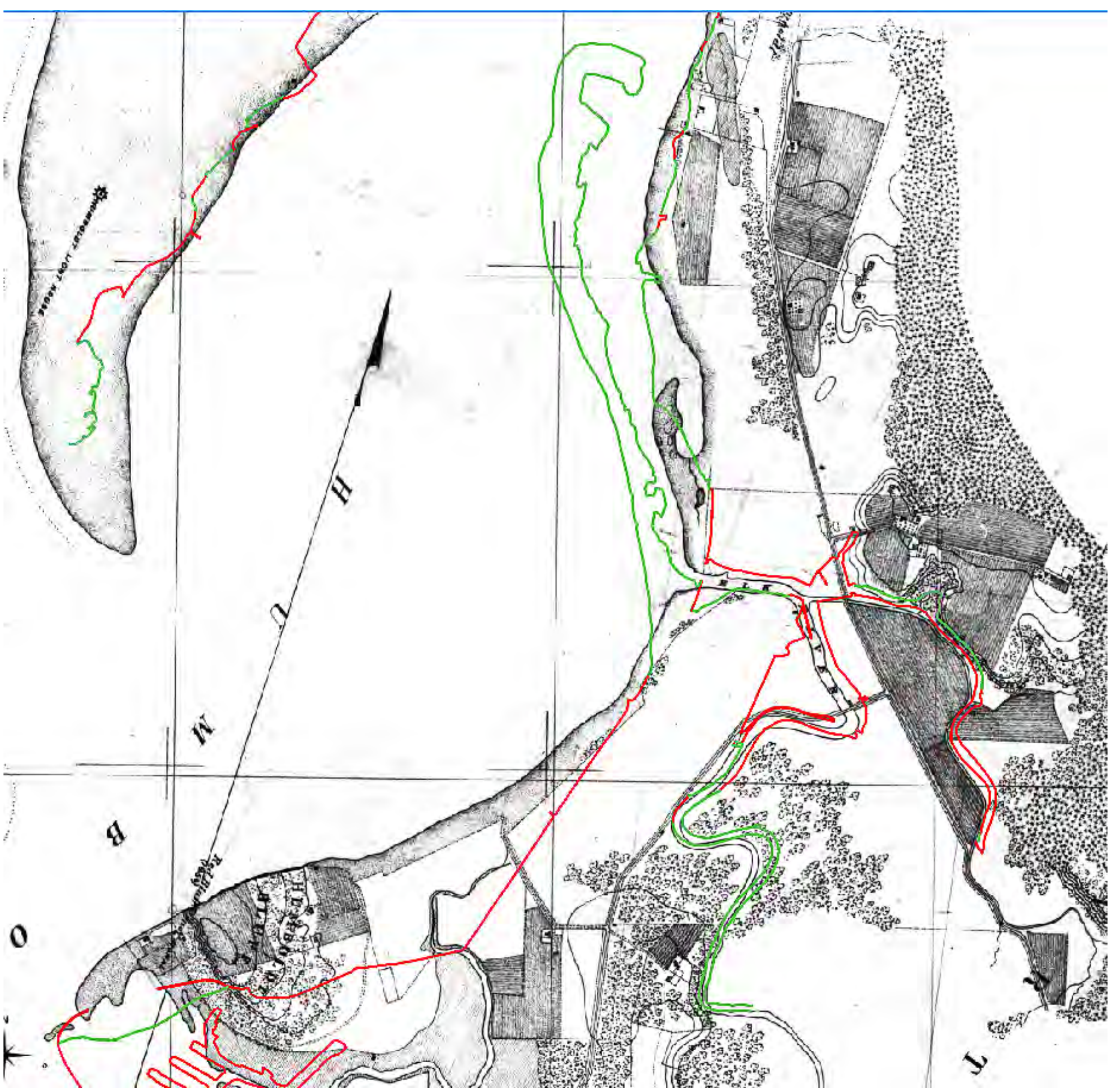

Figure 43. Elk River Slough, 2009 shoreline location overlaid on 1870 USCGS map.

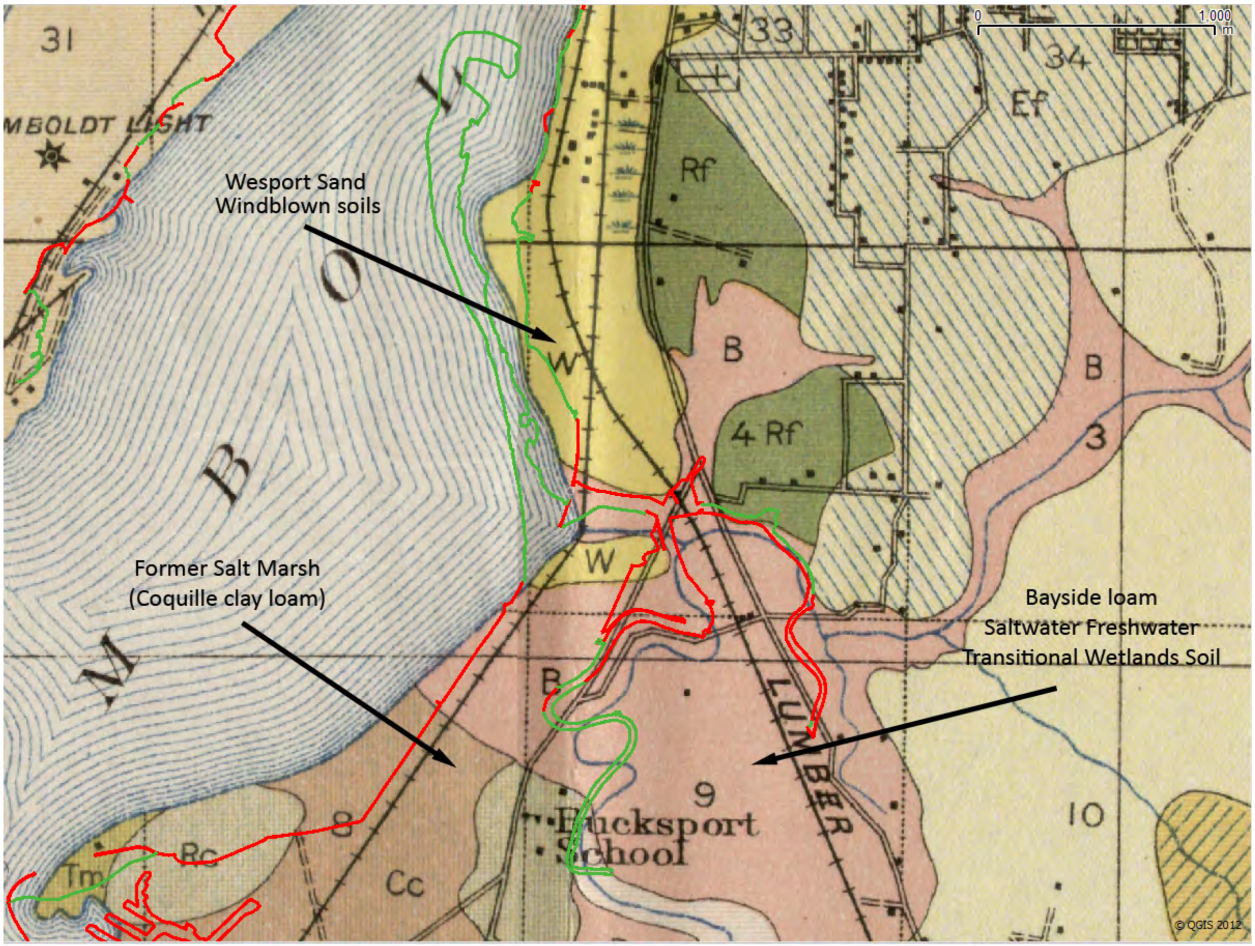

Figure 44. Elk River Slough, 2009 shoreline location overlaid on USDA 1916 soils map

The shoreline of Elk River Slough is 9.7 miles long; 55% of the shoreline is natural and 45% of the shoreline is composed of artificial structures. The three dominant shoreline structures are natural (3.0 miles, 31%), earthen dikes (2.9 miles, 30%) and fore dunes (1.7 miles, 18%)(Table 9). Other types of shorelines are roadway (0.6 miles, 7%), cliff/bluffs (0.6 miles, 6%), and NCRA rail road (0.3 miles, 3%).

Structure		
Elk River Slough	Length (ft)	Percent (%)
Bridge Abutment	520.2	1%
Bulwark	72.7	0%
Cliff/Bluff	3,231.1	6%
Dike	15,333.9	30%
Fill	955.2	2%
Fore Dune	9,246.1	18%
Fortified	748.5	1%
None	15,919.0	31%
Railroad	1,714.0	3%
Road	3,442.6	7%
Tidegate	42.6	0%
TOTAL	**51,225.7**	

Table 9. Elk River Slough shoreline structures by type, with length and percentage of total.

b) Shoreline Cover

The type and condition of shoreline cover is important when evaluating the ability of a shoreline to resist wave induced erosion or bank saturation and collapse. Man-made shoreline structures occupy 75% of the shoreline on Humboldt Bay and protect thousands of acres of property, land uses, and infrastructures. Earthen dikes are the most prevalent shoreline structure, functioning as an elevated tidal barrier shielding the lands behind them. The consequence of a dike breach can be substantial. For example, in 2003, a single dike breach on Mad River Slough flooded approximately 600 acres of former tidelands. On Humboldt Bay, railroad grades, dikes, and some roadways offer similar protection to the lands behind them. In order to assess the vulnerability of existing shorelines, it is important to inventory the type of cover on the shoreline's tidal slope. Shoreline cover can be grouped in two broad types: fortified and unfortified. Fortified shorelines can be a form of revetment or rip rap composed of materials such as rock, concrete, or even fronted by a structure such as a bulwark made of wood or steel. Unfortified shorelines found on Humboldt Bay are either vegetated or exposed; both of these conditions indicate a lack of maintenance. Earthen dikes that are not fortified and not maintained are more vulnerable to erosion and breaching.

Humboldt Bay

The Humboldt Bay shoreline is predominately unfortified (72.9%). Shoreline with vegetative cover occupies 65.4 miles (63.9%), 9.2 miles (9.0%) of the shoreline are exposed or with no cover, and 27.0 miles of shoreline are fortified (Figure 45, Table 10, Chart 2).

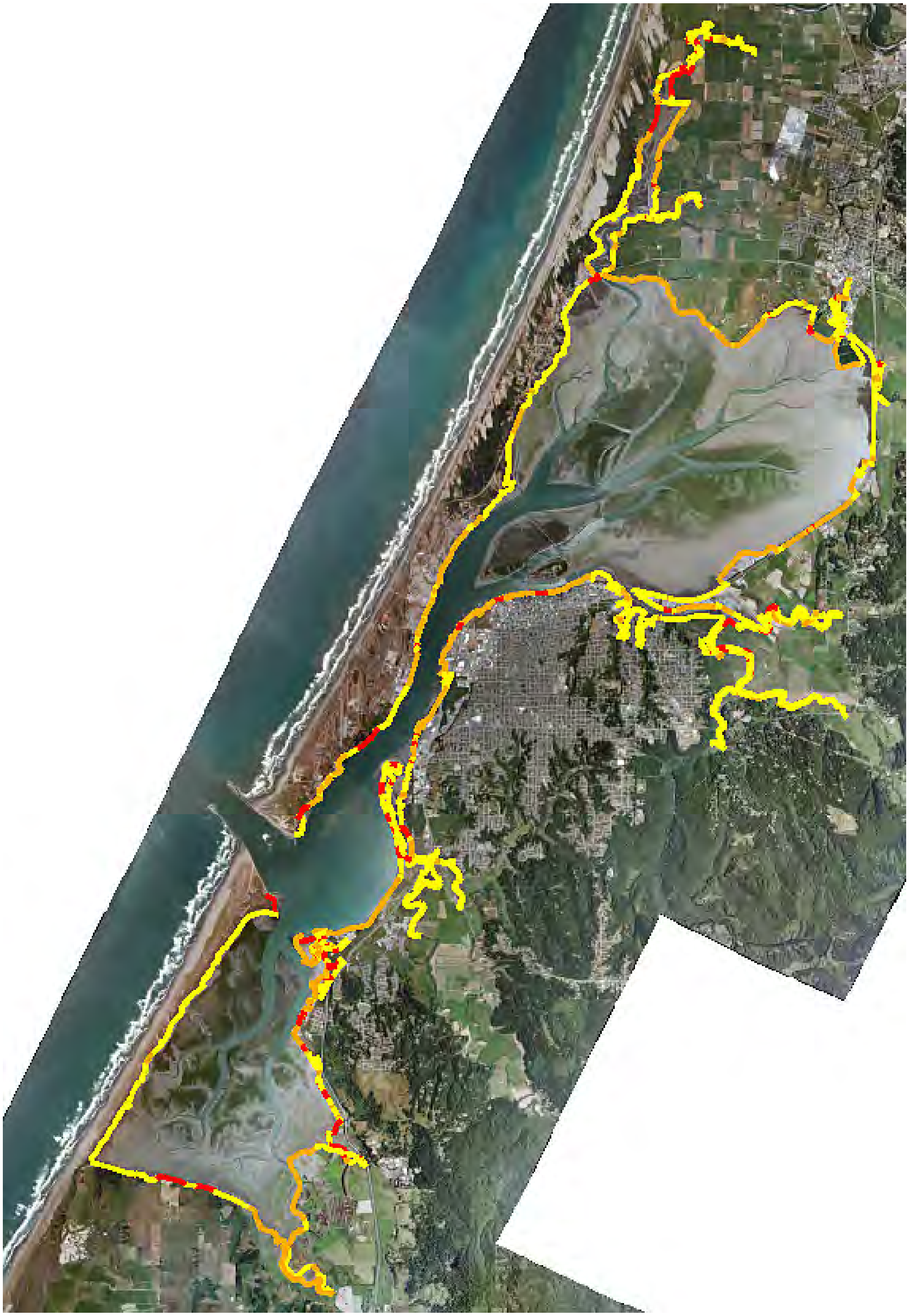

Figure 45. Distribution of shoreline cover on Humboldt Bay: vegetated (yellow), fortified (brown), and exposed (red).

SHORELINE COVER	ARCATA BAY	EUREKA BAY	SOUTH BAY	MAD RIVER SLOUGH	EUREKA SLOUGH	ELK RIVER SLOUGH	TOTAL FEET	TOTAL PERCENT
Exposed	9.3%	22.0%	33.9%	17.0%	13.9%	4.0%	**48,801**	**9.0%**
Vegetated	18.8%	8.0%	18.4%	14.0%	27.3%	13.6%	**345,390**	**63.9%**
Fortified	27.2%	30.6%	24.3%	10.7%	5.5%	1.7%	**142,325**	**26.3%**

Table 10. Humboldt Bay hydrologic unit's fortified versus un-fortified shoreline percentage and length.

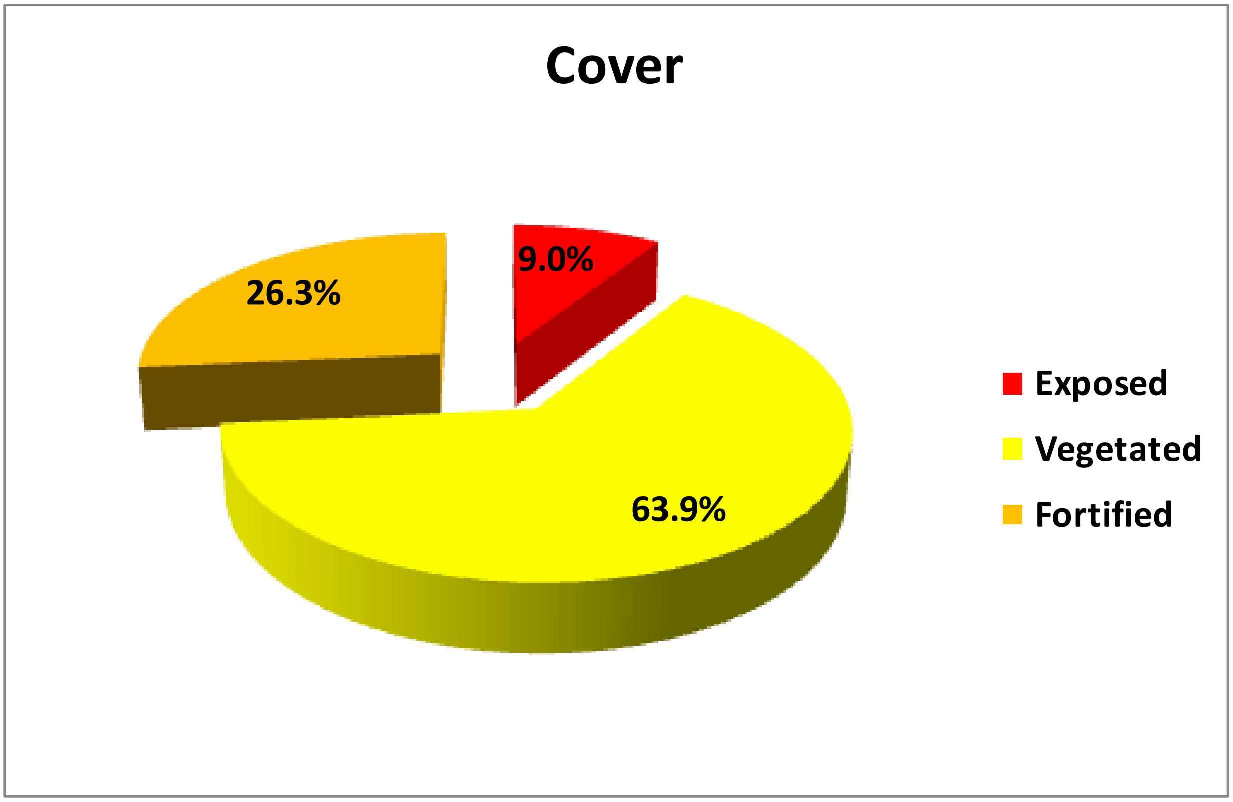

Chart 2. The percent of shoreline that is fortified or un-fortified: vegetated and exposed, on Humboldt Bay.

On Humboldt Bay, eight types of cover were encountered on the man-made shoreline of 76.7 miles; 42.5 miles were vegetated, 27.7 miles fortified (asphalt, concrete, rock, rock/concrete, steel, and wood), and 6.4 miles were exposed and eroding (Table 11).

ARTIFICIAL STRUCTURE COVER	ARCATA BAY	EUREKA BAY	SOUTH BAY	MAD RIVER SLOUGH	EUREKA SLOUGH	ELK RIVER SLOUGH	TOTAL FEET
Asphalt	0	0	0	0	113	0	**113**
Concrete	4,048	13,978	8,872	10,806	5,383	1,202	**44,289**
Exposed	3,605	3,587	11,936	8,189	6,166	100	**33,582**
Rock	26,864	29,419	25,094	4,374	2,093	1,155	**88,998**
Rock/Concrete	7,338	119	646	0	333	99	**8,535**
Steel	229	300	0	297	0	0	**826**
Vegetated	56,126	10,154	31,008	33,957	73,128	20,273	**224,646**
Wood	274	1,717	534	0	830	0	**3,356**
Total (ft)	**98,484**	**59,274**	**78,089**	**57,623**	**88,046**	**22,829**	**404,345**

Table 11. Humboldt Bay hydrologic unit's shoreline cover types, length (feet), and percentage.

The five most prevalent shoreline structures are: dikes (40.7 miles), railroad (10.5 miles), fill (7.7 miles), fortified (7.6 miles), and roadways (5.0 miles). There are 3.3 miles of exposed dikes, 2.0 miles of exposed fill, 0.2 miles of exposed fortified shoreline, 0.2 miles of exposed railroad, and 0.5 miles of exposed roadway (Table 12). Vegetation covers 25.7 miles of dikes, 7.1 miles of railroad, 5.3 miles of fill, and 3.3 miles of roadway (Table 13).

ARTIFICIAL STRUCTURE COVER-EXPOSED	ARCATA BAY	EUREKA BAY	SOUTH BAY	MAD RIVER SLOUGH	EUREKA SLOUGH	ELK RIVER SLOUGH	TOTAL FEET	TOTAL MILES
Dike	33,107	3,077	40,215	47,471	75,588	15,334	**214,792**	**40.7**
Length (ft)	116	-	3,429	7,969	6,098	74	**17,686**	**3.3**
Percent	0.1%	0.0%	1.6%	3.7%	2.8%	0.0%	**8.2%**	
Railroad	34,431	8,794	7,197	2,968	551	1,714	**55,655**	**10.5**
Length (ft)	525	-	346	25	-	-	**896**	**0.2**
Percent	0.9%	0.0%	0.6%	0.0%	0.0%	0.0%	**1.6%**	
Fill	12,935	6,309	13,816	469	6,059	955	**40,543**	**7.7**
Length (ft)	2,056	2,015	6,353	91	-	-	**10,516**	**2.0**
Percent	5.1%	5.0%	15.7%	0.2%	0.0%	0.0%	**25.9%**	
Fortified	330	29,657	8,019	1,345	163	749	**40,262**	**7.6**
Length (ft)	-	382	522	-	-	-	**904**	**0.2**
Percent	0.0%	0.9%	1.3%	0.0%	0.0%	0.0%	**2.2%**	
Roadway	6,788	3,851	3,607	5,050	3,666	3,443	**26,405**	**5.0**
Length (ft)	909	963	635	104	-	26	**2,636**	**0.5**
Percent	3.4%	3.6%	2.4%	0.4%	0.0%	0.1%	**10.0%**	

Table 12. Length of exposed shoreline for the five most prevalent shoreline structures and percentage of that structure's total length that is exposed.

ARTIFICIAL STRUCTURE COVER-VEGETATED	**ARCATA BAY**	**EUREKA BAY**	**SOUTH BAY**	**MAD RIVER SLOUGH**	**EUREKA SLOUGH**	**ELK RIVER SLOUGH**	**TOTAL FEET**	**TOTAL MILES**
Dike	33,107	3,077	40,215	47,471	75,588	15,334	**214,792**	**40.7**
Length (ft)	12,199	3,077	14,362	26,518	64,029	15,260	**135,444**	**25.7**
Percent	5.7%	1.4%	6.7%	12.3%	29.8%	7.1%	**63.1%**	
Railroad	34,431	8,794	7,197	2,968	551	1,714	**55,655**	**10.5**
Length (ft)	24,694	2,980	5,787	2,865	552	803	**37,680**	**7.1**
Percent	44.4%	5.4%	10.4%	5.1%	1.0%	1.4%	**67.7%**	
Fill	12,935	6,309	13,816	469	6,059	955	**40,543**	**7.7**
Length (ft)	10,277	4,043	6,981	378	5,224	955	**27,858**	**5.3**
Percent	25.3%	10.0%	17.2%	0.9%	12.9%	2.4%	**68.7%**	
Fortified	330	29,657	8,019	1,345	163	749	**40,262**	**7.6**
Length (ft)	-	-	23	-	-	-	**23**	**0.0**
Percent	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	**0.1%**	
Road	6,788	3,851	3,607	5,050	3,666	3,443	**26,405**	**5.0**
Length (ft)	4,484	54	2,288	4,196	3,323	3,256	**17,601**	**3.3**
Percent	17.0%	0.2%	8.7%	15.9%	12.6%	12.3%	**66.7%**	

Table 13. Length of vegetated shoreline for the five most prevalent shoreline structures and percentage of that structure's total length that is vegetated.

Arcata Bay

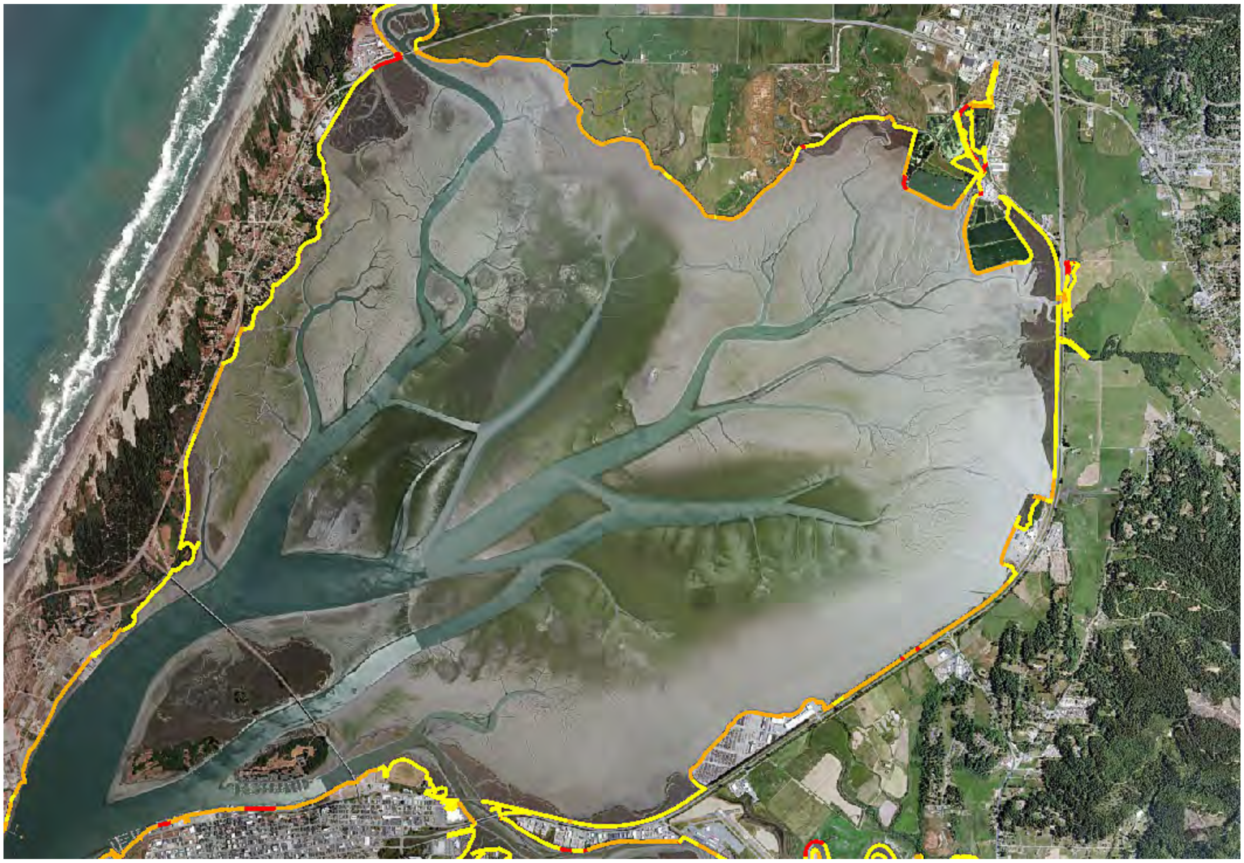

Figure 46. Distribution of shoreline cover types on Arcata Bay: vegetated (yellow), fortified (brown), and exposed (red).

The dominant shoreline cover on Arcata Bay is vegetation (12.3 miles, 60%), revetment covers 7.2 miles of shoreline (36%), and 0.8 miles is exposed or eroding (4%)(Table 14). The two dominant artificial shoreline structures on Arcata Bay are railroad grade (32%) and earthen dikes (31%). The railroad grade is mostly unfortified (4.8 miles, 73%); 4.7 miles is vegetated, 525 feet is exposed, and 1.7 miles is fortified (27%). A significant length of the dikes was recently fortified (3.9 miles, 62.8%) by Reclamation District 768 and the California Redwood Company. 2.3 miles of Arcata Bay are vegetated (36.8%), and just 116 feet are exposed.

Cover		
Arcata Bay	Length (ft)	Percent (%)
Concrete	4,048.1	4%
Exposed	4,396.2	4%
None	134.3	0%
Rock	26,863.6	25%
Rock/Concrete	7,338.4	7%
Steel	229.1	0%
Vegetated	64,820.3	60%
Wood	274.0	0%
TOTAL	**108,104.1**	

Table 14. Arcata Bay's shoreline cover types, length, and percentage.

Eureka Bay

Figure 47. Distribution of shoreline cover types on Eureka Bay: vegetated (yellow), fortified (brown), and exposed (red).

The majority of the shoreline cover on Eureka Bay's 15.9 mile shoreline is fortified (8.6 miles, 54%), while there are 7.3 miles (46%) of unfortified shoreline composed of 5.2 miles with vegetative cover (33%), 1.8 miles of exposed or eroding shoreline (11%), and 0.3 miles with no cover (2%)(Table 15). Eureka Bay's shoreline structure is composed of 35% fortified shoreline, 10% railroad grade, 5% roadway, and only 4% dikes. The railroad's 1.7 miles of shoreline has rock revetment covering 66% and 44% in vegetative cover. Roadways occupy 0.7 miles and are 74% rock revetment with 963 feet (25%) exposed. Dikes are on 0.6 miles of shoreline and are entirely unfortified with vegetative cover.

Cover		
Eureka Bay	**Length (ft)**	**Percent (%)**
Concrete	13,978.1	17%
Exposed	9,400.1	11%
None	1,347.8	2%
Rock	29,419.2	35%
Rock/Concrete	119.5	0%
Steel	299.6	0%
Vegetated	27,621.8	33%
Wood	1,717.4	2%
TOTAL	**83,903.4**	

Table 15. Eureka Bay shoreline cover types, length and percentage.

South Bay

Figure 48. Distribution of shoreline cover types on South Bay: vegetated (yellow), fortified (brown), and exposed (red).

The shoreline of South Bay is 21.8 miles long and the dominant shoreline cover is vegetation (12.0 miles, 55%). Fortified cover comprises 6.7 miles of shoreline (36%), and 3.1 miles (14%) is exposed or eroding (Table 16). The dominant artificial shoreline structures on South Bay are: earthen dikes (7.6 miles), fill (2.6 miles), fortified (1.5 miles), and railroad (1.4 miles). A significant length of the dikes has been recently fortified (4.3 miles, 56%), while 2.7 miles are vegetated (12%), and 0.7 miles are exposed (3%). The 2.6 miles of filled shoreline is nearly entirely unfortified (97%): 1.3 miles with vegetative cover (51%), and 1.2 miles exposed (46%). The 1.5 miles of fortified shoreline is nearly entirely composed of revetments (93%) with 522 feet exposed (7%). The 1.4 miles of railroad has 1.1 miles of vegetative cover (80%), and 346 feet exposed (4%).

Cover		
South Bay	**Length (ft)**	**Percent (%)**
Concrete	8,871.9	8%
Exposed	16,558.5	14%
Rock	25,093.6	22%
Rock/Concrete	645.6	1%
Vegetated	63,550.9	55%
Wood	534.3	0%
TOTAL	**115,254.7**	

Table 16. South Bay shoreline cover types, length and percentage.

Mad River Slough

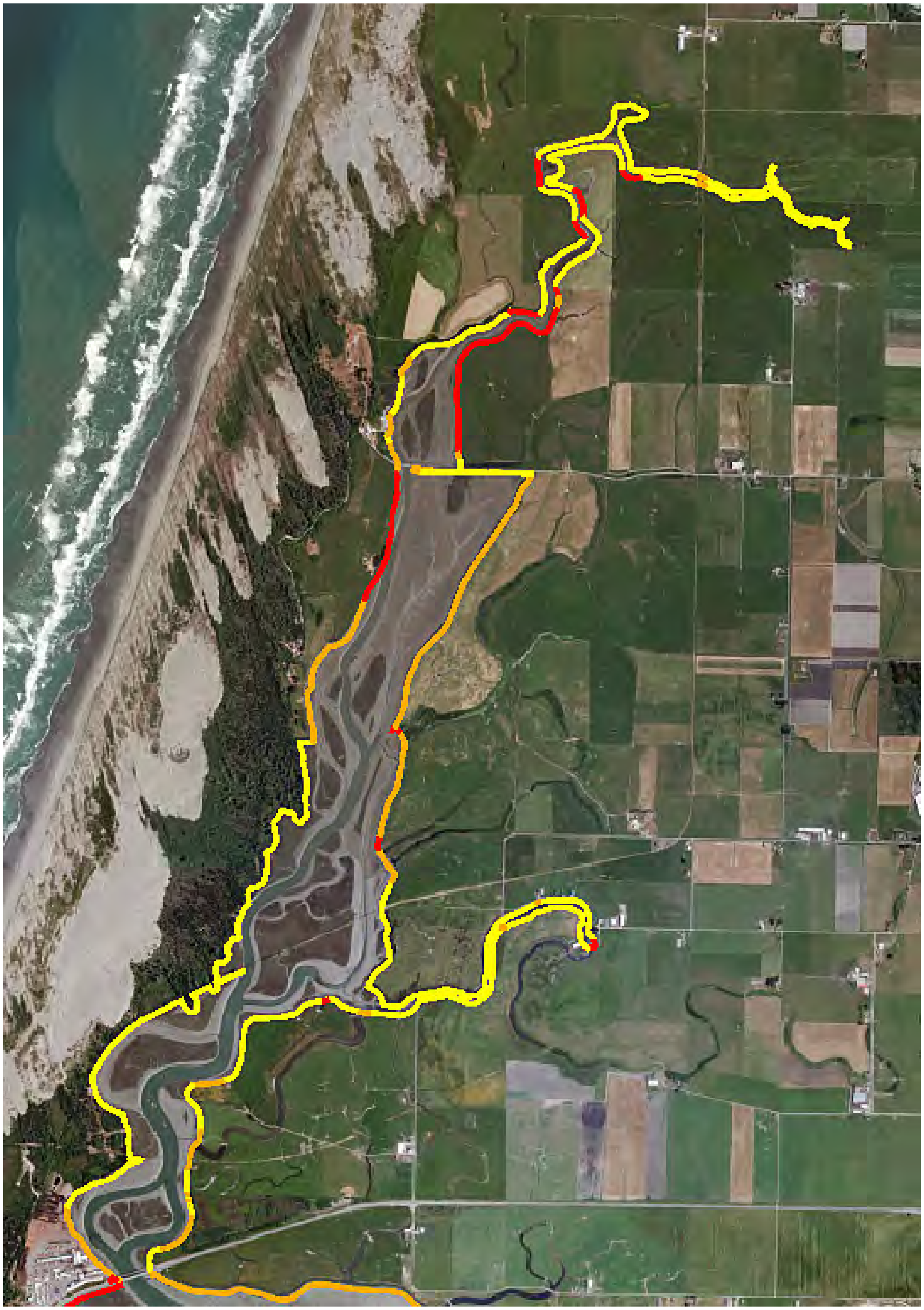

Figure 49. Distribution of shoreline cover types on Arcata Bay: vegetated (yellow), fortified (brown), and exposed (red).

There are 13.7 miles of shoreline on Mad River Slough and the dominant shoreline cover is vegetation (9.2 miles, 67%). Fortified cover comprises 2.9 miles (21.5%), and 1.6 miles is exposed or eroding (11.5%)(Table 17). Dikes are the dominant shoreline structure (9.0 miles), 5.0 miles are vegetated (56%), 2.5 miles are composed of rock and concrete revetment (23%), and 1.5 miles are exposed (17%).

Cover		
Mad River Slough	**Length (ft)**	**Percent (%)**
Concrete	10,805.8	15%
Exposed	8,273.2	11%
Rock	4,373.9	6%
Steel	297.3	0%
Vegetated	48,381.0	67%
TOTAL	**72,131.1**	

Table 17. Mad River Slough shoreline cover types, length and percentage.

Eureka Slough

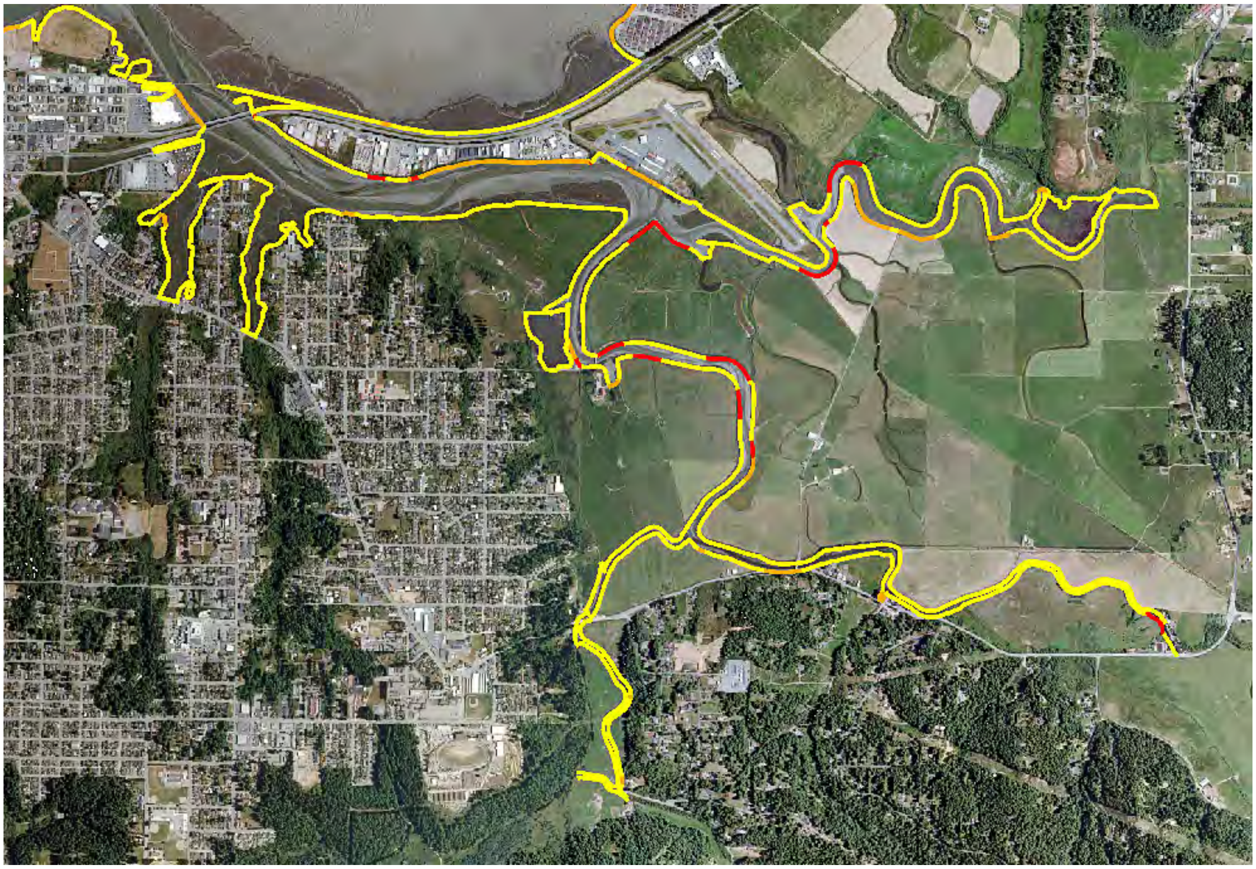

Figure 50. Distribution of shoreline cover types on Eureka Slough: vegetated (yellow), fortified (brown), and exposed (red).

The 20.8 miles of shoreline on Eureka Slough is predominantly artificial (16.6 miles, 80%) with 14.3 miles of earthen dikes. The dominant shoreline cover on Eureka Slough is vegetation (17.8 miles, 86%), fortified cover comprises 1.7 miles (8%), and 1.3 miles is exposed or eroding (6%)(Table 18). The majority of the dikes are un-fortified (13.3 miles, 93%): 12.1 miles are vegetated (85%), 1.1 miles are exposed (8%) while 1.0 miles has rock and concrete revetment (7%).

Cover		
Eureka Slough	**Length (ft)**	**Percent (%)**
Concrete	5,382.7	5%
Exposed	6,760.3	6%
Rock	2,092.6	2%
Rock/Concrete	333.1	0%
Vegetated	94,176.6	86%
Wood	830.3	1%
Asphalt	112.7	0%
TOTAL	**109,688.4**	

Table 18. Eureka Slough shoreline cover types, length and percentage.

Elk River Slough

Figure 51. Distribution of shoreline cover types on Elk River slough: vegetated (yellow), fortified (brown), and exposed (red).

The 9.7 miles of shoreline on Elk River Slough is predominately natural (5.4 miles, 55%). The dominant artificial shoreline structure is earthen dikes covering 2.9 miles (30%) and the dikes are in vegetative cover for nearly their entire length (99.6%)(Table 19). Roadways occupy 0.6 miles of the shoreline and 95% is vegetatively covered, and the railroad along 0.3 miles of shoreline is nearly evenly split between rock revetment and vegetative cover.

Cover		
Elk River Slough	**Length (ft)**	**Percent (%)**
Concrete	1,202.4	2%
Exposed	1,930.3	4%
Rock	1,155.2	2%
Rock/Concrete	98.6	0%
Vegetated	46,839.2	91%
TOTAL	**51,225.7**	

Table 19. Elk River Slough shoreline cover types, length and percentage.

c) Shoreline Elevation

The MMMW elevation of 7.74 feet at the north spit tidal station was used as the baseline from which to measure existing shoreline elevations. NOAA's 2012 LiDAR dataset, which reflects surface elevations in 2010, was used to generate a shoreline elevation profile; an average relative elevation to MMMW elevation was calculated for each one meter shoreline segment and used as the basis for analysis (Figure 52).

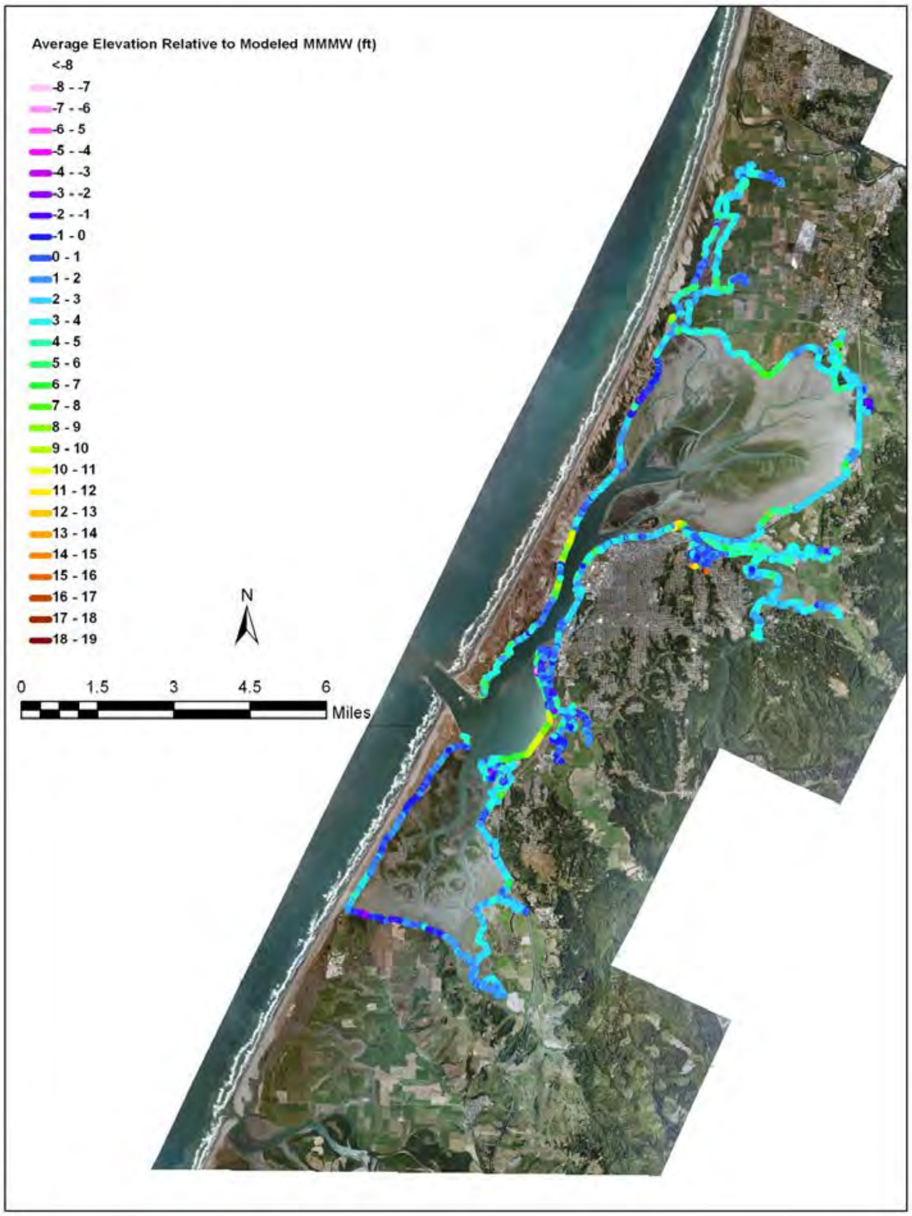

Figure 52. Existing shoreline elevations in relation to the MMMW elevation of 7.74 feet.

Shoreline elevation is an important attribute. While a well fortified dike may not be vulnerable to coastal erosion, if overtopped, a dike may be susceptible to breaching and the lands behind it to flooding. As mentioned earlier, in 2003, during an extreme high tide (EHT) and storm surge, a dike on Mad River Slough experienced a 230 foot breach which flooded approximately 600 acres of former tide lands. It was not until several years later, when Reclamation District 768 received Federal Emergency Management Agency (FEMA) funding to fortify its dikes, that the 2003 breach was repaired. In 2006, a period of heavy precipitation combined with the EHT on New Year's Eve, resulted in a state of emergency being declared on Humboldt Bay. Consequently, California Coastal Commission (CCC) and Humboldt Bay Harbor District issued numerous emergency permits to property owners to repair their overtopped dikes. With 75% of the shoreline on Humboldt Bay composed of man-made structures, it is important to establish the elevation of these structures; this information is necessary for an assessment of the shoreline's vulnerability to overtopping.

Humboldt Bay

The MMMW elevation of 7.74 feet at the North Spit tidal station was used as the baseline from which to measure existing shoreline elevations. Table 20 lists the length of artificial shoreline for each hydrologic unit by elevation; these are not cumulative shoreline lengths.

ARTIFICIAL SHORELINE ELEVATION	ARCATA BAY	EUREKA BAY	SOUTH BAY	MAD RIVER SLOUGH	EUREKA SLOUGH	ELK RIVER SLOUGH	TOTAL FEET	TOTAL PERCENT
7.74'	736	2,289	4,611	443	1,756	2,469	12,304	**3.0%**
8.74'	4,596	5,913	11,357	3,318	5,691	9,339	40,214	**9.9%**
9.74'	19,688	12,522	31,485	13,809	18,899	13,777	110,181	**27.2%**
10.74'	54,061	28,592	57,911	30,841	45,157	17,311	233,872	**57.8%**
13.74'	88,910	45,246	75,158	55,068	85,284	21,585	371,251	**91.7%**
Total (ft)	98,619	59,772	78,132	57,623	87,834	22,829	404,810	**100.0%**

Table 20. Humboldt Bay, hydrologic unit's artificial shoreline length (feet) and percent by shoreline elevation.

Most of the artificial shoreline (91.7%) is less than 13.74 feet in elevation: 2.3 miles are less than or equal to 7.74 feet, 5.3 miles are 7.74 to 8.74 feet, 13.3 miles are 8.74 to 9.74 feet, 23.4 miles are 9.74 to 10.74 feet, and 26 miles are 10.74 and 13.74 feet. The majority (57.8%) of the artificial shoreline elevation is within 3 feet of the MMMW elevation and 33.9% is between 3 and 6 feet of MMMW. Chart 3 illustrates the length of artificial shoreline in miles for each of these elevations.

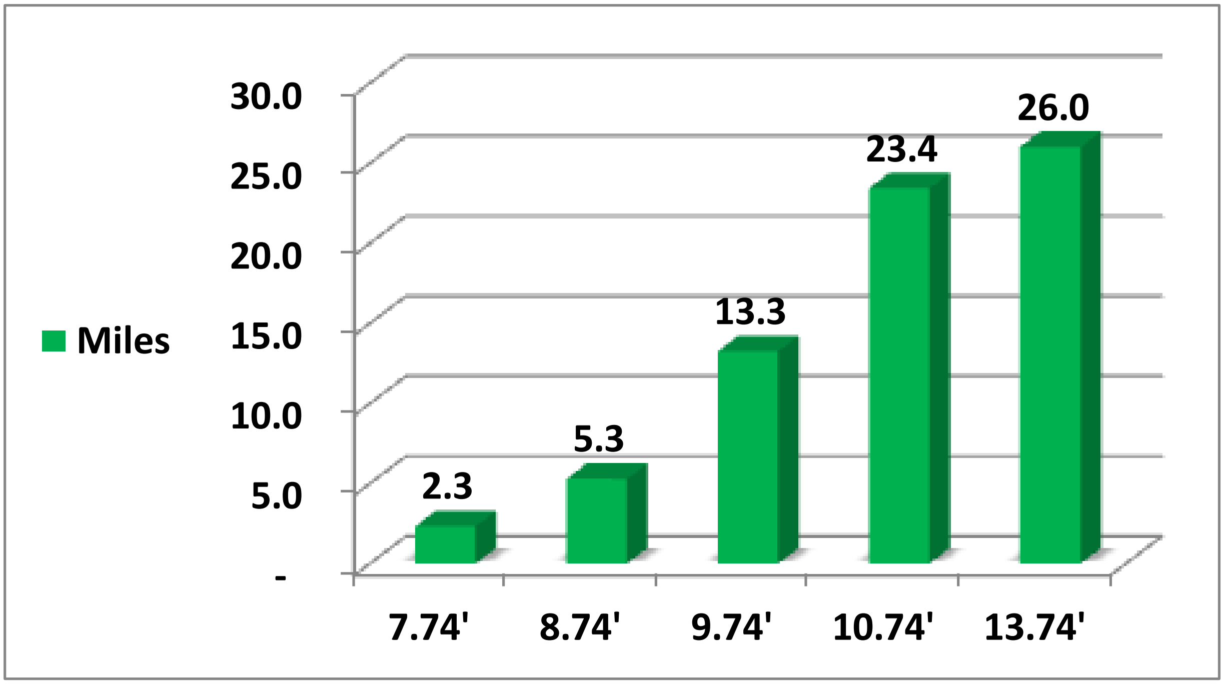

Chart 3. Humboldt Bay, artificial shoreline length in miles by elevation.

The GIS figures below depict the spatial distribution of shoreline segments that are cumulatively less than or equal to: 8.74 feet, 9.74 feet, 10.74 feet, and 13.74 feet.

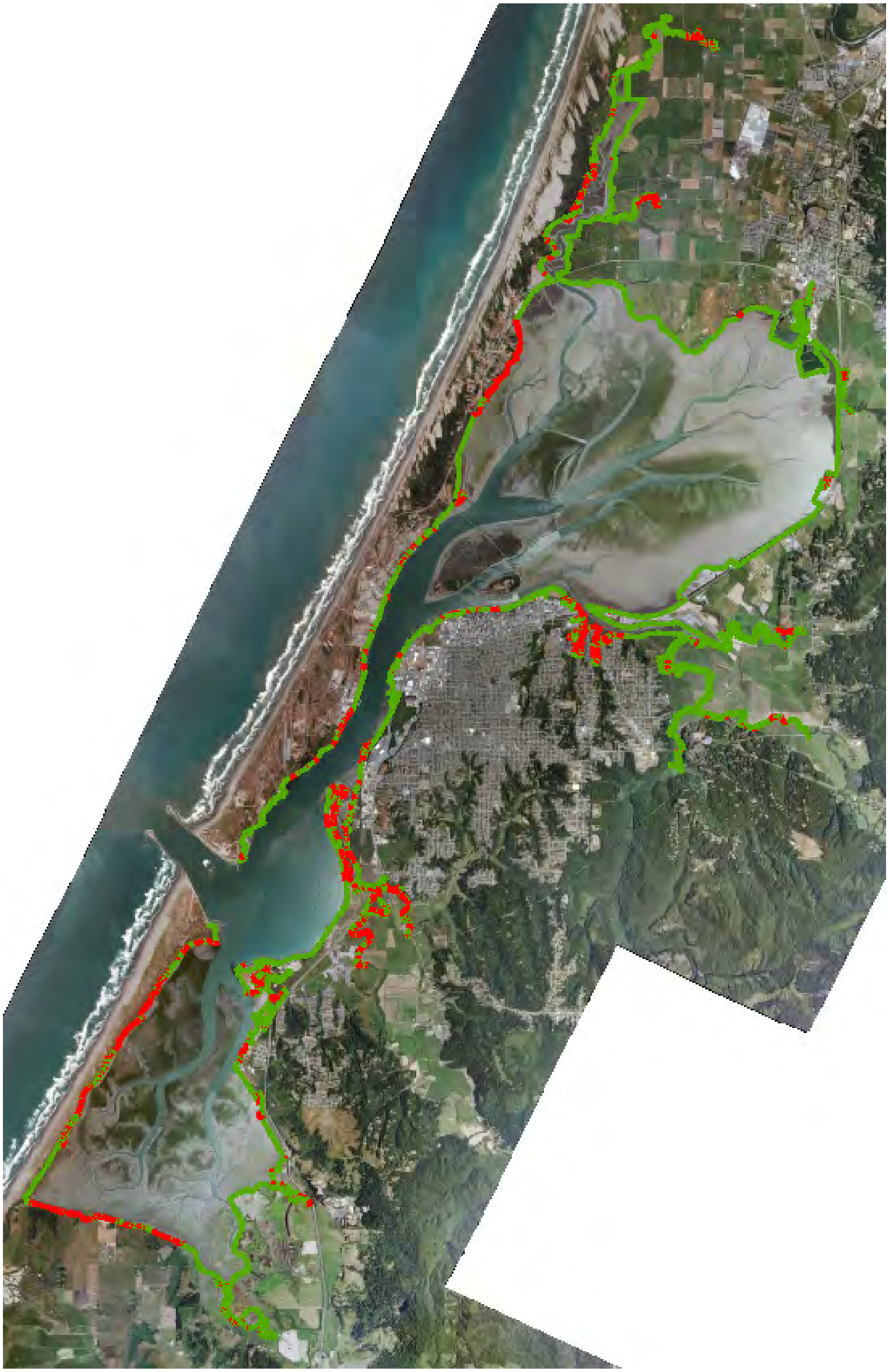

Figure 53. Humboldt Bay shoreline segments with elevations less than or equal to 8.74 feet (red), and segments that are greater than 8.74 feet in elevation (green).

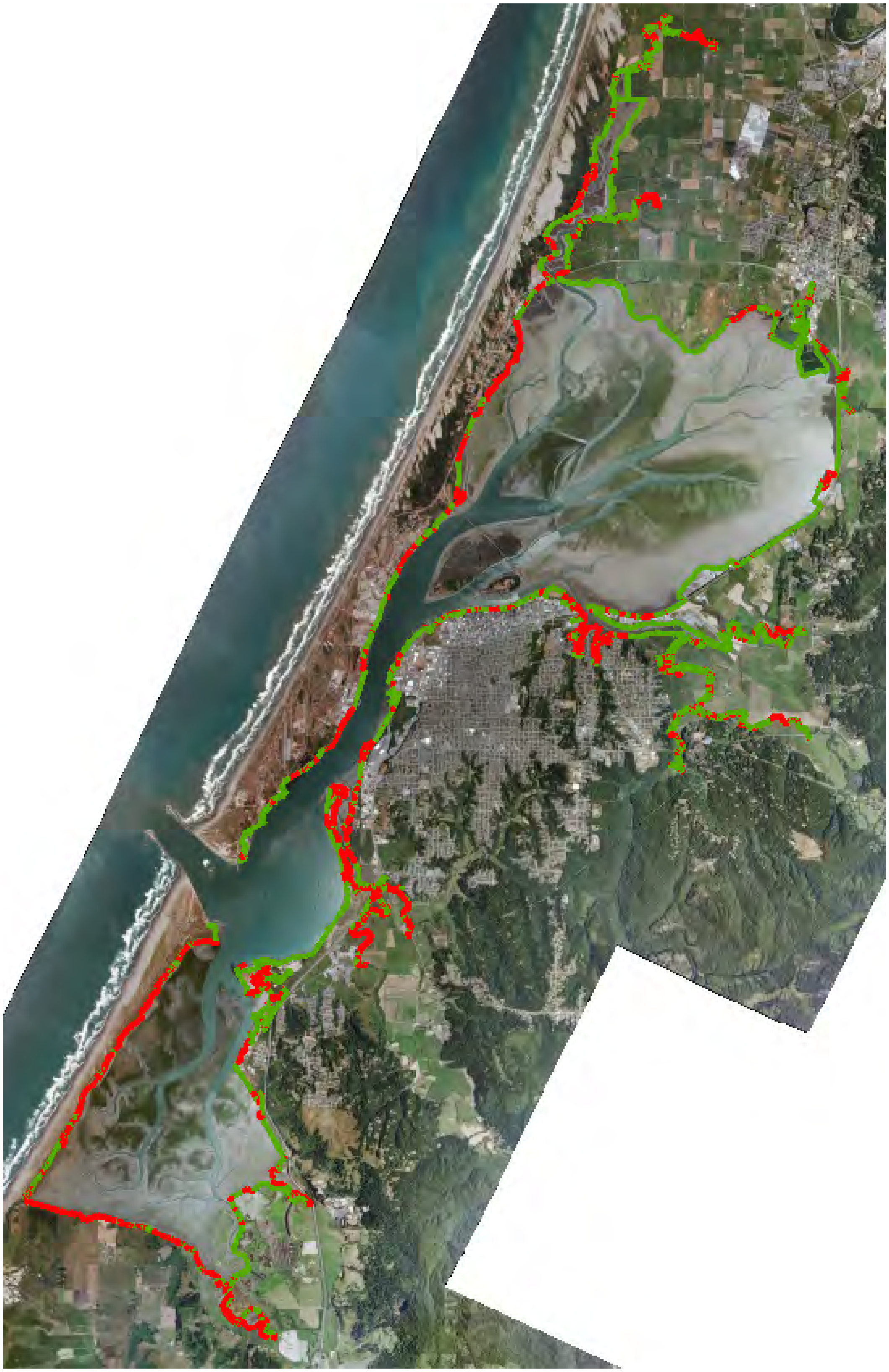

Figure 54. Humboldt Bay shoreline segments with elevations less than or equal to 9.74 feet (red) and segments that are greater than 9.74 feet in elevation (green).

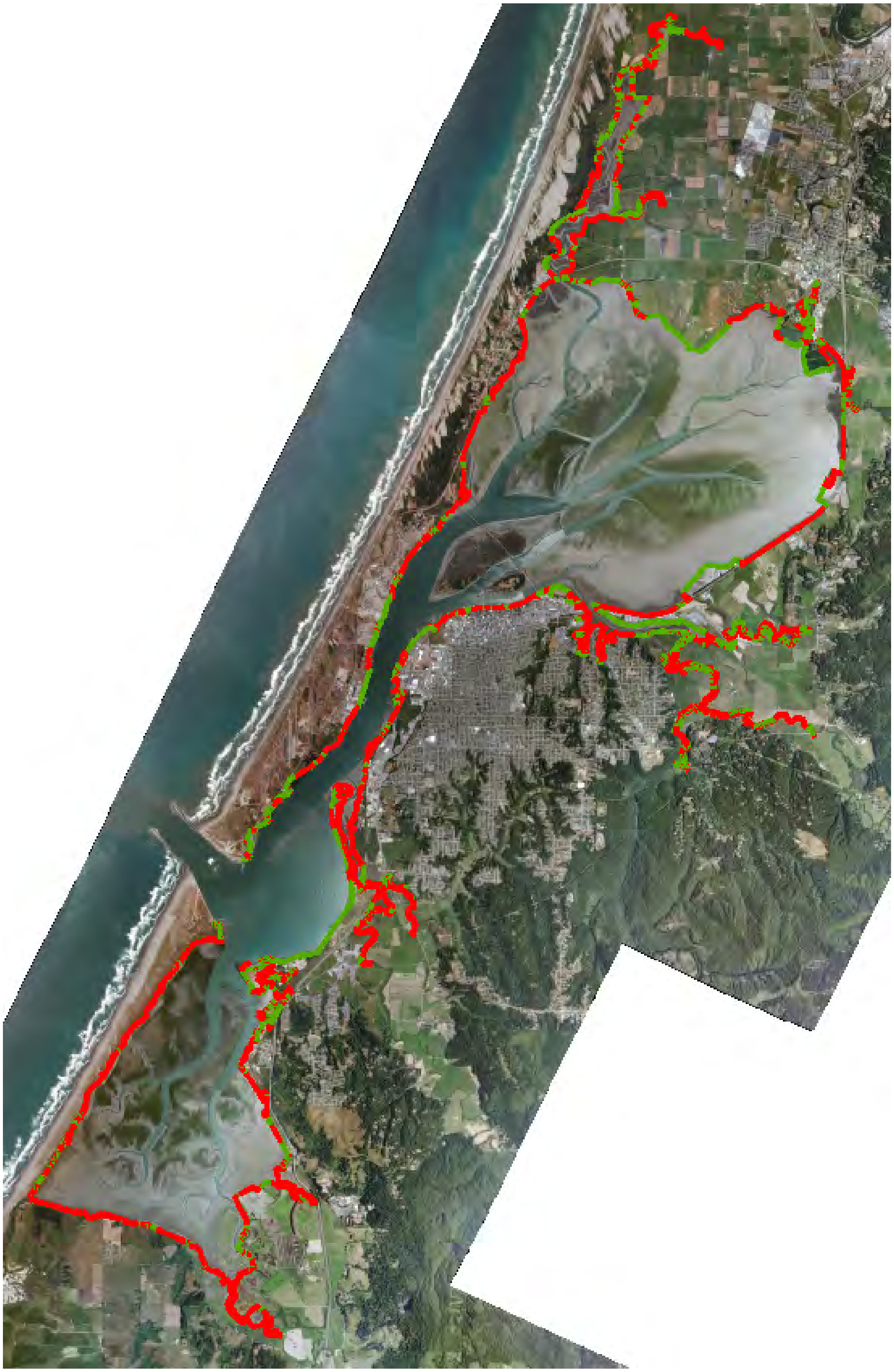

Figure 55. Humboldt Bay shoreline segments with elevations less than or equal to 10.74 feet (red) and segments that are greater than 10.74 feet in elevation (green).

Figure 56. Humboldt Bay shoreline segments with elevations less than or equal to 13.74 feet (red) and segments that are greater than 13.74 feet in elevation (green).

The five most prevalent shoreline structures are: dikes (40.7 miles), railroad (10.5 miles), fill (7.7 miles), fortified (7.6 miles), and roadways (5.0 miles). Table 21 lists shoreline length by elevation for these five structures. One characteristic that these shoreline structures share is that they are flat and of uniform elevation. Almost a third (31.3%) of these structures has a surface elevation between 10 and 11 feet (Chart 4). Cumulatively, 59.3% of these structures are less than or equal to 10.74 feet, and 91.9% of these structures are less than or equal to 13.74 feet.

HUMBOLDT BAY	ELEVATION					TOTAL
Linear (ft)	MMMH	8.74'	9.74'	10.74'	13.74'	FEET
Dike	4,273	12,899	43,184	63,097	79,331	214,792
Railroad	18	375	7,722	28,378	13,850	55,655
Fill	3,573	5,002	10,113	9,105	8,523	40,543
Fortified	1,465	4,426	5,892	9,188	12,046	40,263
Road	593	2,216	3,856	8,344	9,606	26,405
Total	**9,922**	**24,918**	**70,767**	**118,112**	**123,356**	**377,658**
Percent	**2.6%**	**6.6%**	**18.7%**	**31.3%**	**32.7%**	

Table 21. Shoreline structure length by elevation and the total length of the shoreline for five specific structural types: dike, railroad, fill, fortified, and road.

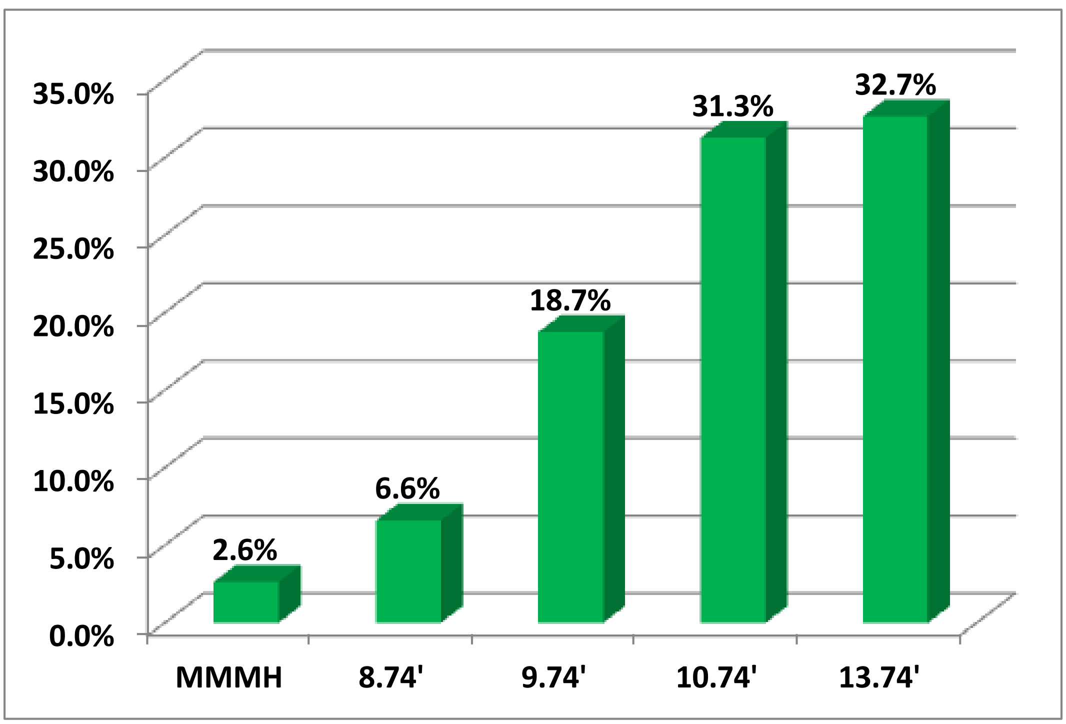

Chart 4. Shoreline structure elevations as a percent of the total length of shoreline for five specific structural types: dike, railroad, fill, fortified, and road.

Arcata Bay:

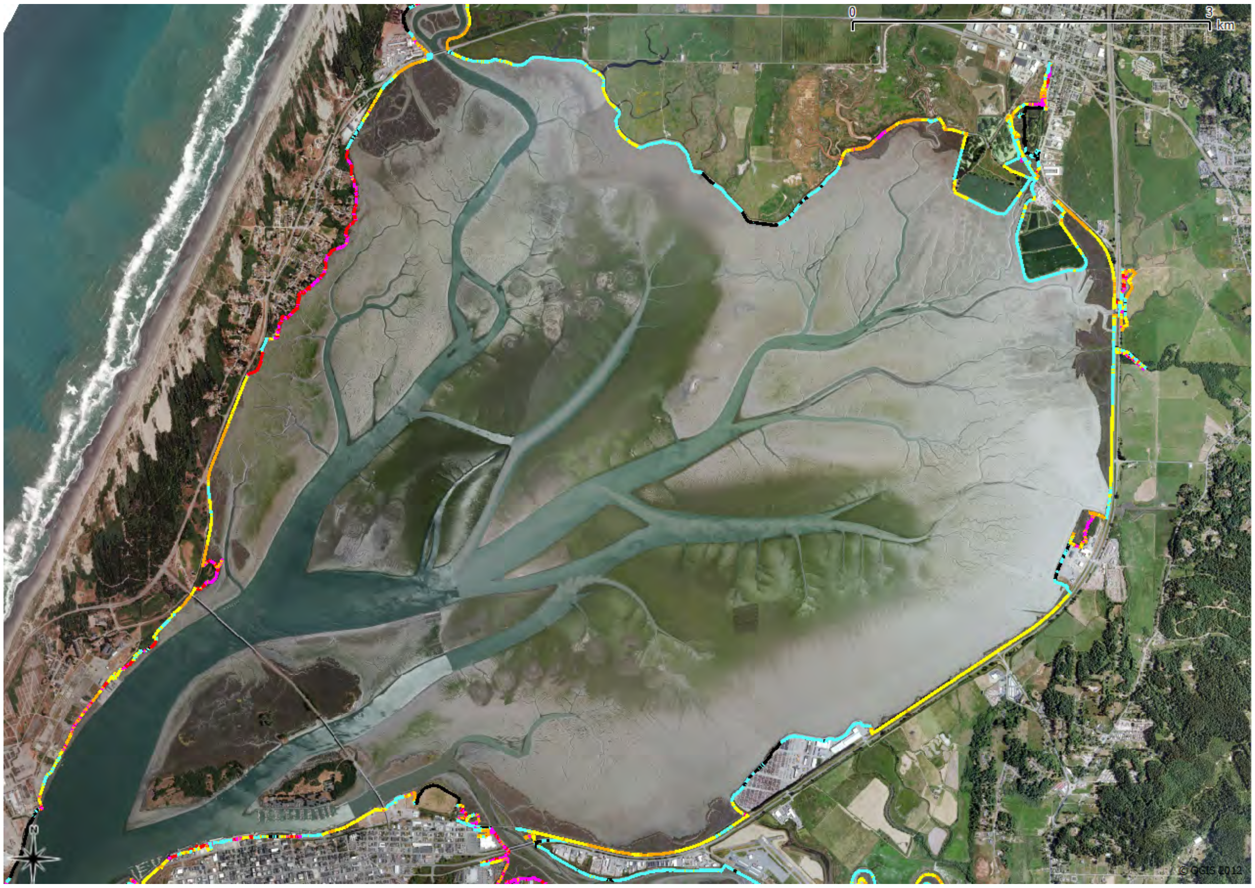

Figure 57. Distribution of shoreline elevations on Arcata Bay: 7.74 feet (red), 8.74 feet (magenta), 9.74 feet (brown), 10.74 feet (yellow), 13.74 feet (turquoise), and greater than 13.74 feet (black).

The shoreline of Arcata Bay is 20.5 miles long; 91% of the shoreline is composed of artificial structures. The two dominant shoreline structures on Arcata Bay are the railroad with 6.5 miles (32%) of the shoreline, and dikes on 6.3 miles (31%) of the shoreline (Table 22). Other types of shoreline structures on Arcata Bay are fill (2.5 miles,12%), the City of Arcata's waste water treatment and marsh ponds (1.9 miles, 9%), and roadways (1.3 miles, 6%). Nearly two thirds (67.4%) of the recently rehabilitated diked shoreline on Arcata Bay is equal to or greater than 13.74 feet in elevation. A significant length, 61.4% of the railroad grade, is at an elevation of 10.74 feet, and 93.9% of the wastewater treatment/marsh pond on Arcata Bay has an elevation of 13.74 feet, although 996 feet is 3 feet lower in elevation.

ARCATA BAY	ELEVATION					TOTAL
Linear (ft)	MMMH	8.74'	9.74'	10.74'	13.74'	FEET
Dike	154	815	4,168	5,645	15,739	33,107
Railroad	-	262	6,939	21,148	5,956	34,431
Fill	468	2,551	2,413	3,065	2,323	12,935
Wastewater Ponds	-	-	-	1,993	9,606	11,599
Road	3	97	1351	996	4,131	6,788
Total	**625**	**3,725**	**14,871**	**32,847**	**37,755**	**98,860**
Percent	**0.6%**	**3.8%**	**15.0%**	**33.2%**	**38.2%**	

Table 22. Arcata Bay shoreline structures and length for each surface elevation class and percentage of shoreline at elevation.

Eureka Bay:

Figure 58. Distribution of shoreline elevations on Eureka Bay: 7.74 feet (red), 8.74 feet (magenta), 9.74 feet (brown), 10.74 feet (yellow), 13.74 feet (turquoise), and greater than 13.74 feet (black).

The shoreline of Eureka Bay is 15.9 miles long; 71% of the shoreline is composed of artificial structures. The dominant artificial shoreline structures on Eureka Bay are fortified (5.6 miles, 35%), railroad (1.7 miles, 10%), fill (1.2 miles, 8%), bulwark (0.7 miles, 5%), and roadways (0.7 miles, 5%)(Table 23).

EUREKA BAY	**ELEVATION**					**TOTAL**
Linear (ft)	**MMMH**	**8.74'**	**9.74'**	**10.74'**	**13.74'**	**FEET**
Dike	166	285	537	266	128	3,077
Railroad	-	-	517	3,229	1,112	8,794
Fill	188	521	755	2,293	2,355	6,308
Fortified	1,167	1,985	3,573	6,537	9,280	29,657
Bulwark	463	159	400	785	1,735	3,916
Roads	47	268	229	1,905	892	3,852
Total	**2,030**	**3,218**	**6,011**	**15,015**	**15,502**	**55,604**
Percent	**3.7%**	**5.8%**	**10.8%**	**27.0%**	**27.9%**	

Table 23. Eureka Bay shoreline structures and length for each surface elevation class and percentage of shoreline at each elevation.

South Bay:

Figure 59. Distribution of shoreline elevations on South Bay: 7.74 feet (red), 8.74 feet (magenta), 9.74 feet (brown), 10.74 feet (yellow), 13.74 feet (turquoise), and greater than 13.74 feet (black).

The shoreline of South Bay is 21.8 miles long; 68% of the shoreline is composed of artificial structures. The two dominant artificial shoreline structures on South Bay are earthen dikes (7.6 miles, 35%), fill (2.6 miles, 12%), fortified (1.5 miles, 7%), and railroad (1.4 miles, 6%)(Table 24). A significant portion of the diked shoreline on South Bay is at an elevation of 9.74 feet (39.0%) or at 10.74 feet (39.0%). A significant portion of the railroad grade, 50.4%, is at an elevation of 10.74 feet.

SOUTH BAY	ELEVATION					TOTAL
Linear (ft)	MMMH	8.74'	9.74'	10.74'	13.74'	FEET
Dike	653	2,318	15,646	15,655	5,679	40,215
Railroad	-	-	89	3,626	3,503	7,197
Fill	1,972	2,155	2,462	2,710	2,464	13,816
Fortified	1,129	1,106	1,453	2,290	2,400	8,019
Road	313	825	142	**1,133**	**1,260**	3607
Total	**4,067**	**6,404**	**19,792**	**25,414**	**15,306**	**72,854**
Percent	**5.6%**	**8.8%**	**27.2%**	**34.9%**	**21.0%**	

Table 24. South Bay shoreline structures and length for each surface elevation class and percentage of shoreline at each elevation.

Mad River Slough:

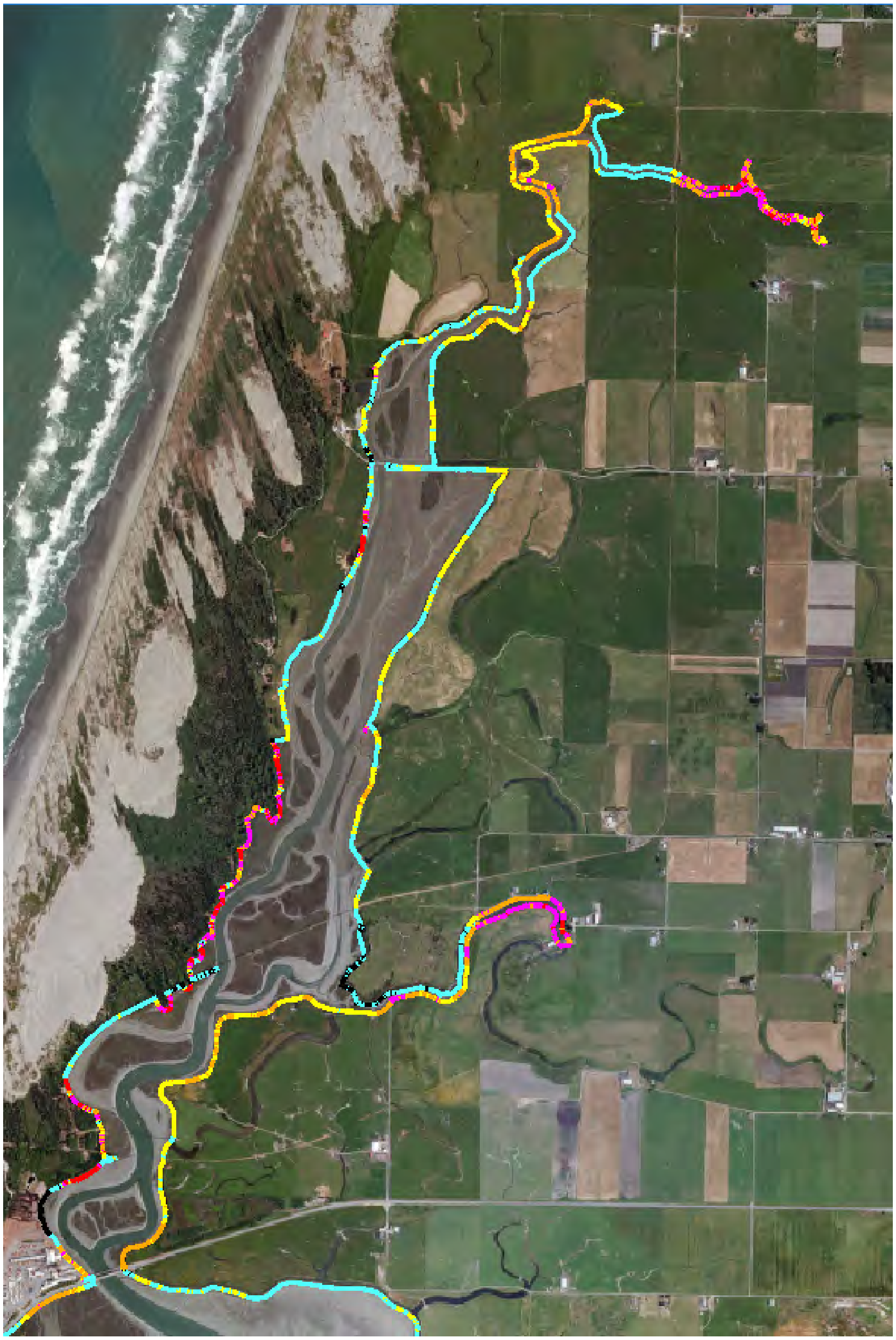

Figure 60. Distribution of shoreline elevations on Mad River Slough: 7.74 feet (red), 8.74 feet (magenta), 9.74 feet (brown), 10.74 feet (yellow), 13.74 feet (turquoise), and greater than 13.74 feet (black).

The shoreline of Mad River Slough is 13.7 miles long; 80% of the shoreline is composed of artificial structures. The dominant artificial shoreline structures are dikes (9.0 miles, 66%), roadway (1.0 miles, 7%), and an abandoned historic Hammond Railroad Grade (0.6 miles, 4%)(Table 25). A significant portion, 42.3%, of the artificial shoreline is at an elevation of 13.74 feet.

MAD RIVER SLOUGH	ELEVATION					TOTAL
Linear (ft)	MMMH	8.74'	9.74'	10.74'	13.74'	FEET
Dike	431	2,330	8,636	15,172	19,274	47,471
Railroad	-	-	-	77	2,462	2,968
Fill	3	3	79	52	445	469
Fortified	-	59	396	159	248	1,345
Road	9	477	1,133	1,522	1,795	5,050
Total	**443**	**2,869**	**10,244**	**16,982**	**24,224**	**57,303**
Percent	**0.8%**	**5.0%**	**17.9%**	**29.6%**	**42.3%**	

Table 25. Mad River Slough shoreline structures and length for each surface elevation class and percentage of shoreline at each elevation.

Eureka Slough:

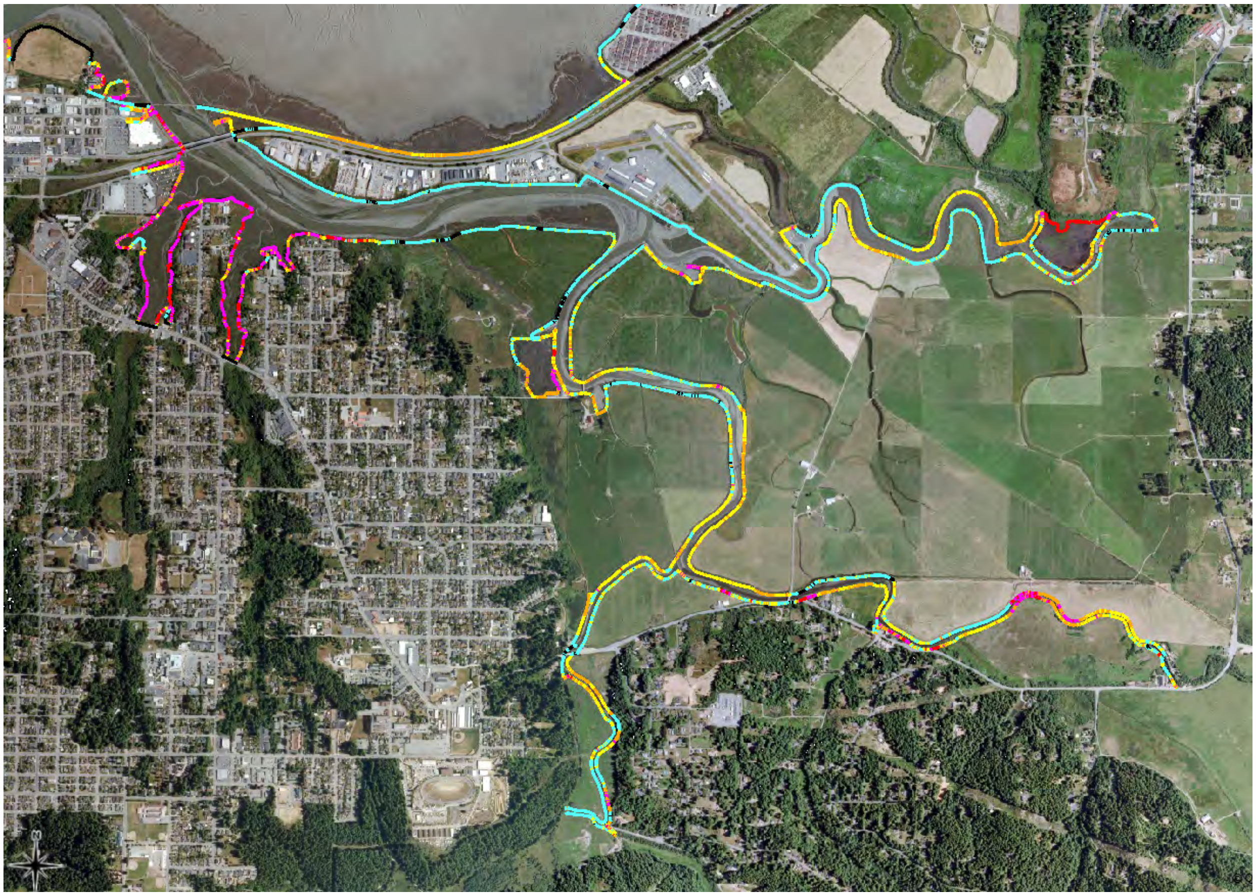

Figure 61. Distribution of shoreline elevations on Eureka Slough: 7.74 feet (red), 8.74 feet (magenta), 9.74 feet (brown), 10.74 feet (yellow), 13.74 feet (turquoise), and greater than 13.74 feet (black).

The shoreline of Eureka Slough is 20.8 miles long; 80% of the shoreline is composed of artificial structures. The dominant shoreline structures are earthen dikes (14.3 miles, 69%), fill (1.2 miles, 6%), and roadway (0.7 miles, 3%) (Table 26). A significant portion, 45.7%, of the artificial shoreline is at an elevation of 13.74 feet.

EUREKA SLOUGH	ELEVATION					TOTAL
Linear (ft)	MMMH	8.74'	9.74'	10.74'	13.74'	FEET
Dike	689	1,465	10,312	23,929	37,332	75,588
Railroad	18	113	164	166	102	551
Fill	828	1,893	1,451	961	924	6,059
Fortified	-	3	66	75	16	163
Road	147	427	866	641	959	3,666
Total	**1,682**	**3,901**	**12,859**	**25,772**	**39,333**	**86,027**
Percent	**2.0%**	**4.5%**	**14.9%**	**30.0%**	**45.7%**	

Table 26. Eureka Slough shoreline structures and length for each surface elevation class and percentage of shoreline at each elevation.

Elk River Slough:

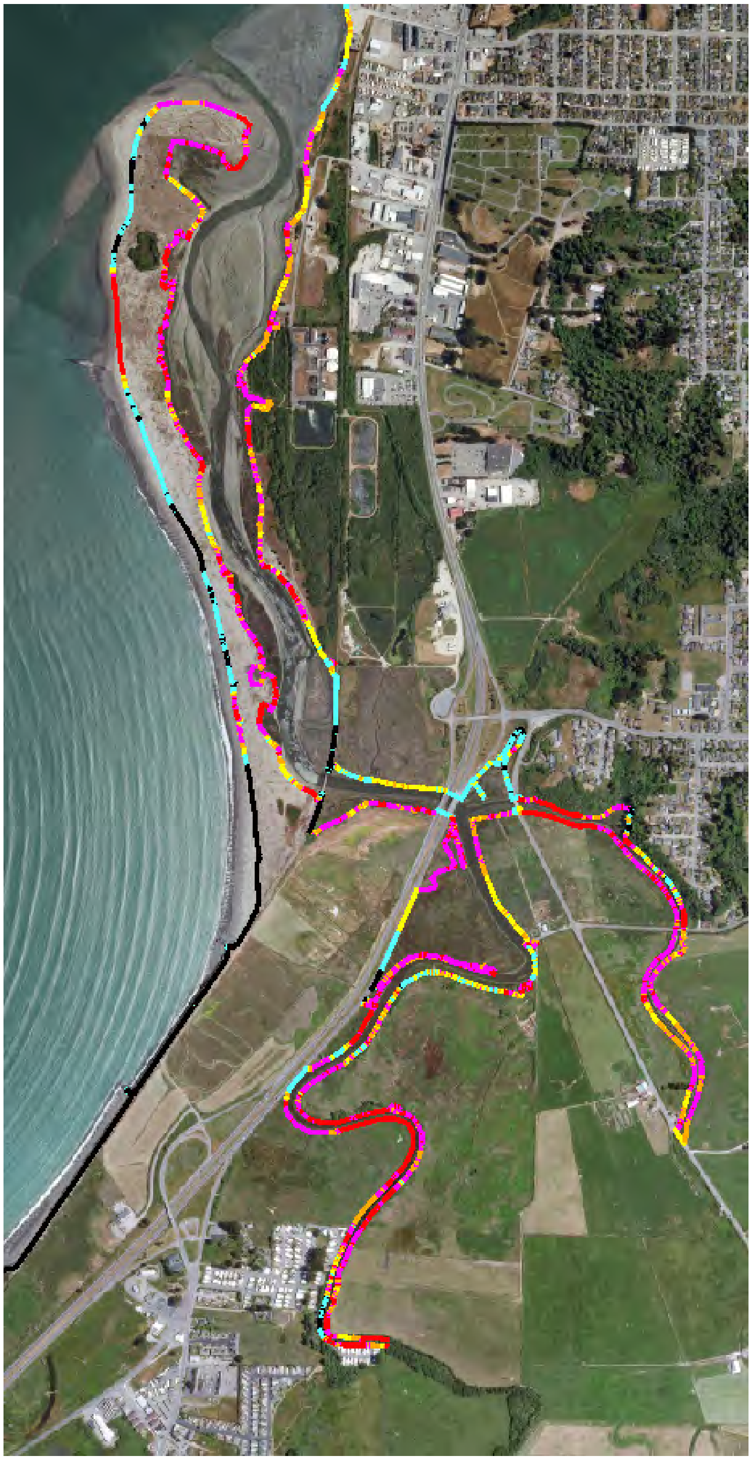

Figure 62. Distribution of shoreline elevations on Elk River Slough: 7.74 feet (red), 8.74 feet (magenta), 9.74 feet (brown), 10.74 feet (yellow), 13.74 feet (turquoise), and greater than 13.74 feet (black).

The shoreline of Elk River Slough is 9.7 miles long; 5.4 miles (55%), of the shoreline is natural and 4.2 miles, (45%) of the shoreline is composed of artificial structures. The three dominant shoreline structures are natural (3.0 miles, 31%), earthen dikes (2.9 miles, 30%), and foredunes (1.7 miles, 18%) (Table 27). Other types of shorelines are roadway (0.6 miles, 7%), and railroad (0.3 miles, 3%). A significant portion, 4,500 feet, of the upper tidal reach of Elk River Slough, has natural channel banks, 31% at an elevation 7.74 feet, and 37.2% at 8.74 feet. 51.3% of the earthen dikes are also at an elevation less than or equal to 8.74 feet.

ELK RIVER SLOUGH	ELEVATION					TOTAL
Linear (ft)	MMMH	8.74'	9.74'	10.74'	13.74'	FEET
Dike	2,180	5,685	3,885	2,420	1,179	15,334
None	4,938	5,916	3,013	1,706	438	15,919
Fore dune	3,000	3,772	1,341	991	147	9,246
Road	75	122	136	829	1,884	3,443
Railroad	-	-	13	131	714	1,714
Total	**10,193**	**15,495**	**8,388**	**6,077**	**4,362**	**45,656**
Percent	**22.3%**	**33.9%**	**18.4%**	**13.3%**	**9.6%**	

Table 27. Elk River Slough shoreline structures and length for each surface elevation class and percentage of shoreline at each elevation.

d) Salt Marsh

The salt marsh habitat present today is less than 900 acres (Pickart 2001), significantly less than the nearly 9,000 acres mapped in 1870 (USCGS) (Figure 63); large areas of salt marsh dissected by tidal tributary channels which were once common around the Bay and in the Sloughs, are now rare.

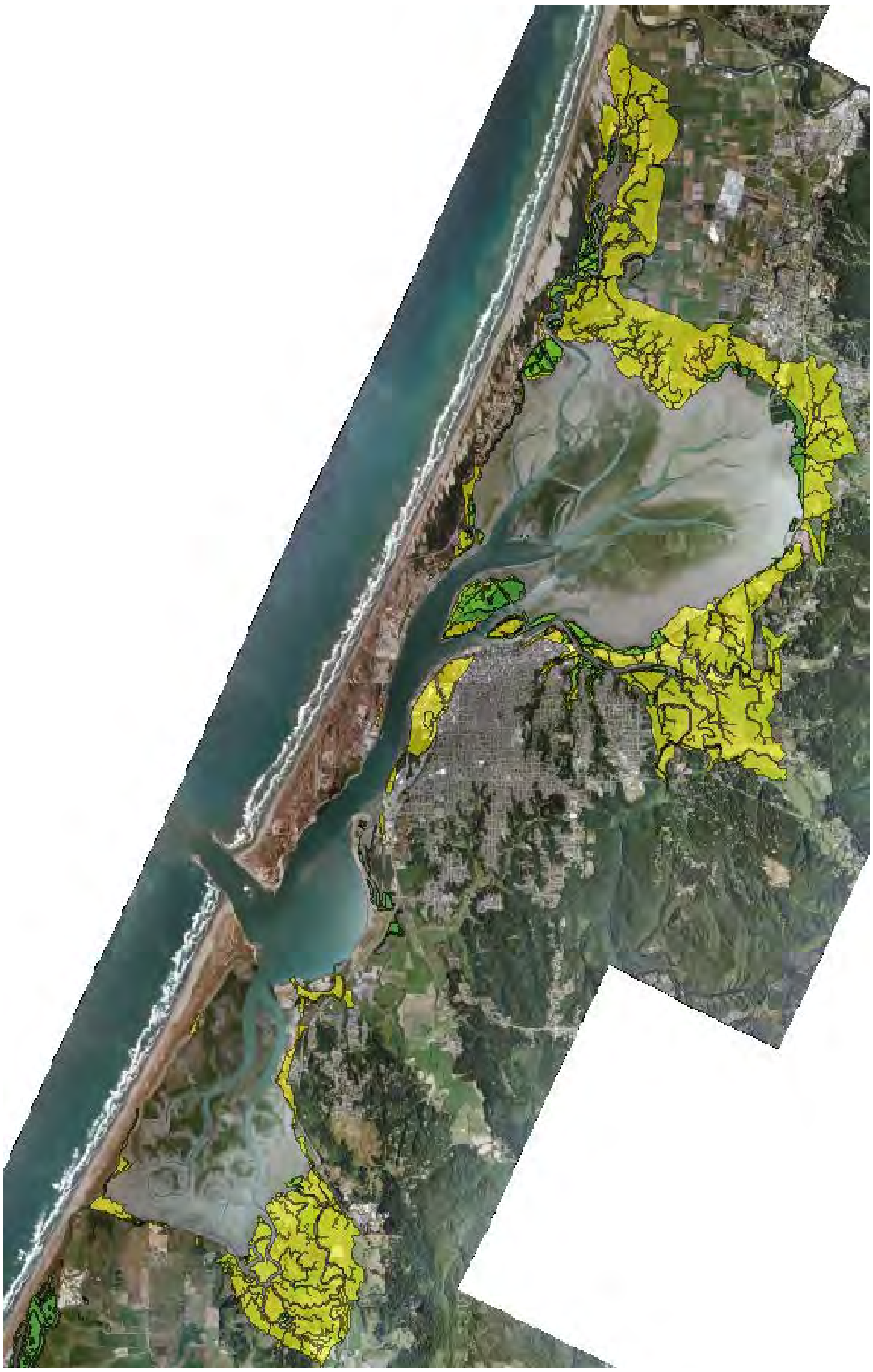

Figure 63. Humboldt Bay, salt marsh distribution and extent; 1870 (yellow) versus 2009 (green).

The presence of salt marsh habitat was one of the attributes used to stratify shoreline into segments. Salt marsh was present on 48.5 miles, brackish marsh occurred on 1.5 miles, and tidal marsh was absent from 52.3 miles of shoreline (Chart 5).

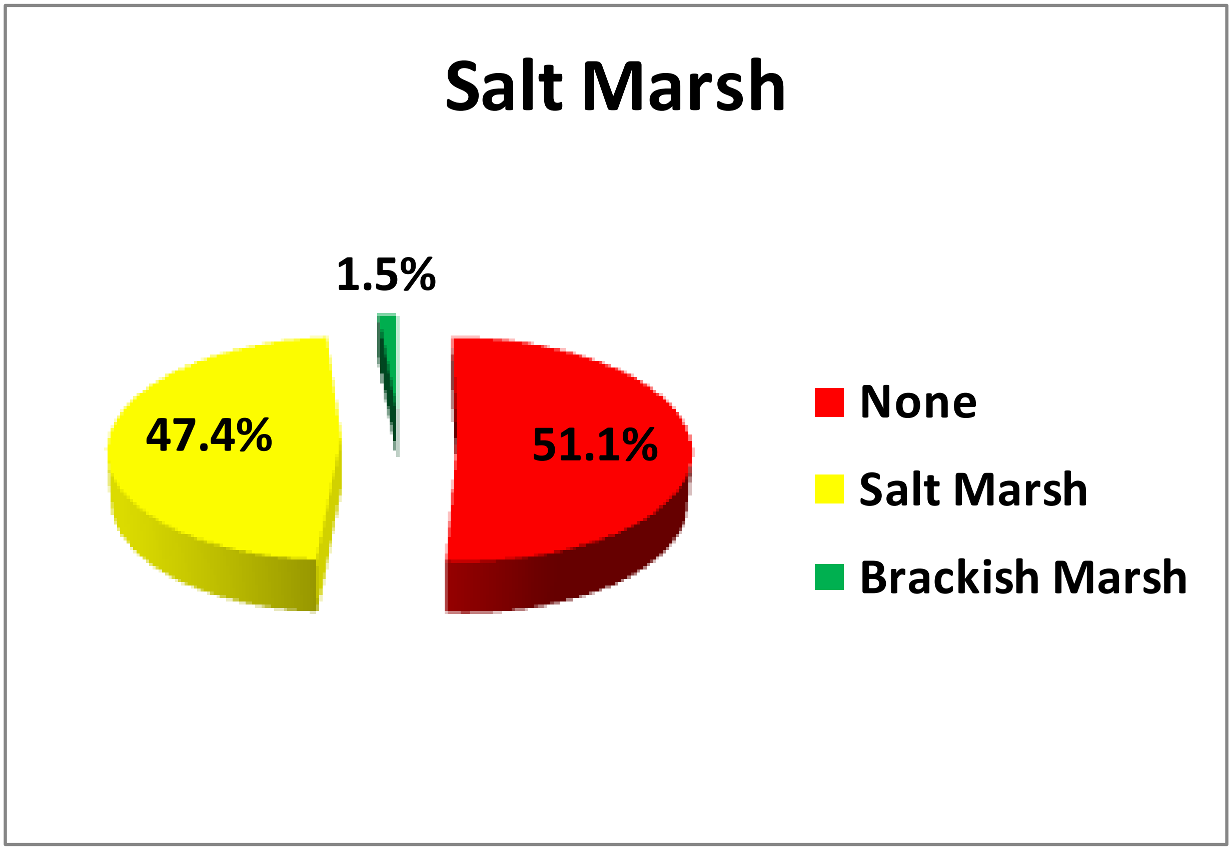

Chart 5. Percentage of shoreline with tidal or brackish marshes.

Salt marsh is spatially associated with several shoreline structures that cover 32.7 miles: building, bulwark, cliff/bluff, jetty, dike, pond, railroad, road, and tidegate (Table 28). Dikes support salt marsh habitats on 18.1 miles, railroad on 7.9 miles, fill on 4.3 miles, roads on 3.0 miles, and cliff/bluffs on 2.2 miles. Salt marsh is present on 10.9 miles of shoreline composed of foredune and natural shoreline with no structure (none).

STRUCTURE	Salt Marsh Present (ft)
Building	256
Bulwark	373
Cliff/Bluff	11,944
Dike	95,798
Fill	22,555
Fore Dune	6,758
Fortified	3,130
Jetty	703
None	50,950
Pond	6,046
Railroad	41,858
Road	15,564
Tidegate	40
TOTAL	**255,975**

Table 28. Shoreline structure and length in feet of associated tidal marshes.

The distribution of tidal marshes on Humboldt Bay is not uniform (Table 29) (Figure 62). Most of the natural shoreline in Arcata Bay has salt marsh present (92%); even the artificial shoreline in Arcata Bay is predominantly associated with salt marsh (59%), and there is a minor component of brackish marsh on Butcher Slough (1%). On Eureka Bay, the majority of the shoreline is without salt marsh (84%), and on South Bay, the greater part of the shoreline is also without salt marsh (59%). Most of the salt marsh in South Bay is associated with South Spit. Salt marsh is prevalent on the natural shoreline of Mad River Slough (76%), and on its artificial shoreline it is evenly split between present (49%) or absent (51%). On Eureka Slough the majority of the shoreline has salt marsh present (53%), as well as brackish marsh (6%). Elk River Slough is also mostly associated with salt marsh (61%).

TIDAL MARSH TYPE (ft)	ARCATA BAY	EUREKA BAY	SOUTH BAY	MAD RIVER SLOUGH	EUREKA SLOUGH	ELK RIVER SLOUGH	TOTAL FEET
None	39,762	70,879	67,826	32,998	45,015	19,846	276,325
Salt Marsh	67,275	13,025	46,907	39,133	58,255	31,380	255,974
Brackish Marsh	1,068	0	522	0	6,418	0	8,008
Total	**108,104**	**83,903**	**115,255**	**72,131**	**109,688**	**51,226**	

Table 29. Shoreline length with tidal marsh by hydrologic unit in feet.

During inventory and mapping, 57 areas were located where salt marsh habitat exists which was not delineated on the 2009 NOAA benthic habitat mapping (Figure 64). These salt marsh areas were found either within the Bay or slough channels or hydrologically connected with the Bay via large diameter culverts or breached dikes. However, the extent of these salt marsh habitats has not been delineated by this project.

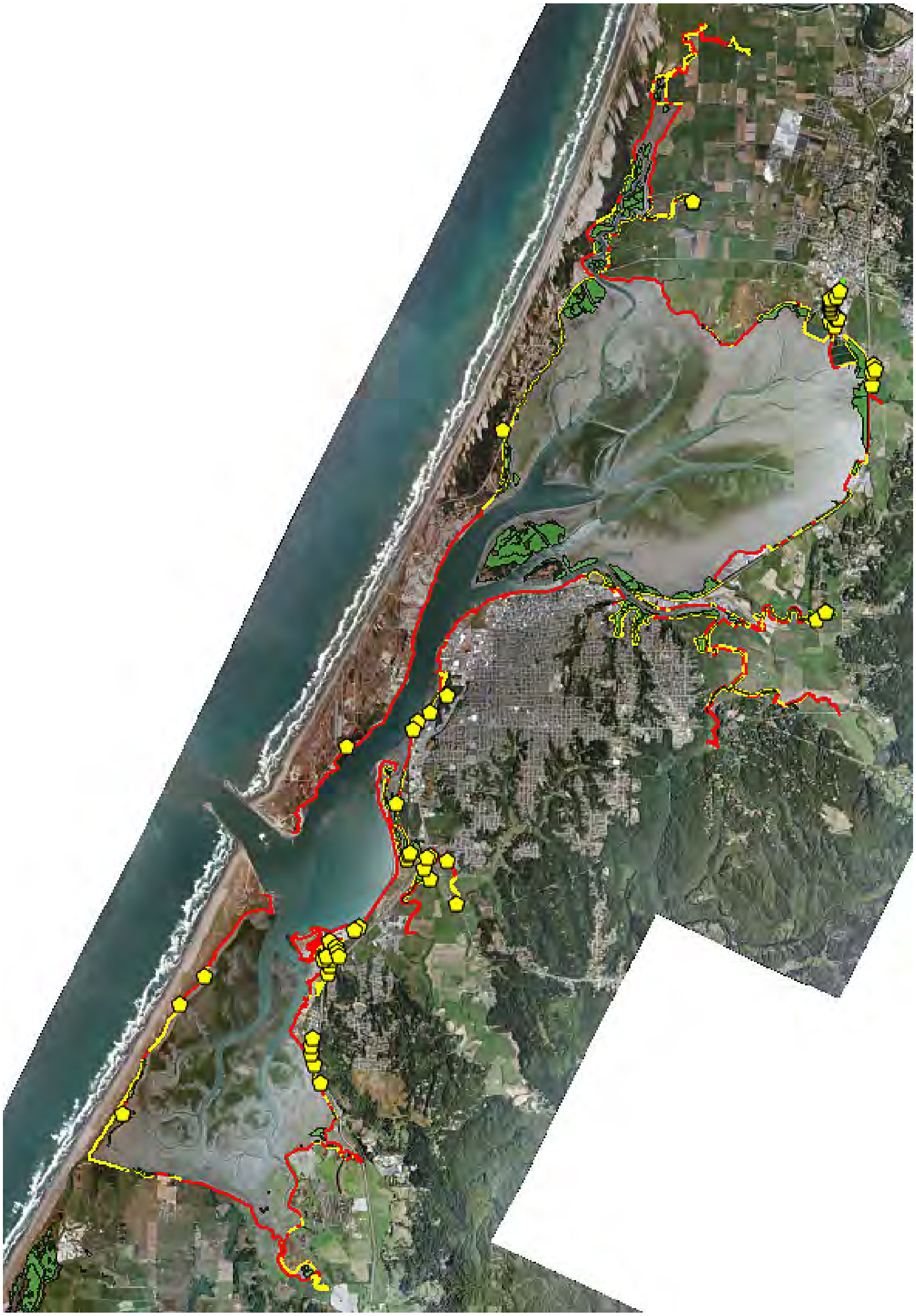

Figure 64. Distribution of shoreline with salt marsh (yellow), without salt marsh (red) and the location of previously un-mapped salt marsh (yellow shield).

e) Water Control Structure

A total of 36 water control structures have been added to USFWS' 2007 water control structures database. The location and type of water control structures have been verified in the field; 18 culverts and 18 tidegates were found at 28 locations (Figure 65).

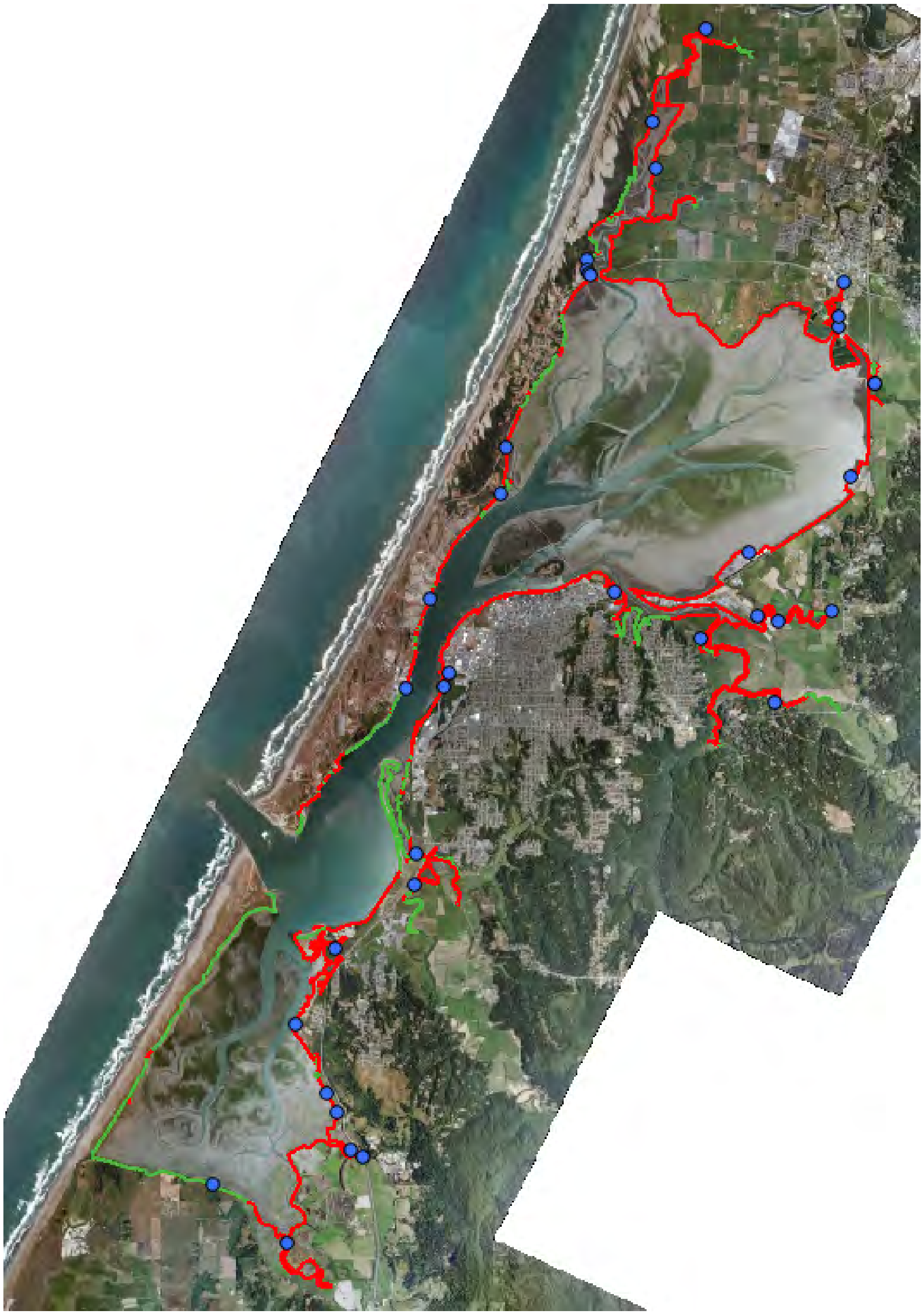

Figure 65. Humboldt Bay, 36 additional water control structures (blue) have been added to USFWS's 2007database.

4 Shoreline Vulnerability Assessment

This chapter will assess the vulnerability of the existing shoreline, to erosion or flooding, under current tidal conditions, and to elevated sea levels. The vulnerability assessment will identify land uses and infrastructure that could be affected if the existing shoreline were to fail to retain the tides. The ability of existing salt marsh habitat areas to migrate with rising sea levels will also be assessed.

This shoreline vulnerability assessment will consider both shoreline structure/cover and shoreline elevations (Figure 66).

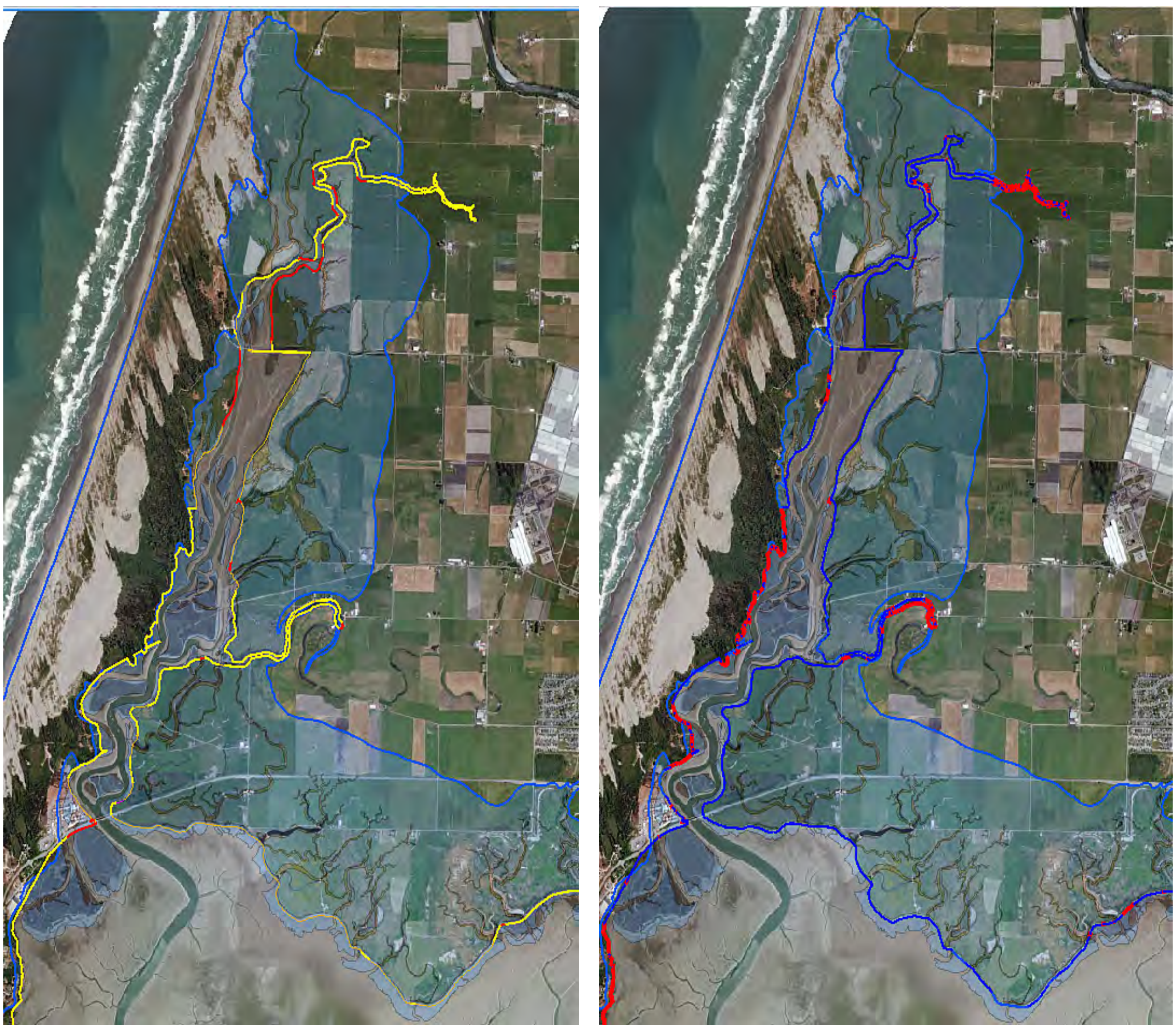

Figure 66. Mad River Slough depicting the location of exposed (red) and unfortified (yellow) shoreline cover on the left versus the location of shoreline elevations that are less than or equal to EHT (red) on the right, and the 1870 tidal inundation footprint.

Shoreline structures such as dikes protect land uses, infrastructure, and resources that reside on former tidelands, from salt water flooding. During the more than 100 years that these former tidelands have been isolated from daily tidal inundation, compaction has lowered their surface elevation, and tectonic subsidence is suspected of also lowering these lands' surfaces. Within the historic tidal footprint, reside land uses, infrastructure, and resources that are important to the Humboldt Bay region. Without a sea level rise inundation model specific to Humboldt Bay, the historic tidal-upland boundary, as surveyed in 1870 by the USCGS, is being used as a minimum or conservative inundation footprint for this shoreline vulnerability assessment (Figures 67 and 68).

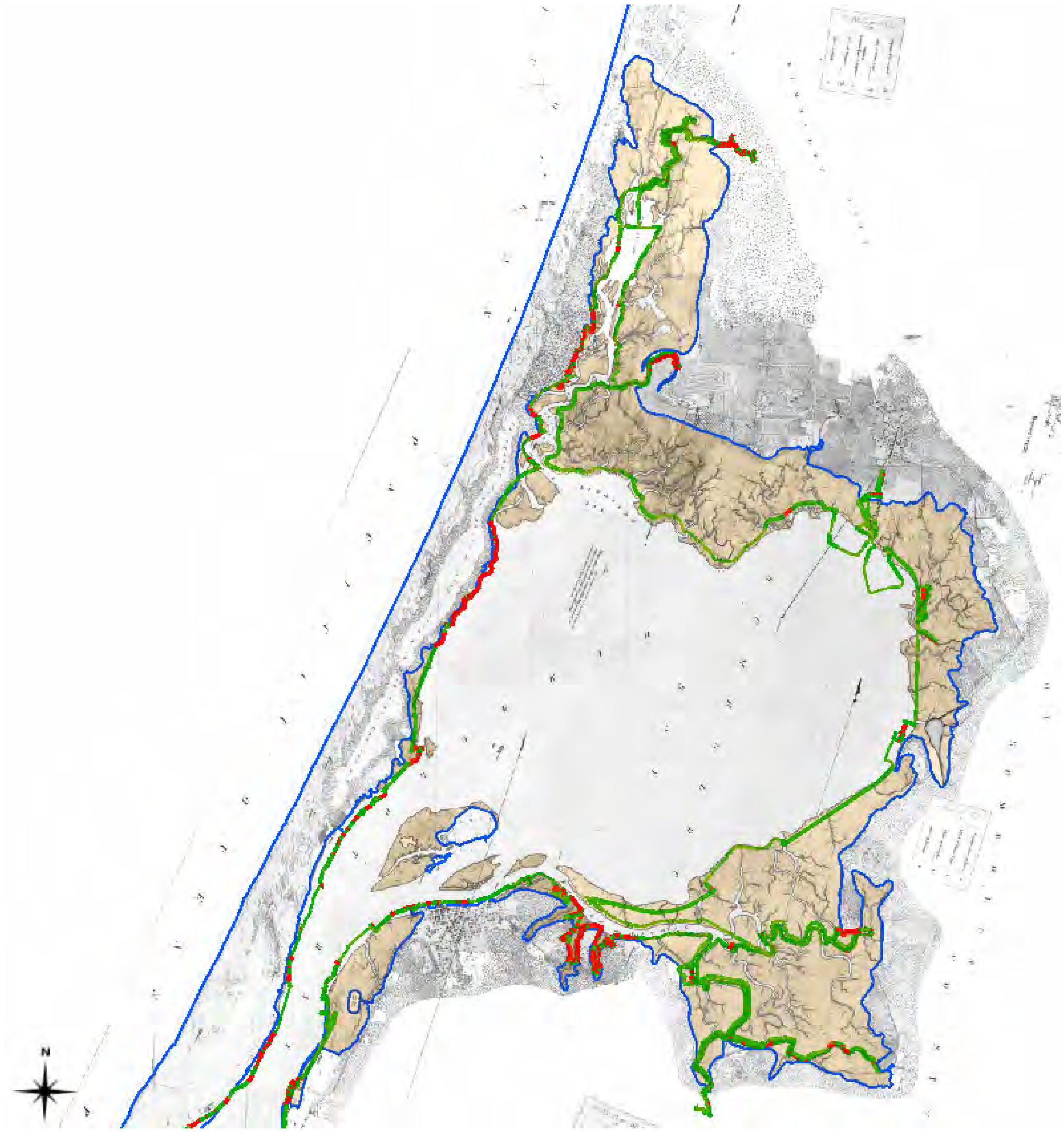

Figure 67. Arcata Bay, Mad River Slough, and Eureka Slough, 2009 shoreline elevations for EHT (red) and shorelines higher in elevation (green) with the 1870 tidal inundation footprint and tidal-upland shoreline (blue) (Laird 2007) on the 1870 USCGS map.

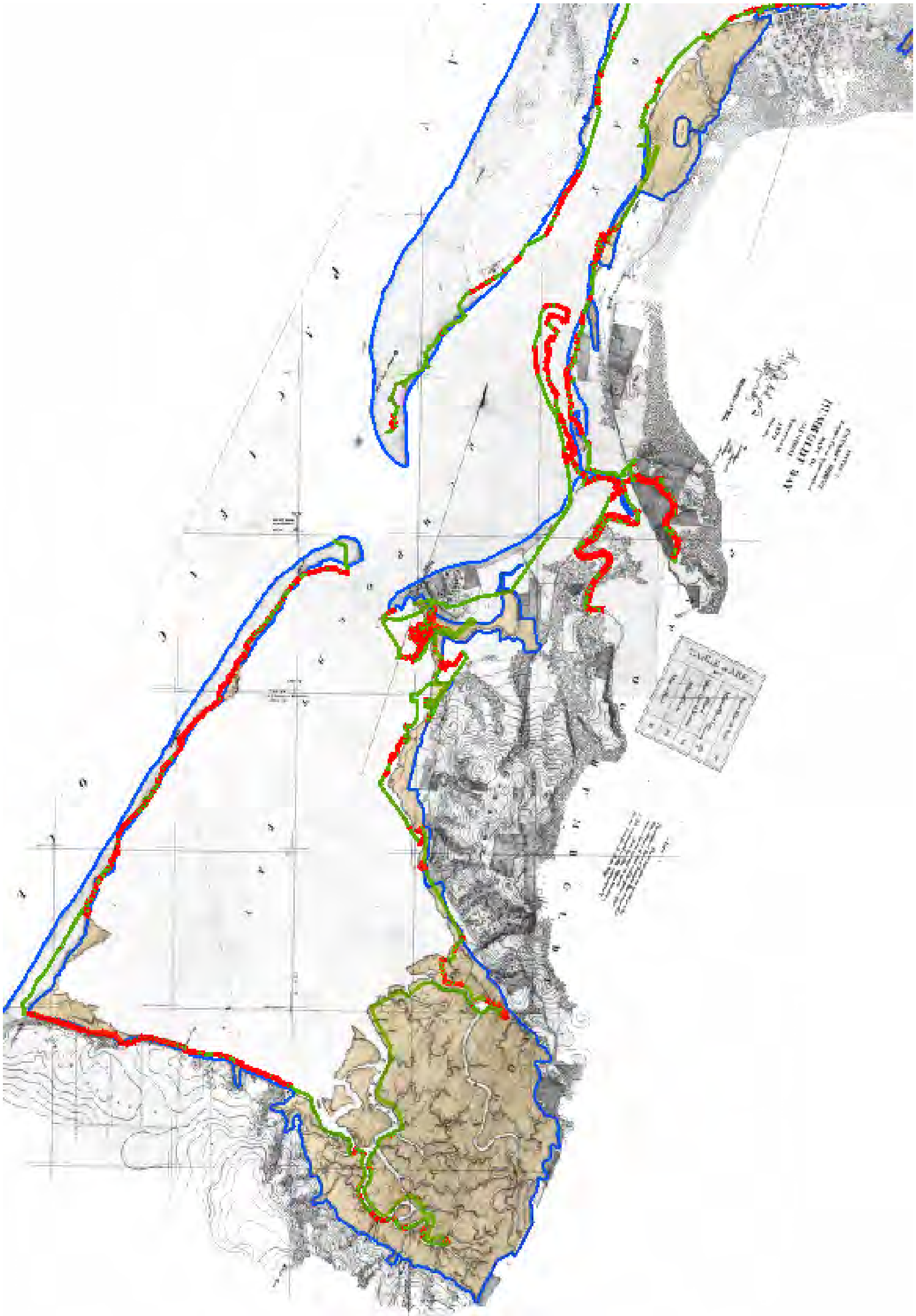

Figure 68. Eureka and South Bays, Elk River Slough, 2009 shoreline elevations for EHT (red) and shorelines higher in elevation (green) with the 1870 tidal inundation footprint and tidal-upland shoreline (blue) (Laird 2007) on the 1870 USCGS map.

This vulnerability assessment describes each hydrologic unit's land uses, infrastructure, and resources that reside in the historic tidal inundation zone that potentially could be flooded if shoreline failure were to occur.

Sea Level Rise

Sea level rise, as used in this vulnerability assessment, is in relation to the MMMW elevation of 7.74 feet measured at the North Spit tidal station. When the Moon is at its closest to Earth, at perigee, and when this occurs during a new or full moon phase, the high tides may be greater than normal. On average each year on Humboldt Bay, we experience one foot of sea level rise during some very high tides. Recently, these very high tides in the winter months have become known as King Tides; otherwise called extreme or annual maximum high tides. King Tides can occur for several days; typically from November through January.

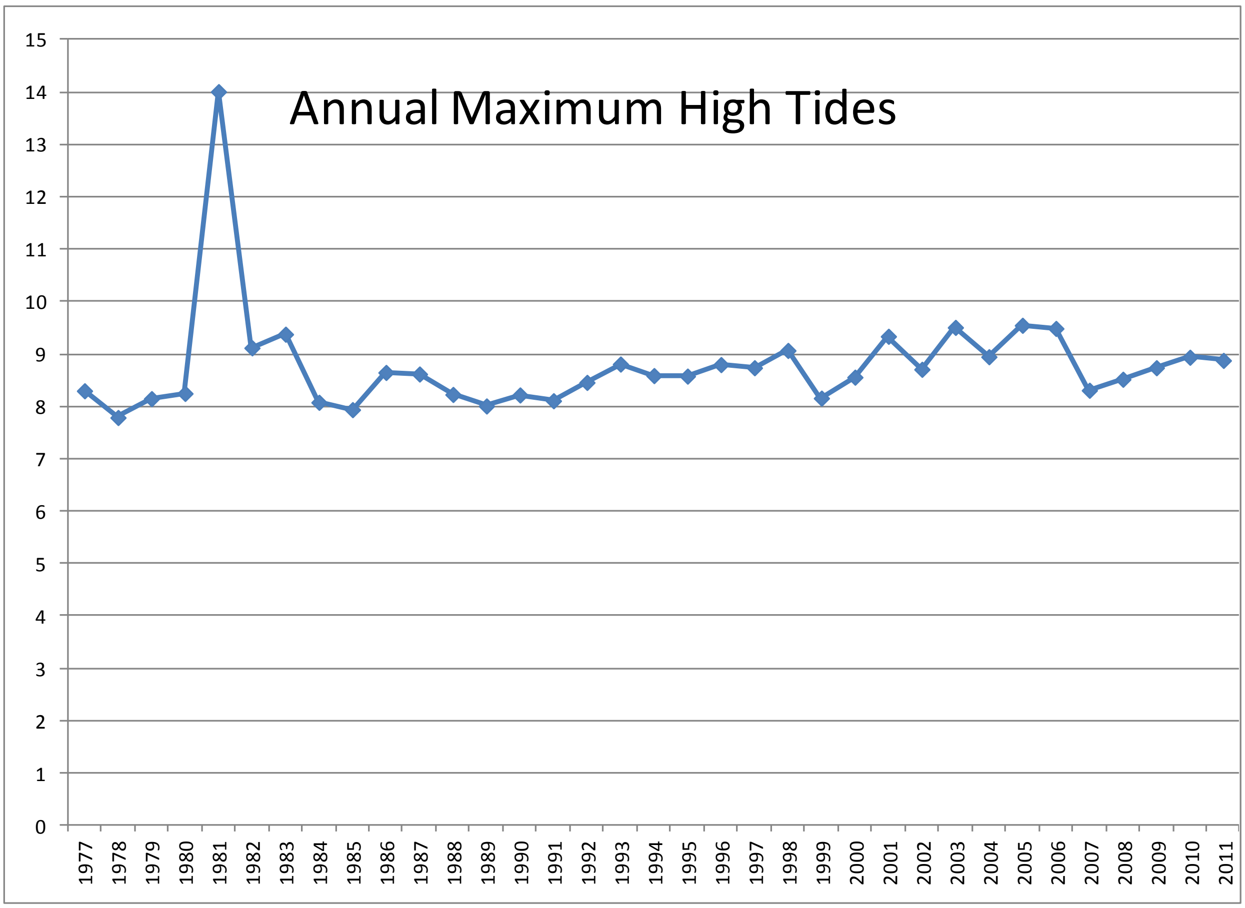

Chart 6. Annual maximum high tide, 1977 through 2011, average annual maximum high tide is 8.79 feet at the north spit tidal datum.

Since 1977, twelve of the annual EHT have exceeded the average annual maximum high tide of 8.79 feet, and since 2000, seven have been greater (Chart 6). El Nino events can also cause elevated tide elevations of 12 inches or more for several months (Griggs 2012). The most recent El Nino events occurred during 1982/1983 and 1997/1998. A combination of King Tides and El Nino event could raise sea levels several feet, even more with storm surges.

During the last 100 years, sea level along California's coast has increased an average of 7 inches (2009 California Climate Adaption Strategy). However, according to the North Spit station records, sea level is rising in Humboldt Bay at a rate of 18.6 inches per century, which is the highest rate in California; Humboldt Bay is subsiding (Russell 2012). The combination of EHT during strong El Nino events or during periods of heavy precipitation can lead to short-term increases in sea level; such as occurred on Humboldt Bay in 2003 and again in 2005/6. A conservative estimation of sea level rise for the coast of California is: 6 inches by 2030, 12 inches by 2050, and 36 inches by 2100. The CCC requires applicants for development permits to evaluate the potential affect of sea level rise on their proposed project, at a minimum of 3 feet and maximum of 6 feet of sea level rise. Relative sea level rise on Humboldt Bay will likely be greater if tectonic subsidence continues to occur. This vulnerability assessment will evaluate the elevation of shoreline structures in one foot increments above MMMH elevation to three feet of sea level rise and at six feet.

a) Humboldt Bay

While overtopping of natural shorelines such as fore dunes on Elk River Spit or South Spit does occur at MMMW and EHT elevations, the dune slope can accommodate a rising tide as the shoreline migrates inland, with little risk to land uses or significant infrastructure. In addition to failing dikes causing flooding of former tidelands, overtopping of natural banks in open tidal channels can also cause flooding of adjacent lands, uses, infrastructure, and resources. There are 7 open tidal channels on Humboldt Bay:

1. Mad River Slough: the uppermost 2,000 feet of channel has natural banks. Overtopping occurs on approximately 500 foot of the south bank at EHT elevation, and at 2 feet of sea level rise both banks will be completely overtopped;
2. Liscom Slough: 1,300 feet of the south bank east of Jackson Ranch is natural ground and is overtopped at EHT elevation;
3. Butcher Slough: is an open channel north of Highway 255 but it is well confined and its banks are higher than 9.74 feet;
4. Jacoby Creek: in the 800 feet of channel east of Highway 101 the south bank currently is overtopped at EHT elevation;
5. Freshwater Creek: the last 2,500 feet of tidal channel has natural banks that are currently over topped at EHT elevation in a few locations. Overtopping increases at 2 feet of sea level rise and complete overtopping occurs with 3 feet of sea level rise,
6. Ryan Slough: is an open channel but it is well confined above the tidal reach south of Mitchell Road;
7. Elk River Slough: the last 4,850 feet of tidal channel has natural banks that are currently overtopped at EHT elevations.

If existing shoreline persist, overbank flooding on Mad River, Liscom, and Elk River, sloughs/ creeks will increase as sea level rises, putting mostly agricultural lands and some roads at risk.

Thousands of acres of former tidelands around Humboldt Bay are primarily protected from tidal flooding by shoreline structures such as dikes and the railroad grade which functions as a dike in most areas. Together, dikes and railroad grade occupy 51.2 miles, which is 66.8% of the artificial shoreline on Humboldt Bay. Currently, there are 17,686 feet (3.3 miles) of exposed dikes, and 896 feet (0.2 miles) of exposed railroad grade. The exposed dike shorelines are predominately located in Mad River Slough (7,969 feet) (Figure 69), Eureka Slough (6,098 feet), and South Bay (3,429 feet). The exposed railroad grade shorelines are located in Arcata Bay (525 feet) and South Bay (346 feet).

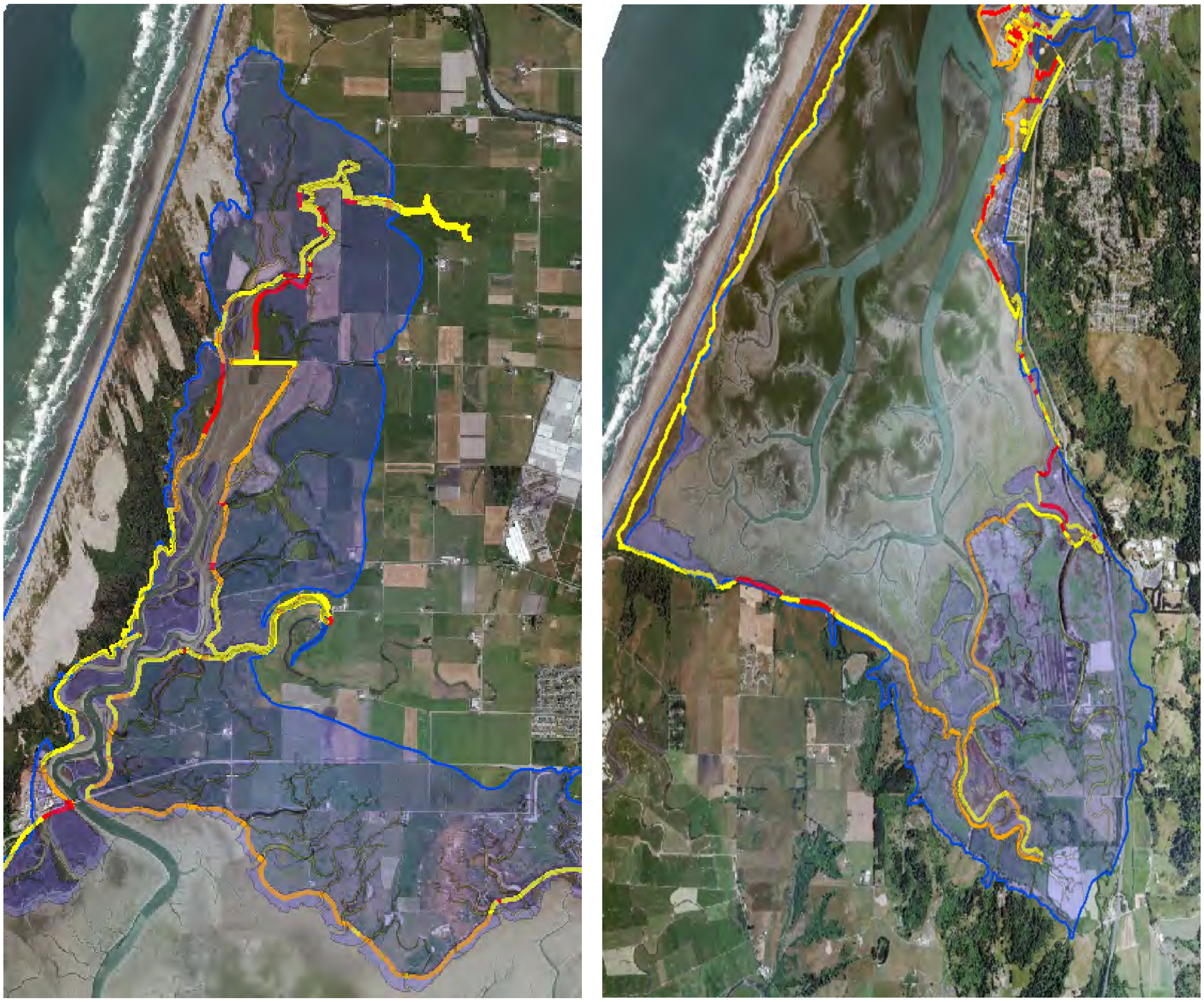

Figure 69. Mad River Slough exposed dikes (red) and South Bay's exposed dikes and railroad grade on the east shore of the Bay, with 1870 tidal inundation area.

On Mad River Slough, the exposed earthen dikes are found on both banks, particularly north of Lanphere Road. There are 12 locations where the dike is exposed, ranging in length from 104 feet to 2,030 feet. Eureka Slough also has exposed dikes on both banks on Fay Slough, Freshwater Slough, and Eureka Slough (Figure 70). There are 15 locations where the dike is exposed, ranging in length from 24 feet to 1,183 feet. South Bay has 7 locations where dikes are exposed, ranging in length from 164 feet to 1,307 feet.

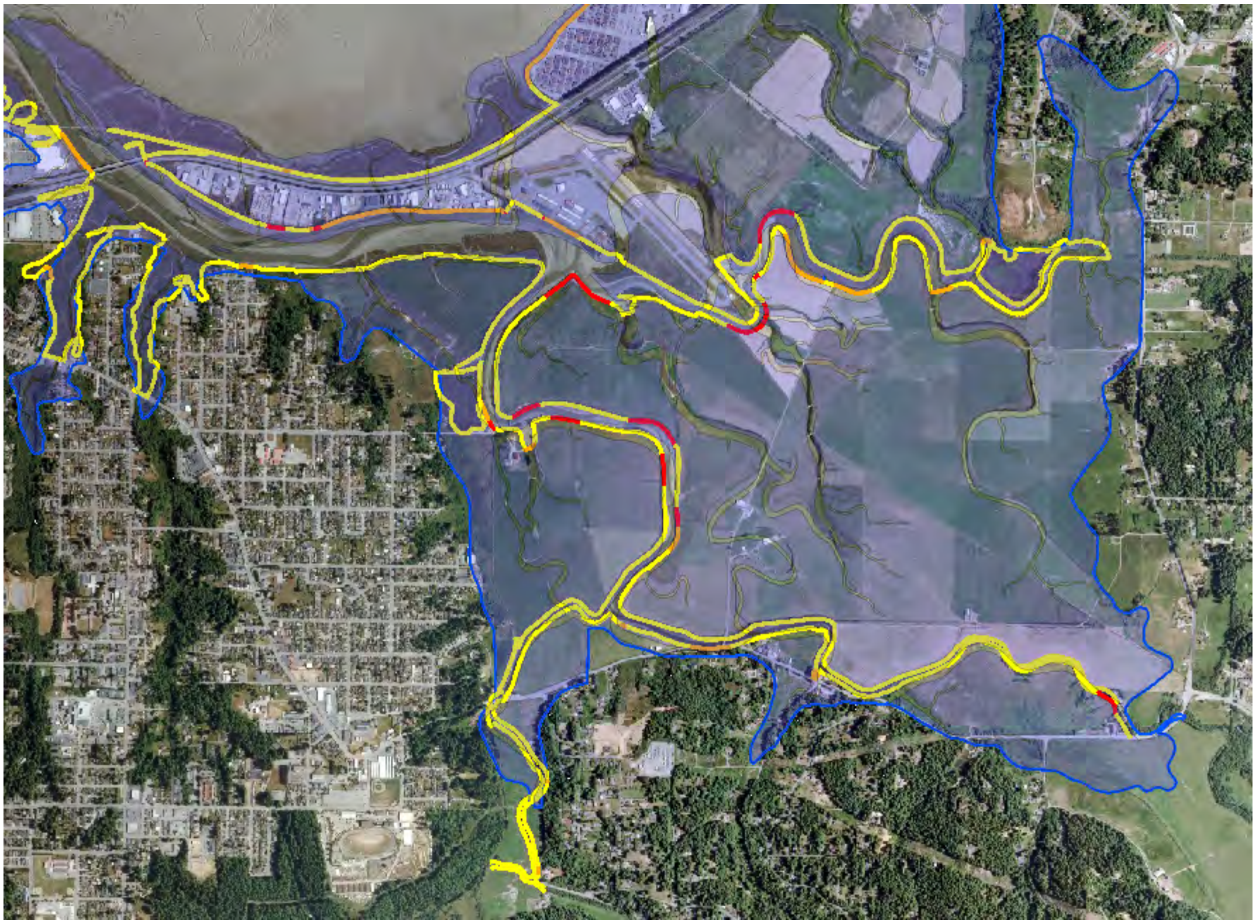

Figure 70. Eureka Slough exposed dikes (red), with 1870 tidal inundation area.

Table 30, lists the length of artificial shoreline in each hydrologic unit that would be overtopped by 1 to 3 feet of sea level rise, and 6 feet of sea level rise. The average EHT elevation, as measured at the north spit, is 8.79 feet and 91% of the artificial shoreline is higher than that elevation, 73% of the artificial shoreline is greater than 9.74 feet, but at 10.74 feet elevation just 42% of the artificial shoreline is higher, and only 8% of the artificial shoreline is greater than 13.74 feet.

	Length (feet) of shoreline at or below specified elevation							
SHORELINE ELEVATION	**ARCATA BAY**	**EUREKA BAY**	**SOUTH BAY**	**MAD RIVER SLOUGH**	**EUREKA SLOUGH**	**ELK RIVER SLOUGH**	**TOTAL FEET**	**TOTAL PERCENT**
7.74' (MMMW)	736	2,289	4,611	443	1,756	2,469	12,304	**3.0%**
8.74' (1' SLR)	4,596	5,913	11,357	3,318	5,691	9,339	40,214	**9.9%**
9.74' (2' SLR)	19,688	12,522	31,485	13,809	18,899	13,777	110,181	**27.2%**
10.74' (3' SLR)	54,061	28,592	57,911	30,841	45,157	17,311	233,872	**57.8%**
13.74' (6' SLR)	88,910	45,246	75,158	55,068	85,284	21,585	371,251	**91.7%**
Total	98,619	59,772	78,132	57,623	87,834	22,829	404,810	

Table 30. Humboldt Bay hydrologic unit's artificial shoreline length (linear feet) by shoreline elevation and percentage of total artificial shoreline length.

South Bay has the most vulnerable artificial shoreline based on 1, 2, and 3 feet of sea level rise. Under existing conditions, approximately 2, 6, and 11 miles of South Bay shoreline would be overtopped. With 6 feet of sea level rise, Arcata Bay has the most vulnerable artificial shoreline, approximately 17 miles would be overtopped, and Eureka Slough would have approximately 16 miles overtopped.

Chart 7 illustrates the cumulative length of shoreline in miles that would be overtopped for each of these elevations. A significant portion of the artificial shoreline, 58%, would be overtopped by 3 feet of sea level rise, and 92% of the artificial shoreline by 6 feet above MMMW.

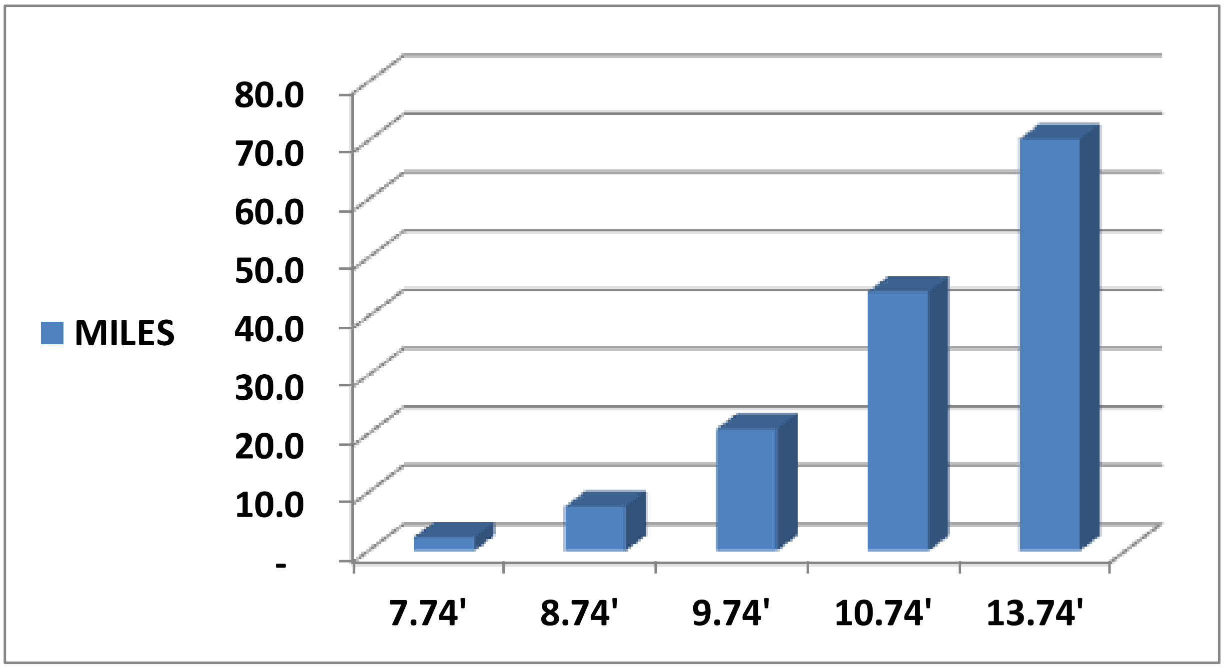

Chart 7. Humboldt Bay artificial shoreline, in miles, that is less than or equal to MMMW (7.74 feet) tide elevation plus 1 through 3 feet and 6 feet of sea level rise.

Significant portions of shoreline structures critical to the protection of thousands of acres of agricultural lands are less than 13.74 feet in elevation: 38.4 miles (94.4%) of the dikes and 9.5 miles (90.5%) of the railroad grade (Table 31). Substantial lengths of these structures are less than 10.74 feet elevation: 23.4 miles (42%) of the dikes and 6.9 miles (34%) of the railroad grade. If existing shoreline elevations persist, there would be two important shoreline overtopping elevation thresholds: 8.74 feet to 9.74 feet, and 9.74 feet to 10.74 feet. The length of dikes that would be overtopped would increase from 3.2 miles to 11.4 miles and then to 23.4 miles, and the length of railroad grade that would be overtopped would increase from 0.7 miles to 1.5 miles and then 6.9 miles. Again, if current shoreline structure elevations persist, when water levels reach 13.74 feet in elevation, 94.4% of the dikes and 90.5% of the railroad grade will be overtopped.

	Length (feet) of shoreline at or below specified elevation					
HUMBOLDT BAY	**ELEVATION**					**TOTAL**
SHORELINE STRUCTURE	**MMMH**	**8.74'**	**9.74'**	**10.74'**	**13.74'**	**LENGTH**
Dike	4,273	17,172	60,356	123,453	202,784	214,792
Railroad	18	393	8,115	36,493	50,343	55,655
Fill	3,573	8,575	18,688	27,793	36,316	40,543
Fortified	1,465	5,891	11,783	20,971	33,017	40,263
Total	**9,329**	**32,031**	**98,942**	**208,710**	**322,460**	**351,253**

Table 31. Cumulative length, of critical shoreline structures that would be overtopped by water elevations less than or equal to MMMW plus 1 to 3 feet, and 6 feet of sea level rise.

The two dominant artificial shoreline structures, dikes and railroad grade, cover over 51 miles (66%) of the artificial shoreline.

Dikes

Because dikes are the most prevalent shoreline structure on Humboldt Bay, covering 40.7 miles of shoreline, it is important to assess their current elevation (Table 32). During EHT, water elevations increase above MMMW, on average, 1 foot (8.78 feet). Under current shoreline conditions, overtopping would occur on 8% of the dikes; with the combination of an El Nino event, tidal elevations could increase 1 more foot to 9.74', in which case approximately 28% of the dikes on Humboldt Bay could be overtopped. With a 3 foot rise in water levels, overtopping of dikes increases to 57.5%, and with 6 feet of rise, 94.4% of the dikes will fail to hold back tidewater. If existing dike conditions persist, there is a threshold for significant increases in overtopping between the average EHT elevation and 1 more foot of sea level rise (9.74 feet) which would result in the 3.3 miles overtopped by EHT increasing to 11.4 miles (Chart 8). When sea level rises 2 feet, and if existing dike elevations are not increased, then overtopping of 11.4 miles of dike would cause tidal flooding of a significant amount of former tidelands around Humboldt Bay. A second threshold between 2 and 3 feet of sea level rise could result in a doubling of the number of miles of dikes being overtopped, from 11.4 to 23.4 miles.

	Length (feet) of shoreline at or below specified elevation							
DIKED SHORELINE ELEVATION	**ARCATA BAY**	**EUREKA BAY**	**SOUTH BAY**	**MAD RIVER SLOUGH**	**EUREKA SLOUGH**	**ELK RIVER SLOUGH**	**TOTAL FEET**	**TOTAL PERCENT**
7.74' (MMMW)	154	166	653	431	689	2,180	4,274	**2.0%**
8.74' (1' SLR)	970	450	2,971	2,761	2,155	7,865	17,171	**8.0%**
9.74' (2' SLR)	5,137	988	18,617	11,397	12,467	11,750	60,356	**28.1%**
10.74' (3' SLR)	10,782	1,265	34,272	26,569	36,395	14,170	123,453	**57.5%**
13.74' (6' SLR)	26,521	1,392	39,951	45,843	73,728	15,349	202,783	**94.4%**
Total	33,107	3,077	40,215	47,471	75,588	15,334	214,792	

Table 32. Cumulative length, of diked shoreline that would be overtopped by water elevations less than or equal to MMMW plus 1 to 3 feet, and 6 feet of sea level rise.

With sea level rise of 1 foot, Elk River Slough would experience the greatest amount of overtopping of its diked shoreline sea level rise of 2 feet would result in overtopping of 46% of South Bay's dikes. With 3 feet of sea level rise, 48% of Eureka Slough's dikes would be overtopped, and at 6 feet, nearly all (94%) of the diked shoreline would be overtopped.

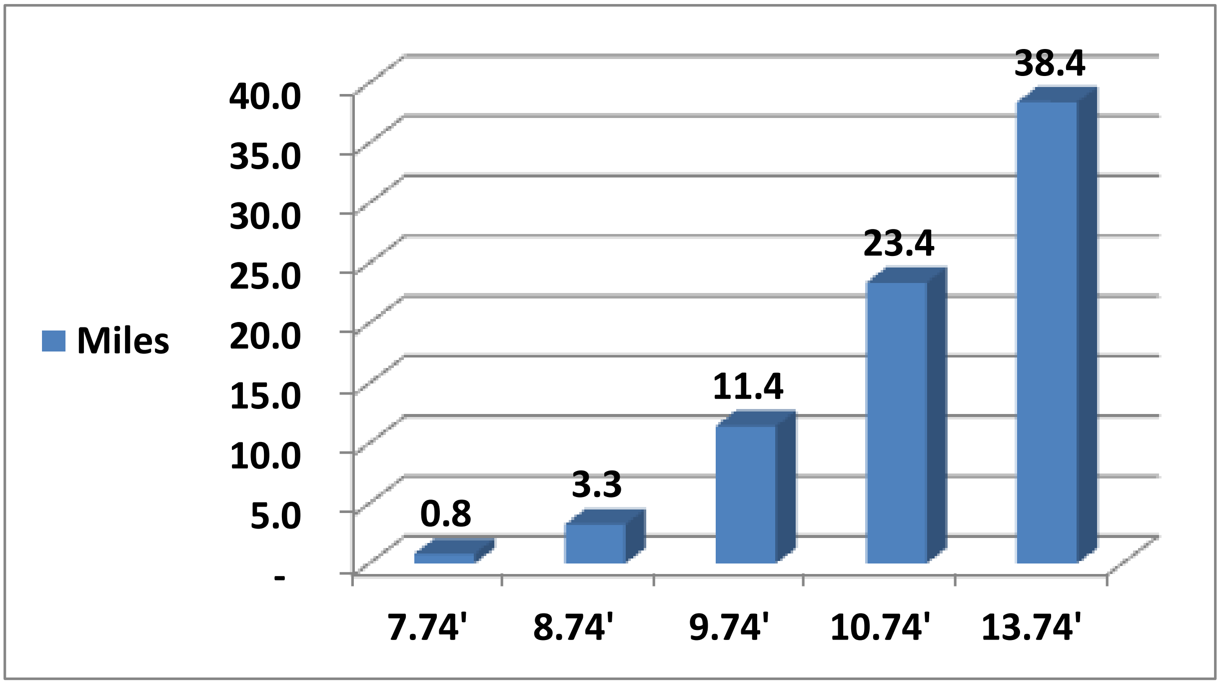

Chart 8. Cumulative length (in miles), of diked shoreline with an elevation that is less than or equal to MMMW, EHT, 2', 3', and 6' of sea level rise.

Railroad

The railroad grade is the second most prevalent artificial shoreline structure on Humboldt Bay; it forms 10.5 miles of shoreline. Based upon existing conditions with sea level rise of 1 foot (EHT), a limited amount (393 feet) of railroad grade would be overtopped. With 2 feet of sea level rise, 15% of the railroad grade would be overtopped mostly on Arcata Bay. With 3 feet of sea level rise, 66% of the entire railroad grade would be overtopped, and at 6 feet, nearly 91% of the railroad would be overtopped (Table 33) (Chart 9). If existing conditions persist there is a threshold between 2 and 3 feet of sea level rise where the length of railroad grade that would be overtopped goes from 1.5 miles (15%) to 6.9 miles (66%).

	Length (feet) of shoreline at or below specified elevation							
RAILROAD SHORELINE ELEVATION	ARCATA BAY	EUREKA BAY	SOUTH BAY	MAD RIVER SLOUGH	EUREKA SLOUGH	ELK RIVER SLOUGH	TOTAL FEET	TOTAL PERCENT
7.74' (MMMW)	-	-	-	-	18	-	18	0.0%
8.74' (1' SLR)	262	-	-	-	131	-	393	0.7%
9.74' (2' SLR)	7,201	517	89	-	295	13	8,115	14.6%
10.74' (3' SLR)	28,349	3,747	3,715	77	461	144	36,493	65.6%
13.74' (6' SLR)	34,305	4,858	7,219	2,540	563	858	50,343	90.5%
Total	34,431	8,794	7,197	2,968	551	1,714	55,655	

Table 33. Cumulative length, of railroad shoreline that would be overtopped by water elevations less than or equal to MMMW plus 1 to 3 feet, and 6 feet of sea level rise.

With sea level rise of 2 feet, 1.4 miles of the railroad grade on Arcata Bay would be flooded, and with 3 feet, 5.4 miles would be flooded. Interstate Highway 101 parallels the railroad grade on Arcata Bay, and in many locations the highway is lower in elevation than the railroad grade. Additionally, sections of State Highway 255 and South G Street also parallel the railroad. Overtopping the railroad shoreline on the eastern shore of Arcata Bay could flood Highway 101 and possibly the former tidelands to the east.

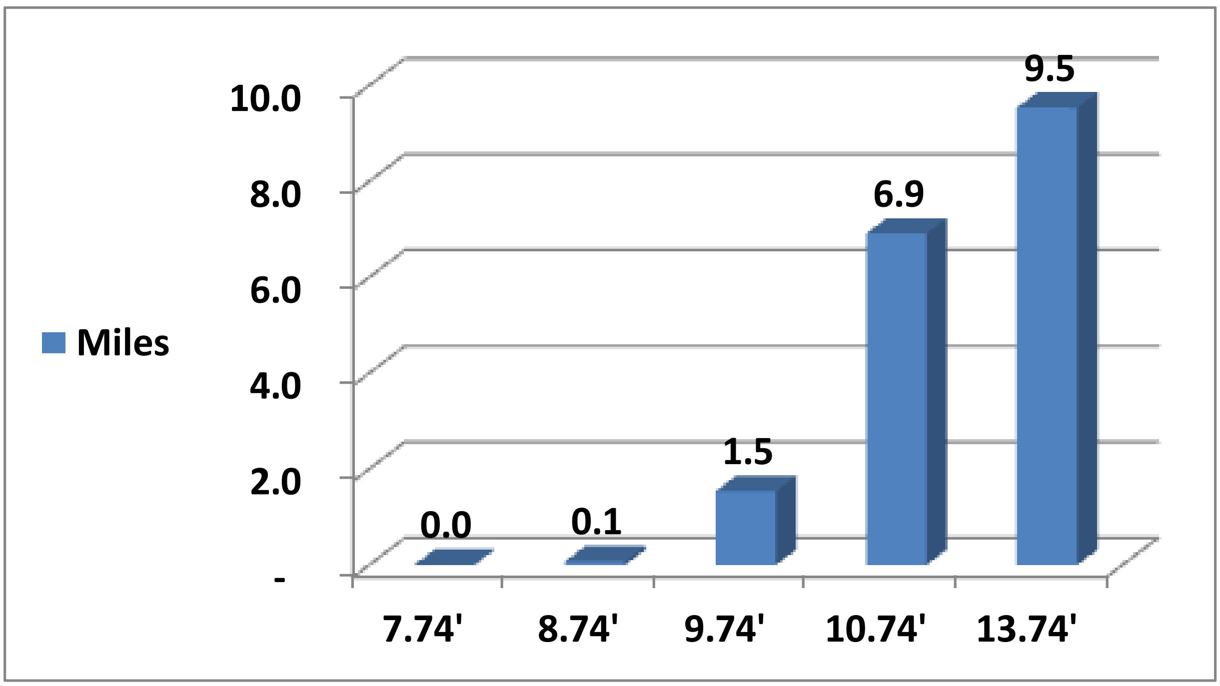

Chart 9. Cumulative length (in miles), of railroad shoreline elevation that is less than or equal to MMMW, EHT, 2’, 3’, and 6’ of sea level rise.

Salt Marsh

Salt marsh habitat can keep pace with rising sea levels if there is a sufficient supply of sediment. If the rate of relative sea level rise exceeds the ability of salt marsh to accrete in place, then these marshes will need to migrate inland in order to maintain this important inter-tidal habitat. Dikes are the dominant shoreline structure in the three sloughs on Humboldt Bay, which are surrounded by thousands of acres of mostly open space currently used for agriculture and waterfowl and wildlife habitat (Figure 71). There are pathways for salt marsh migration in each of these slough areas if dikes were re-located inland or breached. While this may be physically feasible, willing landowners would be necessary to implement this sea level rise adaptation strategy.

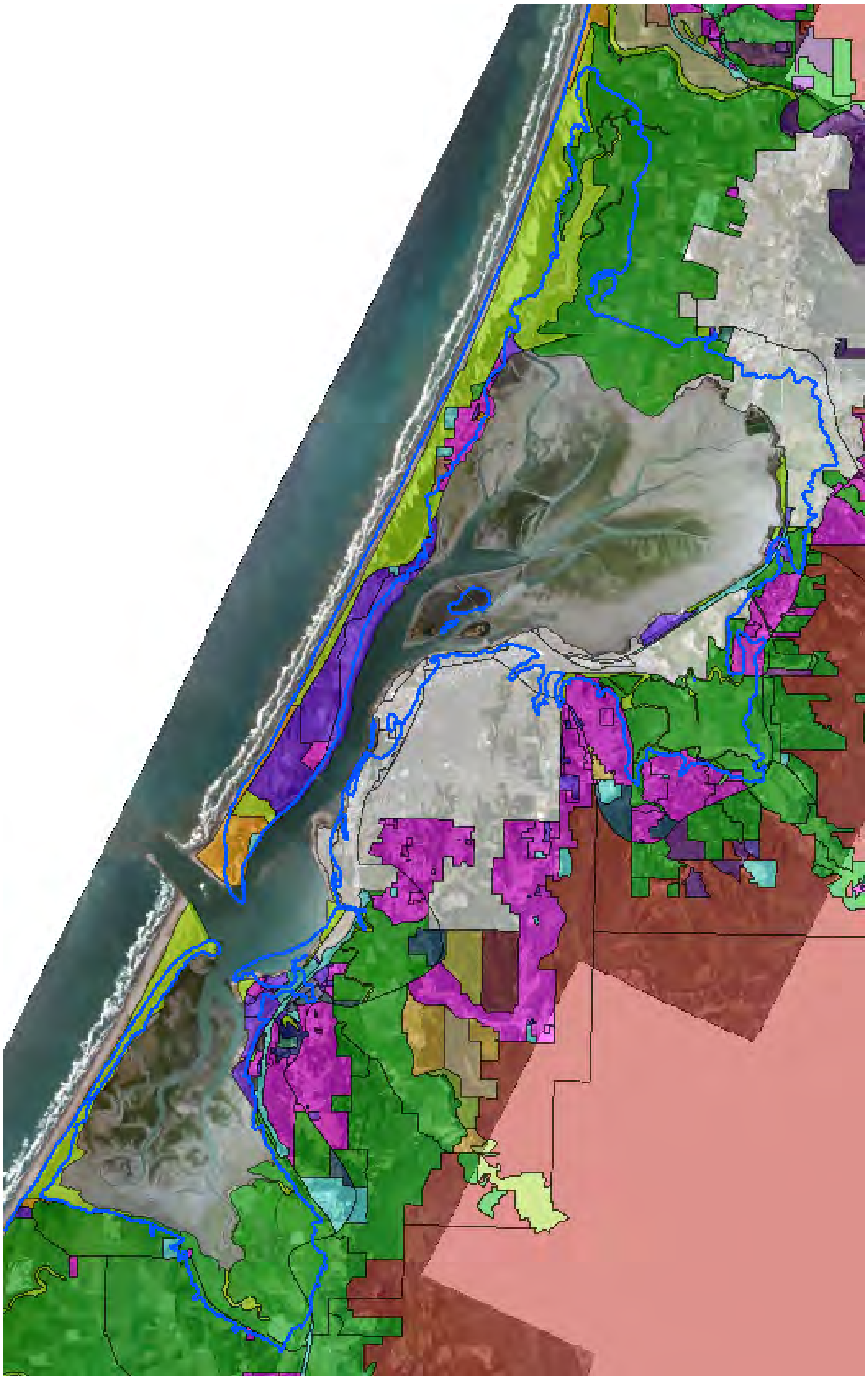

Figure 71. Humboldt County's Humboldt Bay Area Plan land use designations and the 1870 tidal inundation footprint: City of Eureka and Arcata (white), agriculture (dark green), natural resources (light green), public recreation (light brown), timber (brown), residential (pink), manufacturing and commercial (purple), public facilities (light blue).

b) Arcata Bay

The shoreline of Arcata Bay is 20.5 miles long and 91% of the shoreline is composed of artificial structures, but only 4% is exposed (3,605 feet) (Figure 72). The two dominant shoreline structures are the NRCA's railroad grade (32%) and the Reclamation District's dike (31%), which was rehabilitated in 2008. Other types of shorelines are fill (12%), the City of Arcata's wastewater treatment and marsh ponds (9%), which were also rehabilitated in 2008, and roadways (6%). The railroad grade is mostly unfortified (73%); 24,694 feet are vegetated, 525 feet are exposed, and 9,212 feet is fortified (27%). There are 275 feet of exposed railroad grade along Butcher Slough in the Arcata Marsh and the remaining 250 feet of exposed railroad grade are at two locations south of the Indianola cutoff. If the existing exposed condition of the railroad grade at these two locations is allowed to persist, the shoreline has the potential to be breached. A significant length of the dikes on Arcata Bay were recently fortified (20,792 feet, 63%), 12,199 feet are vegetated (37%). Just 116 feet of dike are exposed, which is adjacent to an area that is being restored to tidal functions, so the integrity of the dike is not important here. Highway 255 has 910 feet that are exposed immediately west of the Mad River Slough bridge in front of the Sierra Pacific Lumber Company's operation. The bulk of the remaining exposed shoreline is in fill areas along Butcher Slough and Gannon Slough. Overall, the existing conditions of the artificial shoreline structure and cover in Arcata Bay are not exhibiting any substantial vulnerability.

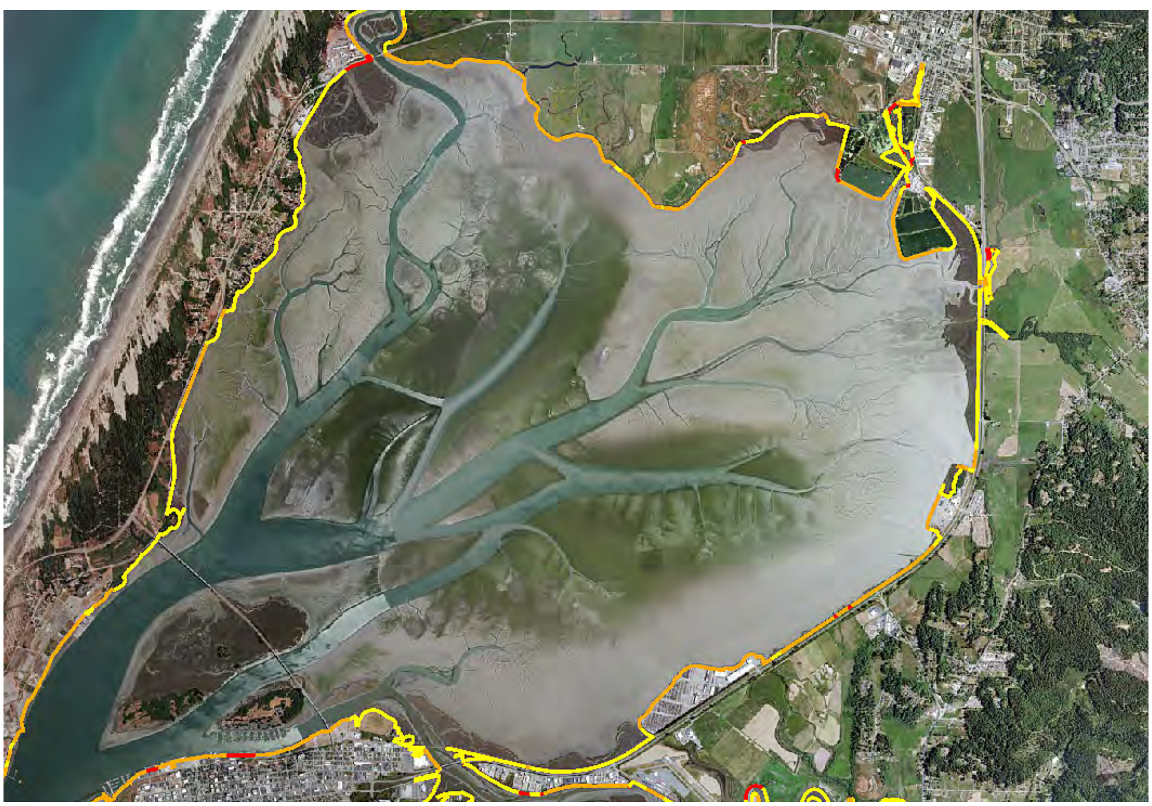

Figure 72. Arcata Bay shoreline cover: fortified (brown), vegetated (yellow), and exposed (red).

While one foot of sea level rise will increase overtopping of filled shorelines significantly (468' to 3,019'), one to two feet of sea level rise will initiate wide spread shoreline overtopping of the railroad grade (262' to 7,201') and dikes (970' to 5,137') (Table 34). While not extensive in regards to shoreline length, the overtopping of the dike on Gannon slough by sea level rise of 1 to 2 feet could flood a large area of former tidelands. Overtopping of Reclamation District 768's dike is in an area that the City of Arcata and DFG have slated for salt marsh restoration. The next increment of sea level rise of two to three feet will overtop a significant length of shoreline: railroad 21.0% to 82.3%, dike overtopping will increase from 15.5% to 32.6%, and fill overtopping will increase from 39.0% to 65.7%. Very little of Arcata Bay's artificial shoreline composed of these four structures, 10.9%, will be above the tides at six feet of sea level rise.

	Length (feet) of shoreline at or below specified elevation					
ARCATA BAY	**ELEVATION**					**TOTAL**
SHORELINE STRUCTURE	**MMMH**	**8.74'**	**9.74'**	**10.74'**	**13.74'**	**LENGTH**
Dike	154	970	5,137	10,782	26,521	33,107
Railroad	-	262	7,201	28,349	34,305	34,431
Fill	468	3,019	5,432	8,496	10,819	12,935
Fortified	48	89	144	215	303	330
Total	**670**	**4,340**	**17,914**	**47,843**	**71,948**	**80,803**

Table 34. Cumulative lengths of shoreline by structure at increasing sea level elevations, and the total length of shoreline structure.

Breaching or overtopping of the shoreline on Arcata Bay has the potential to flood the following land uses, infrastructure, and resources that are located within the historic tidal inundation footprint of 1870:

<u>Land Uses:</u>

- Agricultural: predominately grazing and wildlife management on a substantial amount of acreage,
- Natural resource: predominately open space, and wildlife management,
- Residential: in Manila along the Bay, and at Jacobs Avenue in Eureka,
- Commercial: at the Indianola Cutoff east of Highway 101, Harper Motors east of Highway 101, and on Jacobs Avenue in Eureka,
- Industrial/ Manufacturing: at the Sierra Pacific Company mill, along south G Street in Arcata, Bracut, and the California Redwood Company mill,
- Public facilities: park in Manila, waste water treatment plant at South G Street Arcata, radio station at South G Street Arcata, and Murray Field County airport in Eureka.

Infrastructure:

- Transportation: Interstate Highway 101, State Highway 255, County Roads, service streets in Arcata and Eureka, and NCRA railroad, County airport at Murray Field, and 8 bridges.
- Utilities: City of Eureka's water transmission pipes, PG&E gas transmission pipes, PG&E electrical transmission towers,
- Drainage: numerous tidegates and culverts,
- City of Arcata's waste water treatment facility.

Resources:

- Wiyot Tribe's Tuluwat ceremonial site on Indian Island,
- Department of Fish and Game's (DFG) Mad River Slough and Fay Slough wildlife reserves,
- City of Arcata's Marsh and Wildlife area.

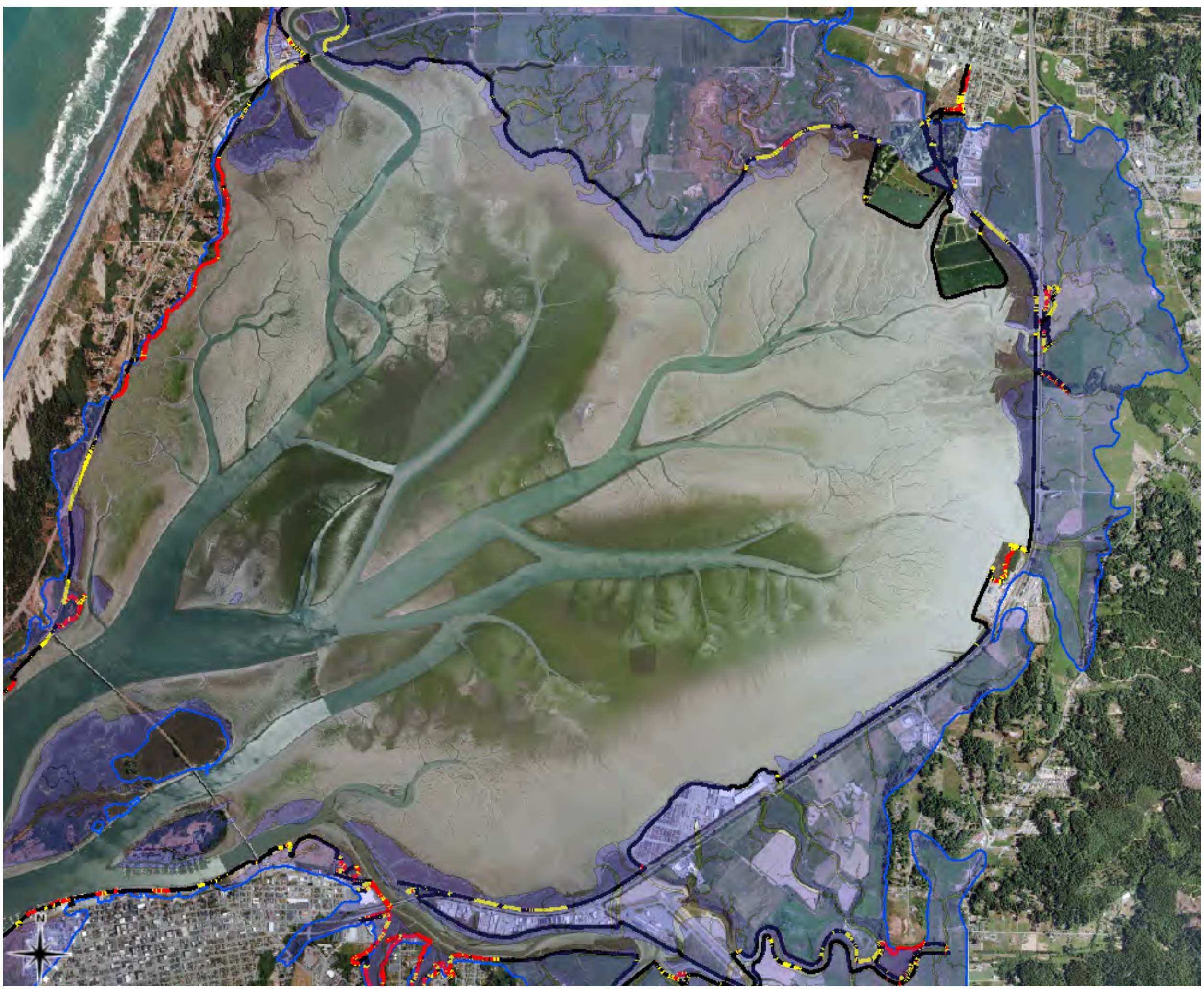

Figure 73. Arcata Bay, shoreline areas overtopped by 1 foot of sea level rise (red), and 2 feet (yellow), and the 1870 tidal inundation footprint (blue).

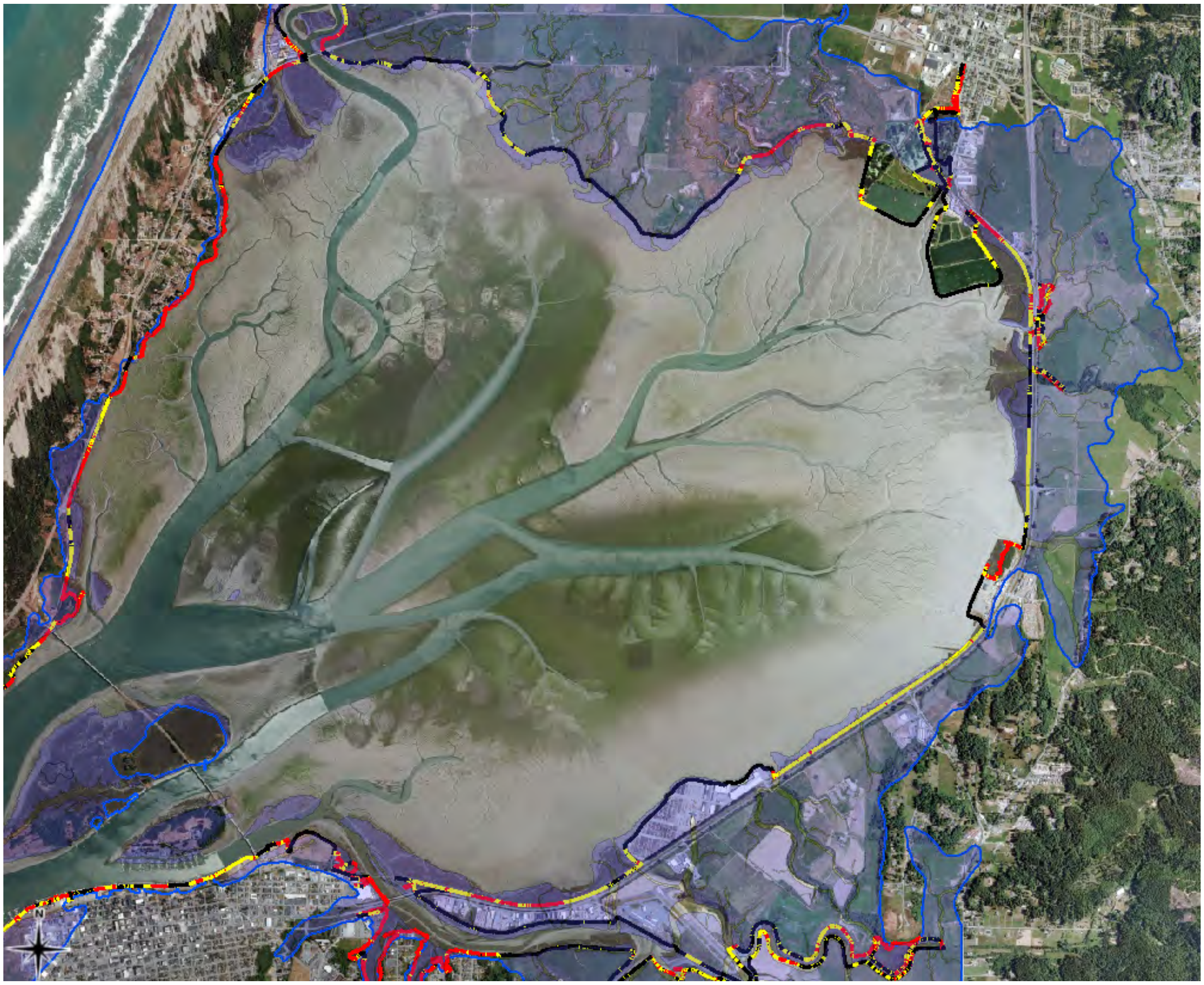

Figure 74. Arcata Bay, shoreline areas overtopped by 2 feet of sea level rise (red), and 3 feet (yellow), and the 1870 tidal inundation footprint (blue).

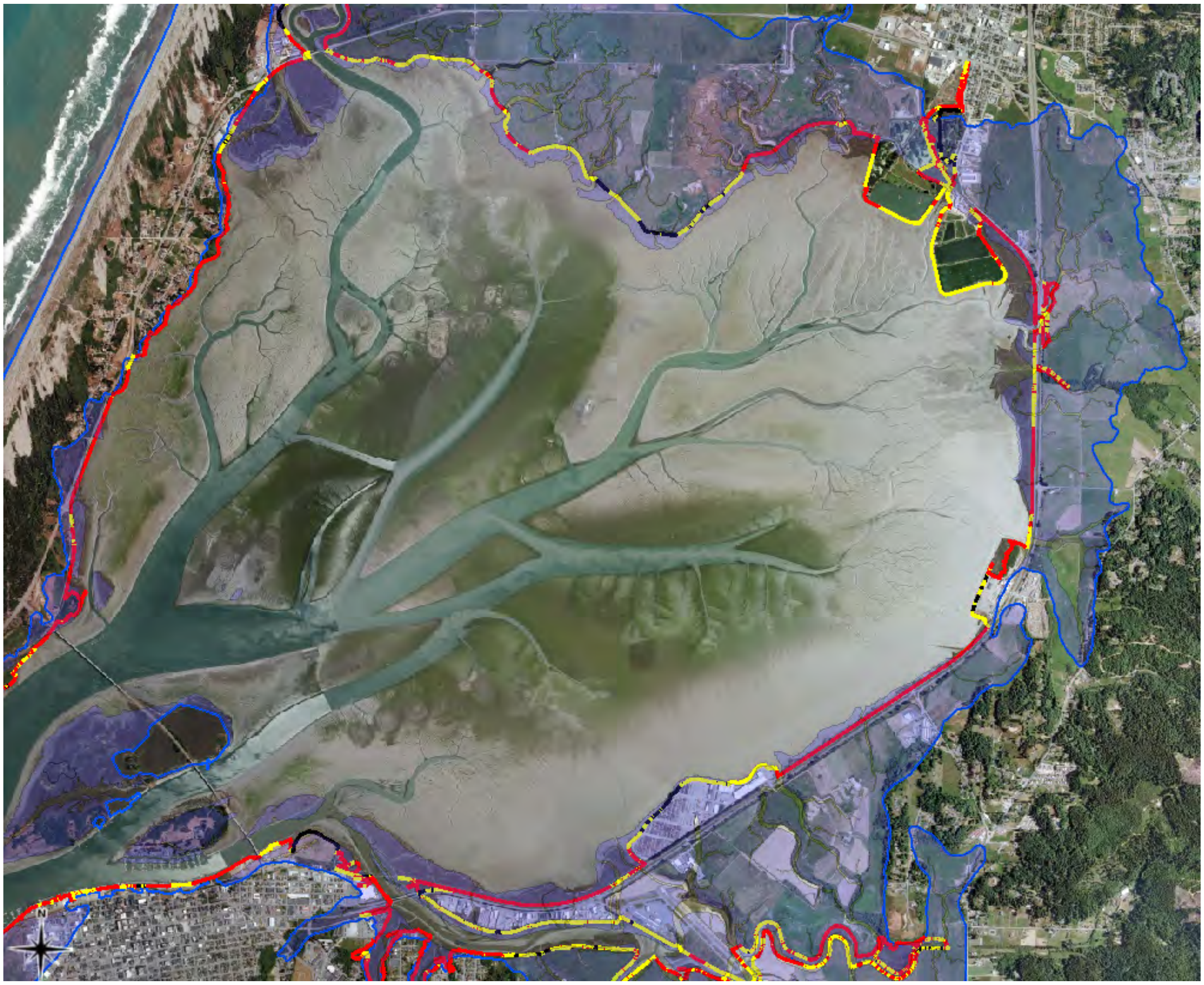

Figure 75. Arcata Bay, shoreline areas overtopped by 3 feet of sea level rise (red), and 6 feet (yellow), and the 1870 tidal inundation footprint (blue).

c) Eureka Bay

The shoreline of Eureka Bay is 15.9 miles long and 71% of the shoreline is composed of artificial structures, but only 6% of the artificial shoreline is exposed (3,587 feet) (Figure 76). The two dominant artificial shoreline structures are fortified shoreline segments (49%, 29,657 feet) and the NCRA's railroad grade (15%, 8,794 feet). Other types of artificial shorelines are fill (10%), bulwarks (6 %), and roadways (6%). The railroad grade is mostly fortified (66%), 2,980 feet are vegetated, and none is exposed. There are 2,015 feet of exposed fill and 963 feet of exposed road way. The 963 feet of exposed County road is on the North Spit facing the Bay south of the Coast Guard station. The bulk of the 2,015 feet of exposed shoreline fill areas are along the eastern shore of the Bay mostly in abandoned waterfront areas. There are 2,600 feet of exposed natural shoreline on the Bayside of the Elk River Spit and 1,200 feet of exposed fore-dune between the Jetties at King Salmon. Existing artificial shoreline conditions of structure and cover in Eureka Bay are not exhibiting any substantial vulnerability.

Figure 76. Eureka Bay shoreline cover: fortified (brown), vegetated (yellow), and exposed (red).

Eureka Bay's existing shoreline elevations are vulnerable to overtopping: one foot of sea level rise will increase overtopping of fortified shorelines significantly (1,167' to 3,152'). One to two feet of sea level rise will initiate shoreline overtopping of the railroad grade (0' to 517'), will increase bulwark overtopping from 622 feet to 1,022 feet, roadway overtopping from 315 feet to 543 feet, and double the overtopping of dikes (450' to 988') and fortified shorelines from 3,152 to 6,725 feet (Table 35). Sea level rise of two to three feet will significantly increase overtopping of the railroad grade (517' to 3,747') and roadways from 543 feet to 2,448 feet. Dike overtopping will increase from 988 feet to 1,265 feet, and a substantial increase in overtopping of bulwark shoreline will occur from 13,262 feet to 22,542 feet. Sea level rise of three to six feet overtops 75% of these artificial shoreline structures.

	Length (feet) of shoreline at or below specified elevation					
EUREKA BAY	**ELEVATION**					**TOTAL**
SHORELINE STRUCTURE	**MMMH**	**8.74'**	**9.74'**	**10.74'**	**13.74'**	**LENGTH**
Dike	166	450	988	1,265	1,392	3,077
Railroad	-	-	517	3,747	4,858	8,794
Fill	188	709	1,465	3,757	6,113	6,308
Fortified	1,167	3,152	6,725	13,262	22,542	29,657
Bulwark	463	622	1,022	1,806	3,541	3,916
Roads	47	315	543	2,448	3,340	3,852
Total	**2,030**	**5,248**	**11,260**	**26,285**	**41,786**	**55,604**

Table 35. Cumulative lengths of shoreline by structure at increasing sea level elevations, and the total length of shoreline structure.

Breaching or overtopping of the shoreline on Eureka Bay has the potential to flood the following land uses, infrastructure, and resources that are located within the historic tidal inundation footprint of 1870:

<u>Land Uses:</u>

<u>On the Western Shoreline</u>

- Natural resources,
- Public recreation,
- Public facility, Coast Guard station,
- Coastal dependent industrial,
- Residential, in Fairhaven (Indian Island).

<u>On the Eastern Shoreline</u>

- Coastal waterfront commercial,
- Coastal dependent industrial,
- Public facilities, wastewater treatment facility, community center,
- Natural resources,
- Public recreation,
- Agricultural,

Infrastructure:

- Transportation: County roads, service streets in Eureka and Fairhaven, and NCRA railroads;
- Harbor: Eureka and Woodley Island Marinas, docks, three boat launches, Coast Guard station, and NOAA weather station on Woodley Island;
- Utilities: Humboldt Bay Municipal Water District's (HBMWD) water transmission pipe, fuel depot
- Drainage: Numerous tidegates and culverts
- City of Eureka's wastewater treatment facility.

Resources:

- Wiyot Tribe village site on Indian Island,
- Egret Rookery on Indian Island.

Figure 77. Eureka Bay, shoreline areas overtopped by 1 foot of sea level rise (red), and 2 feet (yellow), and the 1870 tidal inundation footprint (blue).

Figure 78. Eureka Bay, shoreline areas overtopped by 2 foot of sea level rise (red), and 3 feet (yellow), and the 1870 tidal inundation footprint (blue).

Figure 79. Eureka Bay, shoreline areas overtopped by 3 feet of sea level rise (red), and 6 feet (yellow), and the 1870 tidal inundation footprint (blue).

d) South Bay

The shoreline of South Bay is 21.8 miles long. 68% (78,132 feet) of the shoreline is composed of artificial structures, and 15% (11,936 feet) of the artificial shoreline is exposed (Figure 80). The four dominant artificial shoreline structures are dikes covering 35% (40,215 feet), and fill (12%, 13,816 feet), along with fortified shoreline segments (7%, 8,019 feet), and the NCRA's railroad grade at 6% (7,197 feet). The diked shoreline on South Bay is mostly fortified (56%, 22,424 feet), 35.7% (14,362 feet) is vegetated, and 8.5% (3,429 feet) is exposed. There is 6,353 feet (46%) of exposed fill, and 346 feet (4.8%) of exposed railroad grade.

The majority of the exposed dike shoreline (3,028 feet) is located on the HBNWR in the White Slough area that fronts Highway 101; the remaining exposed dikes are south of King Salmon in an area that has several breaches. There is 3,185 feet of exposed fill in the Fields Landing area and the remainder is in the community of King Salmon. The entire exposed railroad grade is south of Fields Landing. Existing shoreline conditions of structure and cover make the waterfront of Fields Landing vulnerable to erosion and the residential and commercial areas of King Salmon vulnerable to flooding.

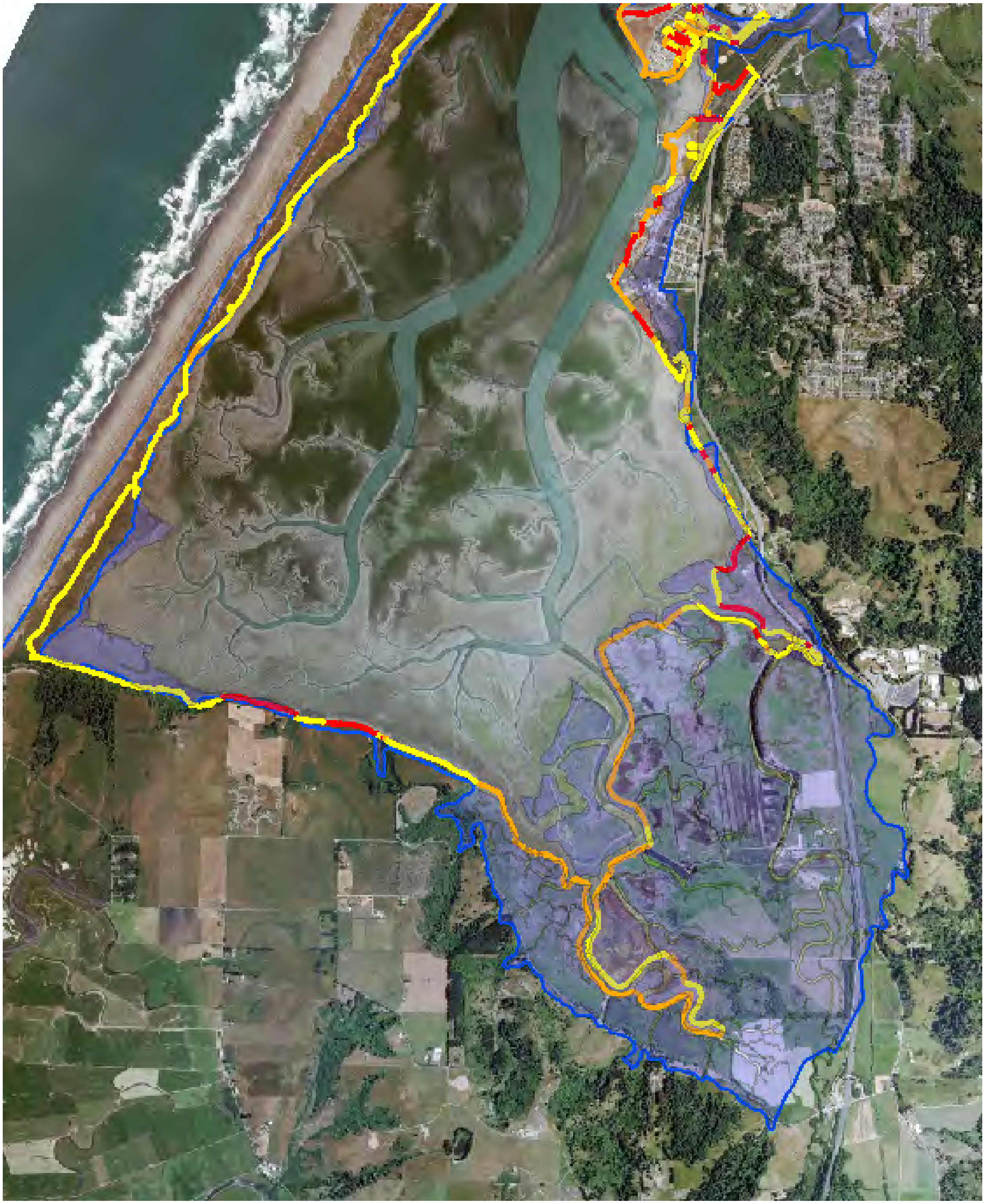

Figure 80. South Bay shoreline cover: fortified (brown), vegetated (yellow), and exposed (red).

With one foot of sea level rise, the length of shoreline of these four dominant structures that will be overtopped will more than double (3,754' to 9,333'). Overtopping of diked shorelines will increase substantially (653' to 2,971'), and overtopping of fill shorelines will more than double (1,972 to 4,127 feet) (Table 36). With one foot of sea level rise, overtopping of dikes is limited in extent to the White Slough and Hookton Slough units of the HBNWR. One to two feet of sea level rise will initiate wide spread shoreline overtopping (1.8 to 5.5 miles) particularly of dikes (2,971' to 18,617'). On the HBNWR, one to two feet of sea level rise will overtop the entire length of the Hookton Slough unit and nearly the entire length of the White Slough unit, and initiate overtopping of the Salmon Creek unit as well. The next increment of sea level rise of two to three feet will overtop a significant length of shoreline 5.5 to 10.1 miles (28,982' to 53,264'); this will particularly affect the railroad grade (89' to 3,715') and dikes (18,617 to 34,272 feet).

The existing HBNWR dikes, while fortified against wave induced erosion, would be overtopped with three feet of sea level rise, which would result in flooding of Highway 101 as it traverses former tidelands. At six feet of sea level rise, 96% of the artificial shoreline in South Bay would be overtopped.

	Length (feet) of shoreline at or below specified elevation					
SOUTH BAY	**ELEVATION**					**TOTAL**
SHORELINE STRUCTURE	**MMMH**	**8.74'**	**9.74'**	**10.74'**	**13.74'**	**LENGTH**
Dike	653	2,971	18,617	34,272	39,951	40,215
Railroad	-	-	89	3,715	7,219	7,197
Fill	1,972	4,127	6,589	9,299	11,762	13,816
Fortified	1,129	2,234	3,687	5,977	8,378	8,019
Total	**3,754**	**9,333**	**28,982**	**53,264**	**67,309**	**69,247**

Table 36. Cumulative lengths of shoreline by structure at increasing sea level elevations, and the total length of shoreline structure.

Breaching or overtopping of the shoreline on South Bay has the potential to flood the following land uses, infrastructure, and resources that are located within the historic tidal inundation footprint of 1870:

<u>Land Uses:</u>

<u>On the Western and Southern Shorelines</u>

- Natural resources: HBNWR, and South Spit,
- Agricultural.

<u>On the Eastern Shoreline</u>

- Agricultural,
- Natural resources: HBNWR, and King Salmon,
- Public recreation: county boat launch at Fields Landing,
- Public facilities: NCRA railroad, Highway 101,

- Industrial: Coastal dependent and resource related in King Salmon and Fields Landing, general in Fields Landing,
- Commercial: General and recreational in King Salmon,
- Residential: north of Hookton Road, Fields Landing and King Salmon.

Infrastructure:

- Recreational: HBNWR's visitor center operations complex, boat launches at Hookton Slough and Fields Landing,
- Transportation: Interstate Highway 101, county roads, service streets in Fields Landing and King Salmon, and NCRA railroad,
- Harbor: King Salmon canals/marina, HBHRCD dry dock in Fields Landing, commercial docks in Fields Landing,
- Utilities: PG&E power plant in Fields Landing, PG&E gas transmission line,
- Drainage: numerous tidegates and culverts.

Resources:

- Wiyot Tribe historical and archeological village sites on South Spit,
- HBNWR South Bay units,
- Bureau of Land Management's Mike Thompson Wildlife area on South Spit.

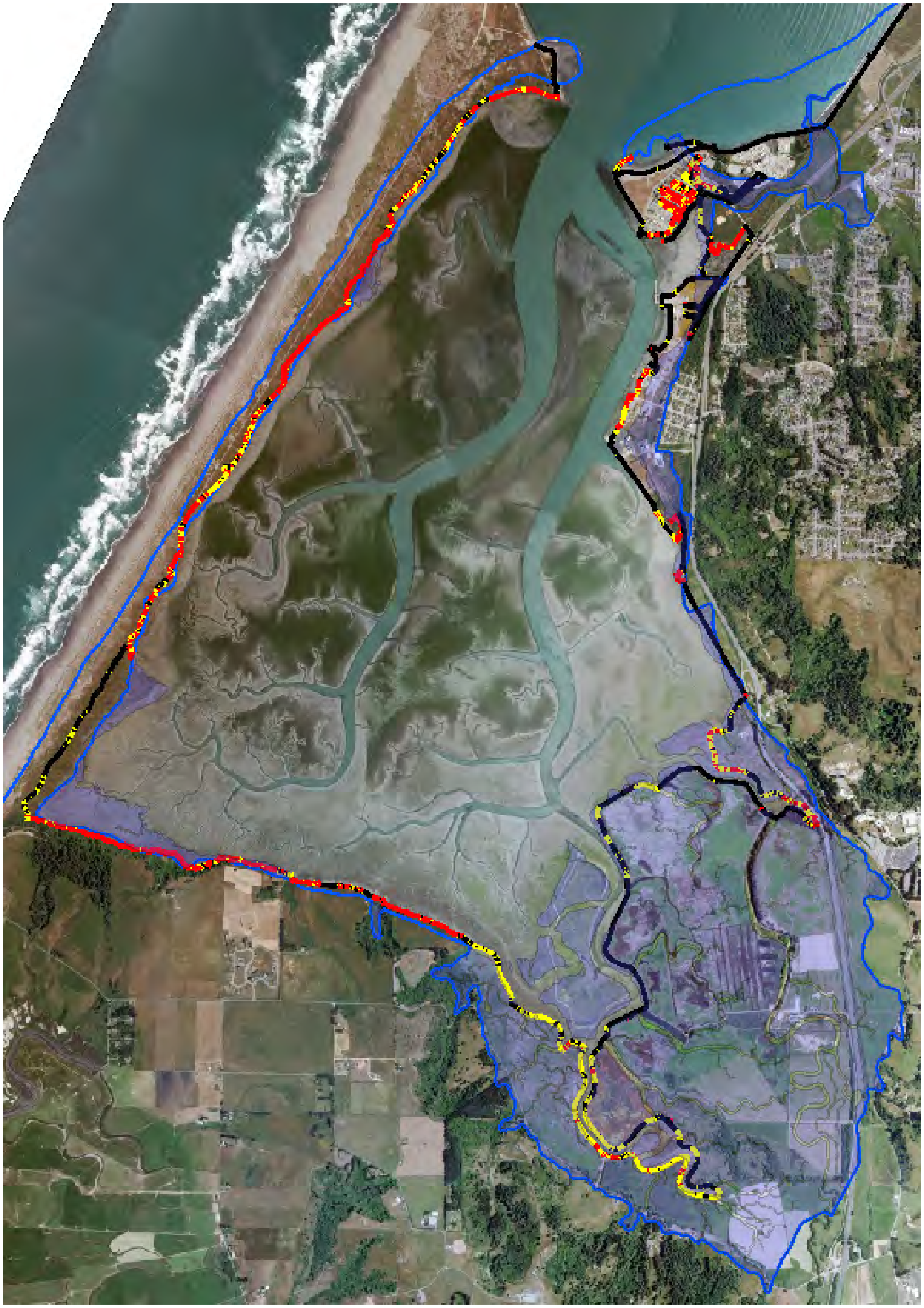

Figure 81. South Bay, shoreline areas overtopped by 1 foot of sea level rise (red), and 2 feet (yellow), and the 1870 tidal inundation footprint (blue).

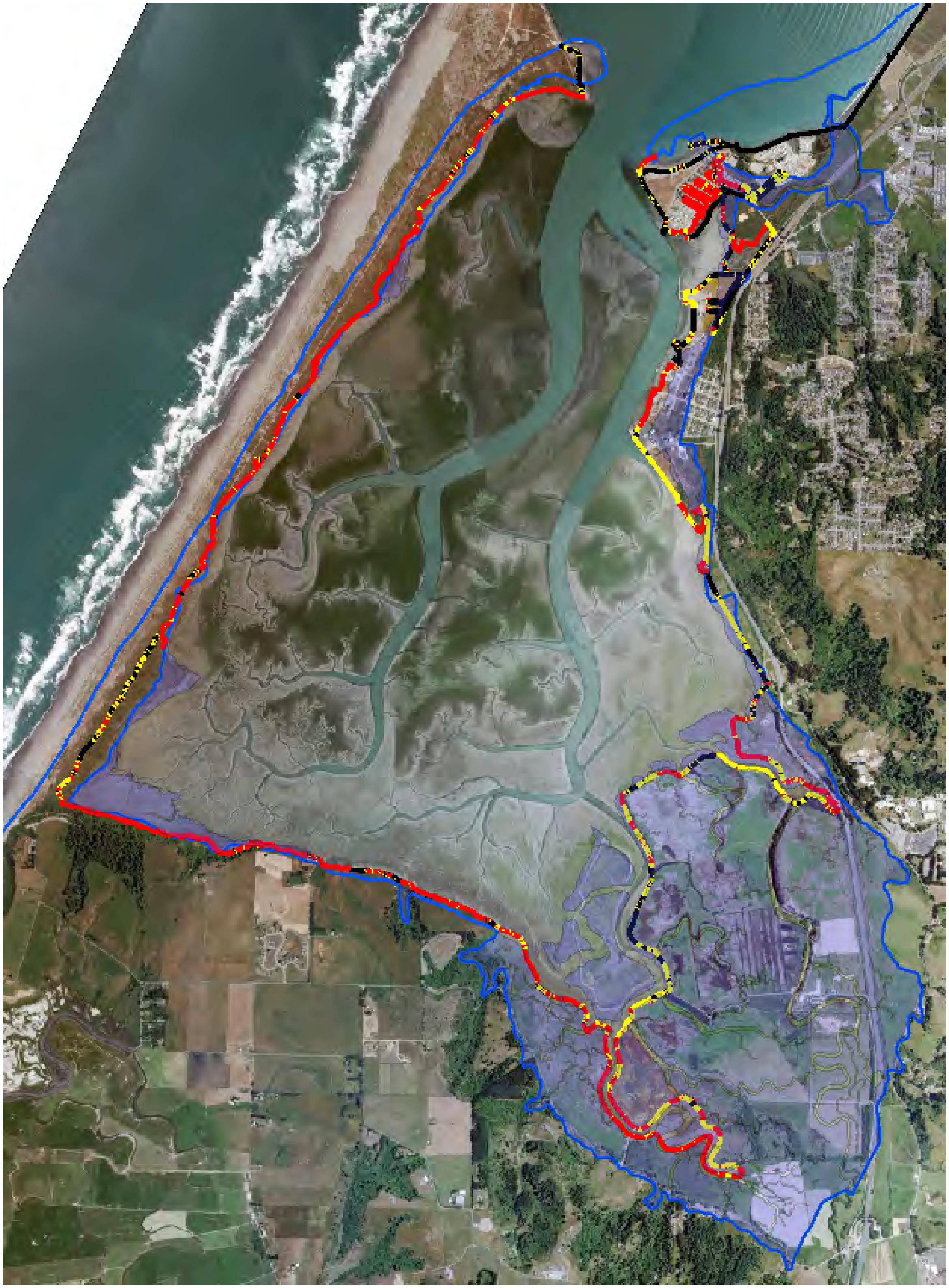

Figure 82. South Bay, shoreline areas overtopped by 2 foot of sea level rise (red), and 3 feet (yellow), and the 1870 tidal inundation footprint (blue).

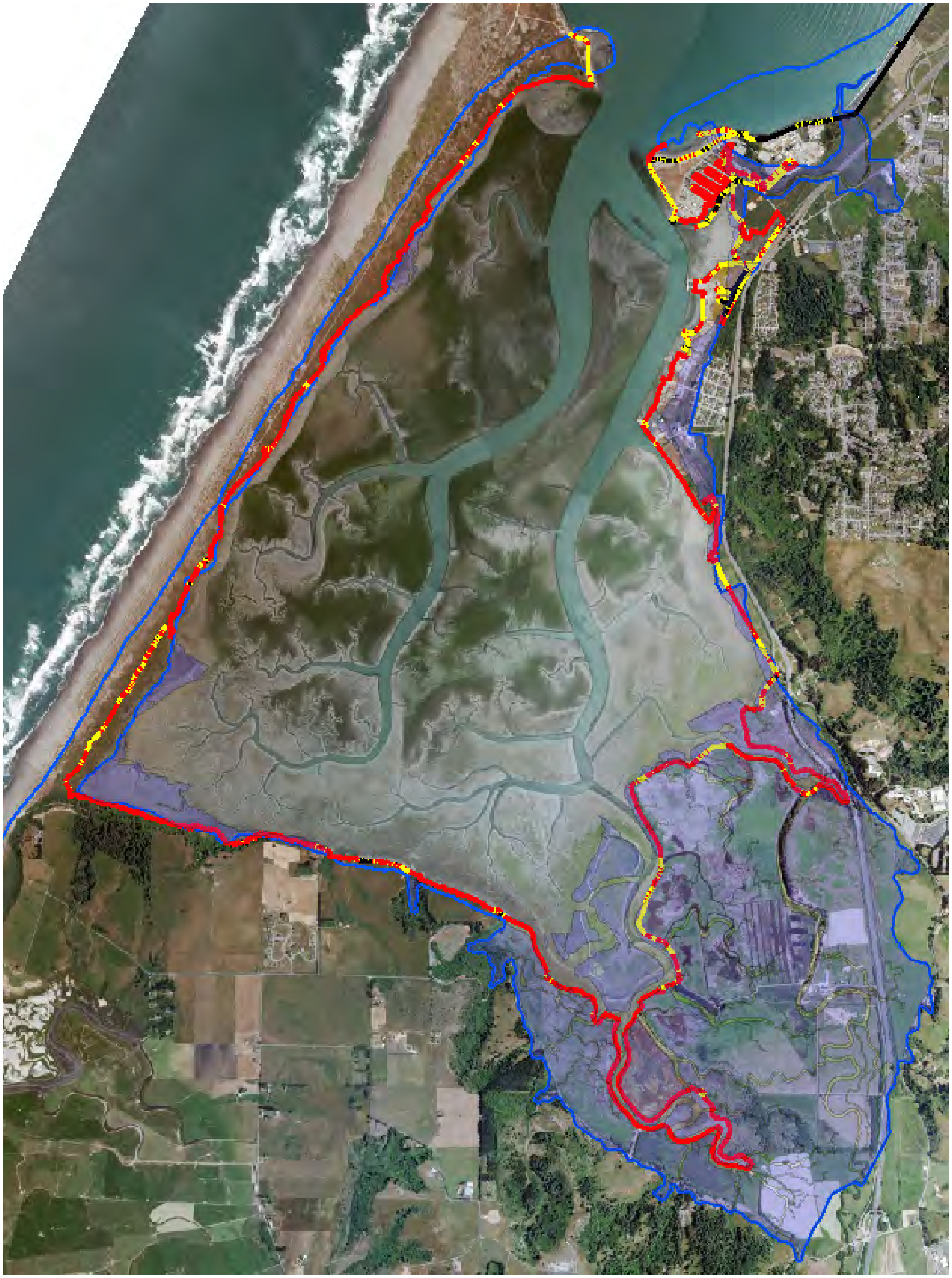

Figure 83. South Bay, shoreline areas overtopped by 3 feet of sea level rise (red), and 6 feet (yellow), and the 1870 tidal inundation footprint (blue).

e) Mad River Slough

The shoreline of Mad River Slough is 13.7 miles long and 80% (57,623 feet) of the shoreline is composed of artificial structures, 14% (8,189 feet) of the artificial shoreline is exposed (Figure 84). The two dominant artificial shoreline structures are dikes (66%, 47,471 feet) and roadway (7%, 5,050 feet). The diked shoreline is 53.7% (25,518 feet) vegetated, and 16.8% (7,968 feet) exposed. There are also 469 feet of exposed fill and 104 feet of exposed roadway.

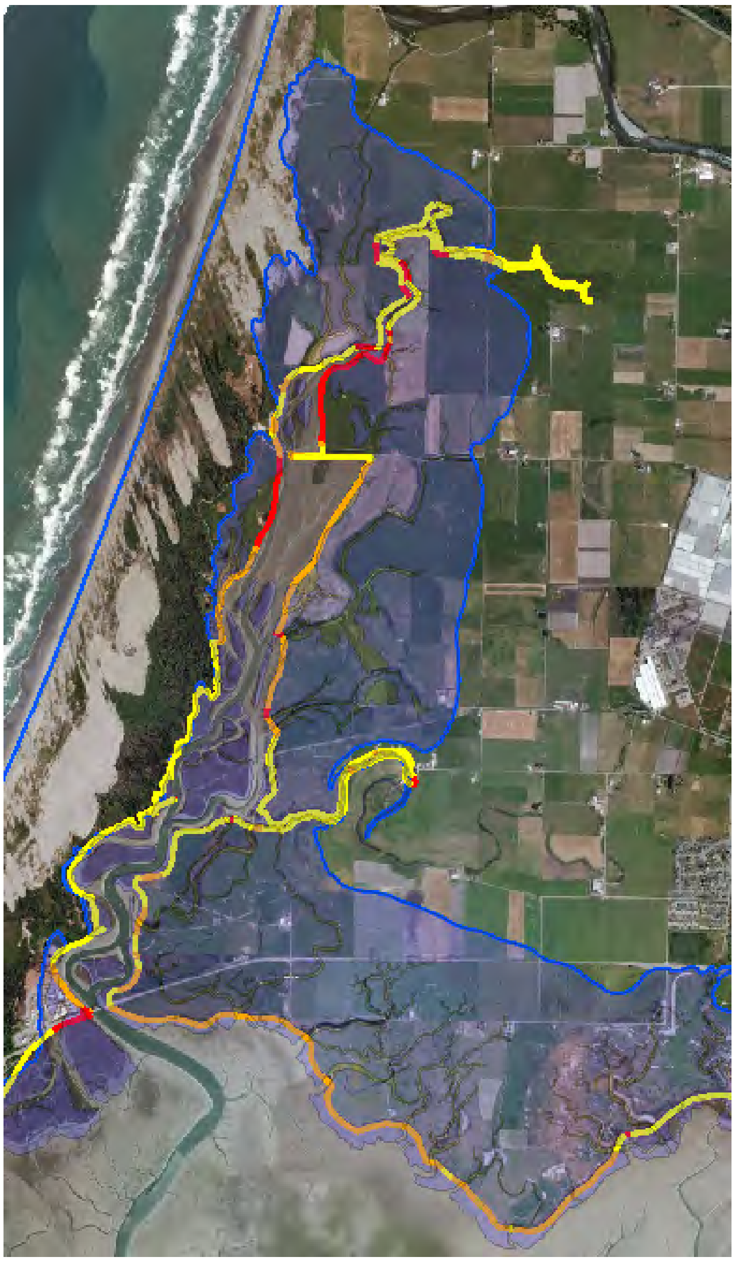

Figure 84. Mad River Slough shoreline cover: fortified (brown), vegetated (yellow), and exposed (red), with the 1870 tidal inundation area (blue).

On the west shoreline of Mad River Slough, there is 1,031 feet of eroded dike below Lanphere Bridge. Above Lanphere Bridge on the West shoreline, there are two units of eroding dike totaling 965 feet (453 and 412 feet in length). If the two units on the Western shoreline were to fail, a large area of agricultural land to the west and north would be flooded. There is a total of 2,418 feet of eroding dike on the eastern shoreline (4 units ranging from 140 to 1,484 feet) above Lanphere Road. If these units above Lanphere Road on the eastern shore were to fail, the agricultural land south and west of the Slough would likely flood to the east to the historical Hammond Railroad grade and south to Lanphere Road. If tidewater were to overtop the road, a large agricultural area south to Liscom Slough could be flooded. This threat illustrates why shoreline fortification needs to occur on a hydrologic basis and not parcel by parcel, as the eastern shoreline of the Slough below Lanphere Road is well fortified but flooding would occur from breaches farther up the Slough. On Liscom Slough, there are 105 feet of eroding dike that, if breached, could flood a large agricultural area to the south and west down to Highway 255. Another 104 feet of eroded shoreline exists on the eastern shoreline of Mad River Slough below Liscom Slough. If this shoreline were to breach, the agricultural area that flooded in the 2003 breach could be flooded again down to Highway 255.

One foot of sea level rise on Mad River Slough will increase the length of diked shoreline that is overtopped from 431 to 2,761 feet (Table 37). The dike on the western shoreline below Lanphere Bridge will be overtopped at one foot of rise, and flood the former tidelands behind the dike. With one foot of rise, the south bank of Mad River Slough, at its terminus, will be overtopped; flooding would extend south to Lanphere Road and possibly beyond to Jackson Ranch road. At the same time, the south bank of Liscom Slough, at its eastern end, will be overtopped with flooding south to Highway 255. One to two feet of sea level rise will initiate widespread dike overtopping, from 2,761 to 11,397 feet in the upper reach above Lanphere Road on both the west and eastern shores. On a few eastern shore segments of Mad River Slough south of Lanphere Road, one to two feet of sea level rise would flood a large agricultural area between Lanphere Road and Jackson Ranch Road. Along Liscom Slough, and the eastern shoreline of Mad River Slough in Reclamation District 768, flooding caused by one to two feet of sea level rise could occur in the same area as the 2003 breach, down to Highway 255. The next increment of sea level rise of two to three feet will more than double the length of shoreline (11,937’ to 27,397’) being overtopped on both sides of Mad River Slough and Liscom Slough, and at six feet, 95% of the shoreline would be overtopped.

	Length (feet) of shoreline at or below specified elevation					
MAD RIVER SLOUGH	**ELEVATION**					**TOTAL**
SHORELINE STRUCTURE	**MMMH**	**8.74'**	**9.74'**	**10.74'**	**13.74'**	**LENGTH**
Dike	431	2,761	11,397	26,569	45,843	47,471
Railroad	-	-	-	77	2,540	2,968
Fill	3	6	84	136	581	469
Fortified	-	59	456	615	862	1,345
Total	**434**	**2,826**	**11,937**	**27,397**	**49,827**	**52,253**

Table 37. Cumulative lengths of shoreline by structure at increasing sea level elevations, and the total length of shoreline structure.

Breaching or overtopping of the shoreline on Mad River Slough has the potential to flood the following land uses, infrastructure, and resources that are located within the historic tidal inundation footprint of 1870:

Land Uses:

On the Western Shoreline

- Natural resources,
- Agricultural,
- Maricultural,
- Industrial.

On the Eastern Shoreline

- Agricultural,
- Natural resources.

Infrastructure:

- Recreational: HBNWR's Ma-le'l Dunes and Lanphere units,
- Transportation: State Highway 255, county roads, and NCRA railroad,
- Utilities: HBMWD's water transmission pipes, and PG&E electrical transmission towers, MCSD's wastewater transmission pipe right-of-way,
- Drainage: numerous tidegates and culverts.

Resources:

- Wiyot Tribe historical and archeological village sites on the western shore,
- Historical Hammond Railroad grade and bridge trestles.

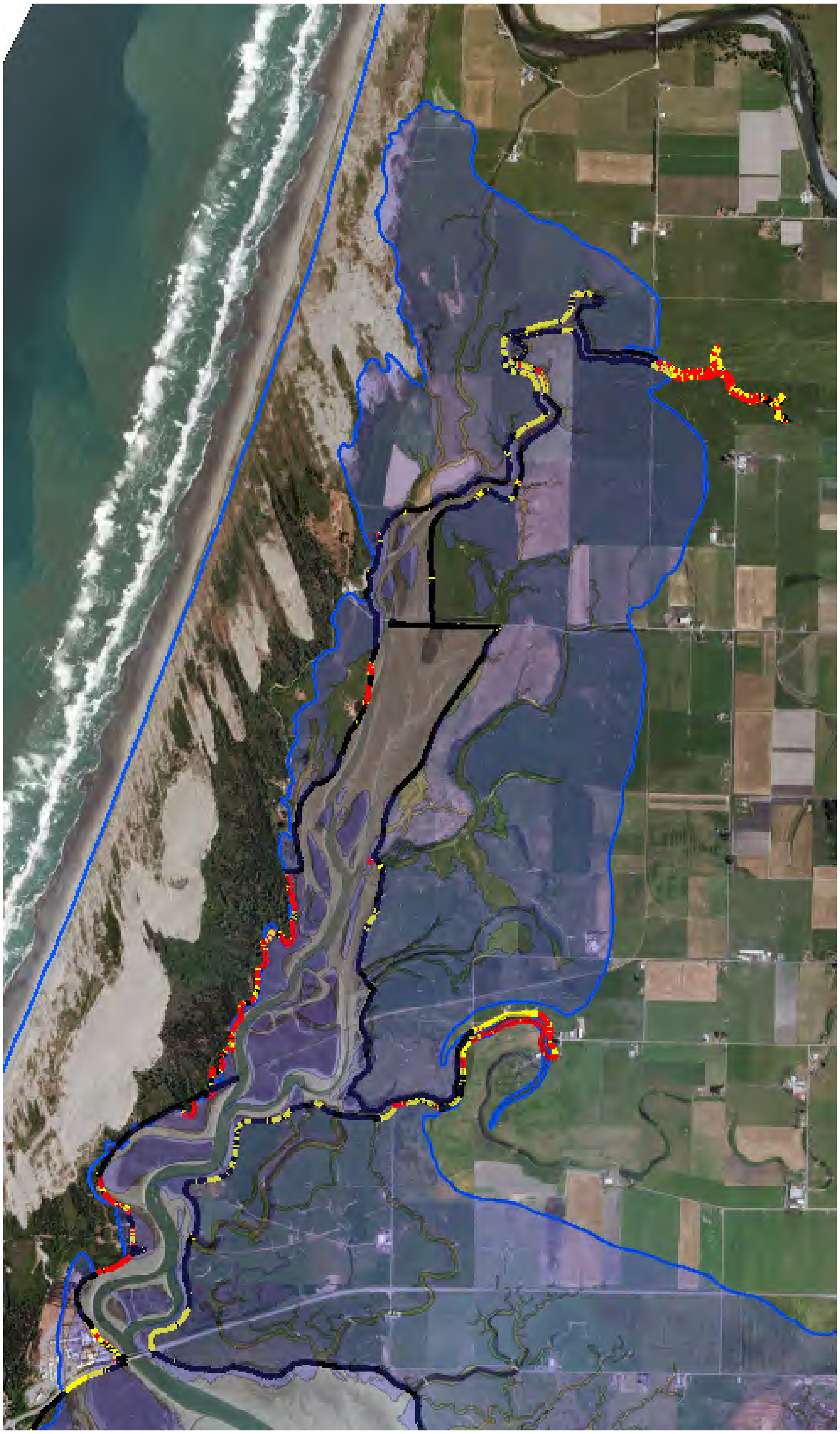

Figure 85. Mad River Slough, shoreline areas overtopped by 1 foot of sea level rise (red), and 2 feet (yellow), and the 1870 tidal inundation footprint (blue).

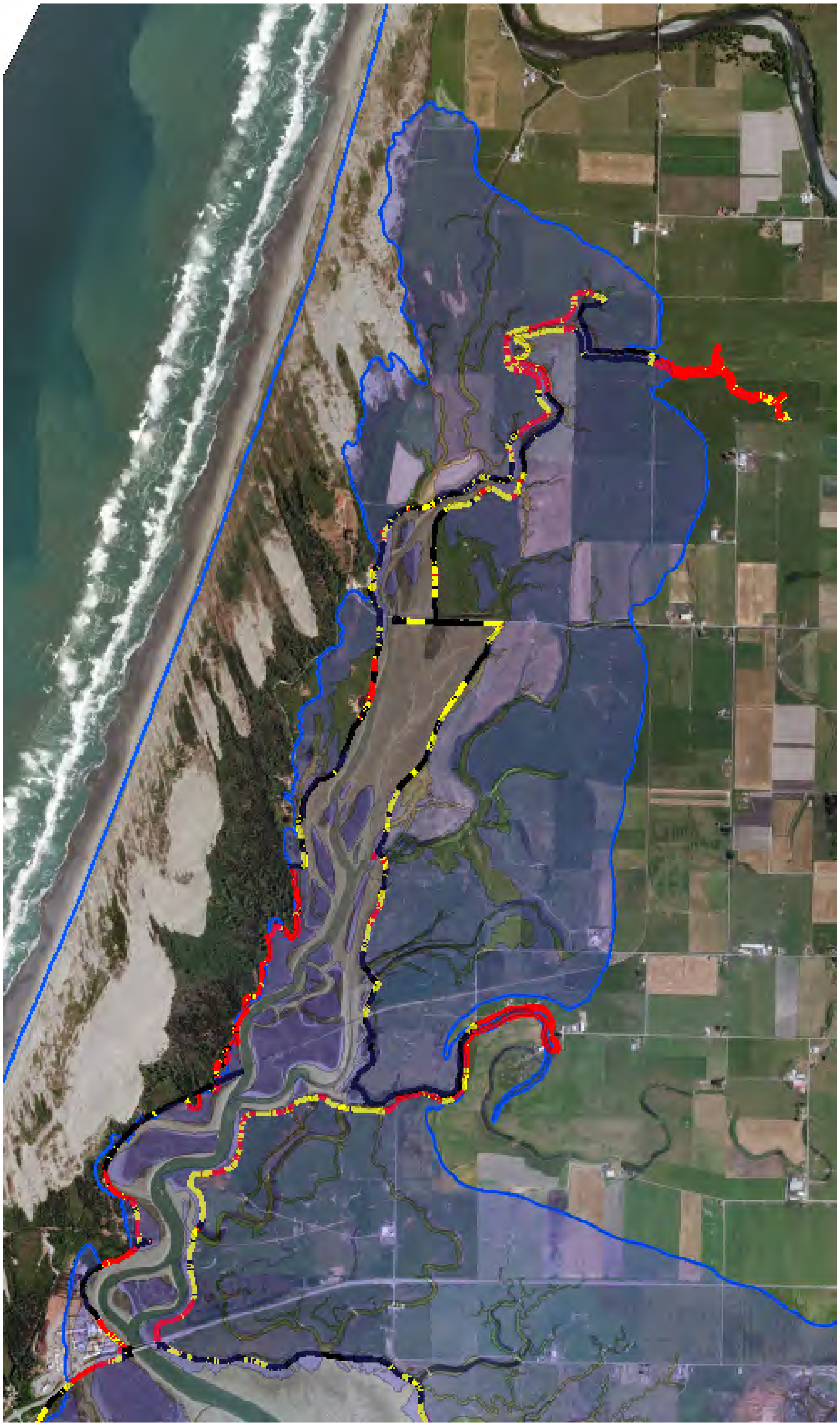

Figure 86. Mad River Slough, shoreline areas overtopped by 2 foot of sea level rise (red), and 3 feet (yellow), and the 1870 tidal inundation footprint (blue).

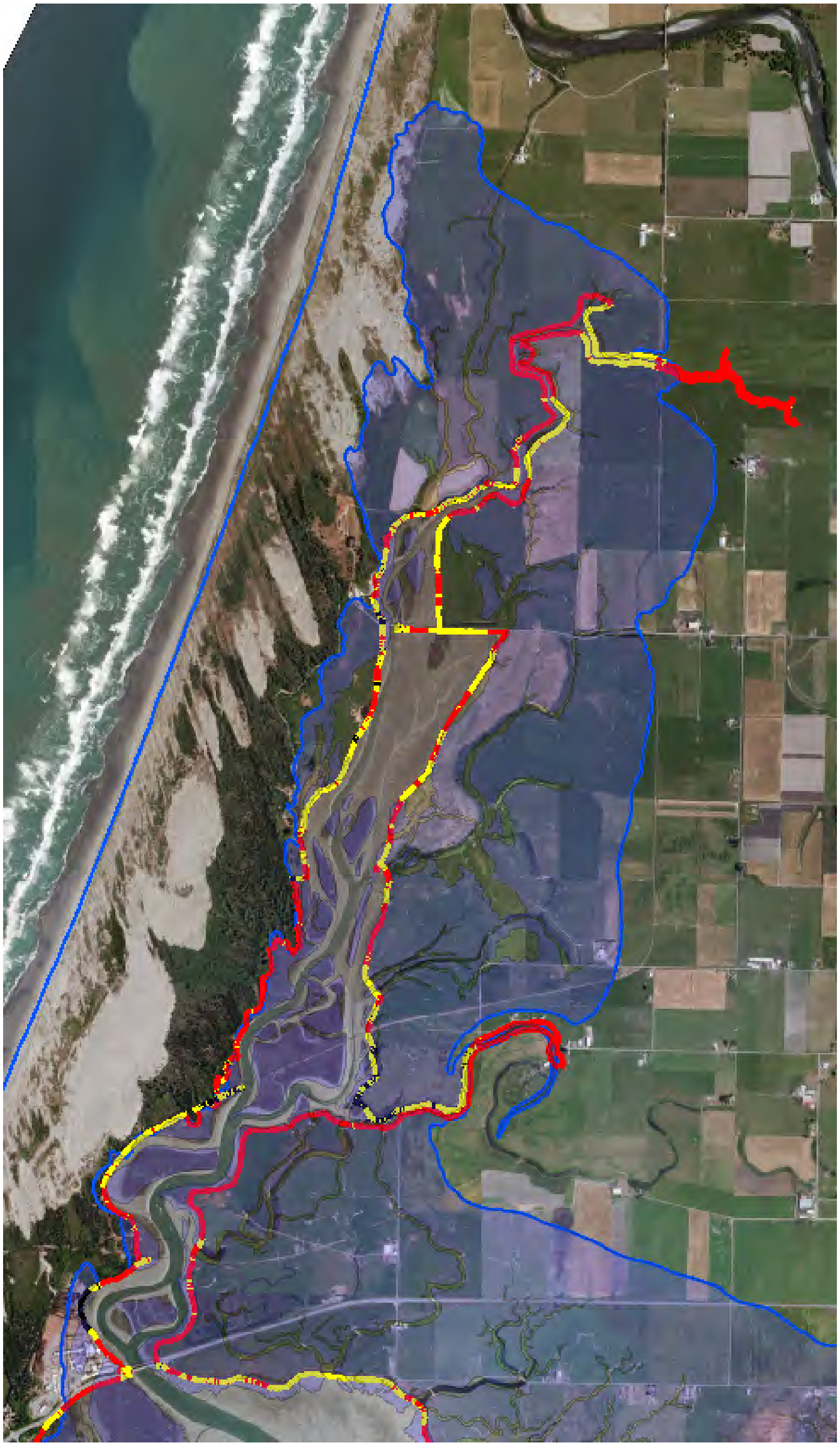

Figure 87. Mad River Slough shoreline areas overtopped by 3 feet of sea level rise (red), and 6 feet (yellow), and the 1870 tidal inundation footprint (blue).

f) Eureka Slough

The shoreline of Eureka Slough is 20.8 miles long. 80% (87,834 feet) of the shoreline is composed of artificial structures, and 7.0% (6,166 feet) of the artificial shoreline is exposed (Figure 88). The dominant artificial shoreline structures are dikes (69%, 75,588 feet) and roadway (3%, 3,666 feet). The diked shoreline is 84.7% (64,029 feet) vegetated, and 8.1% (6,098 feet) exposed.

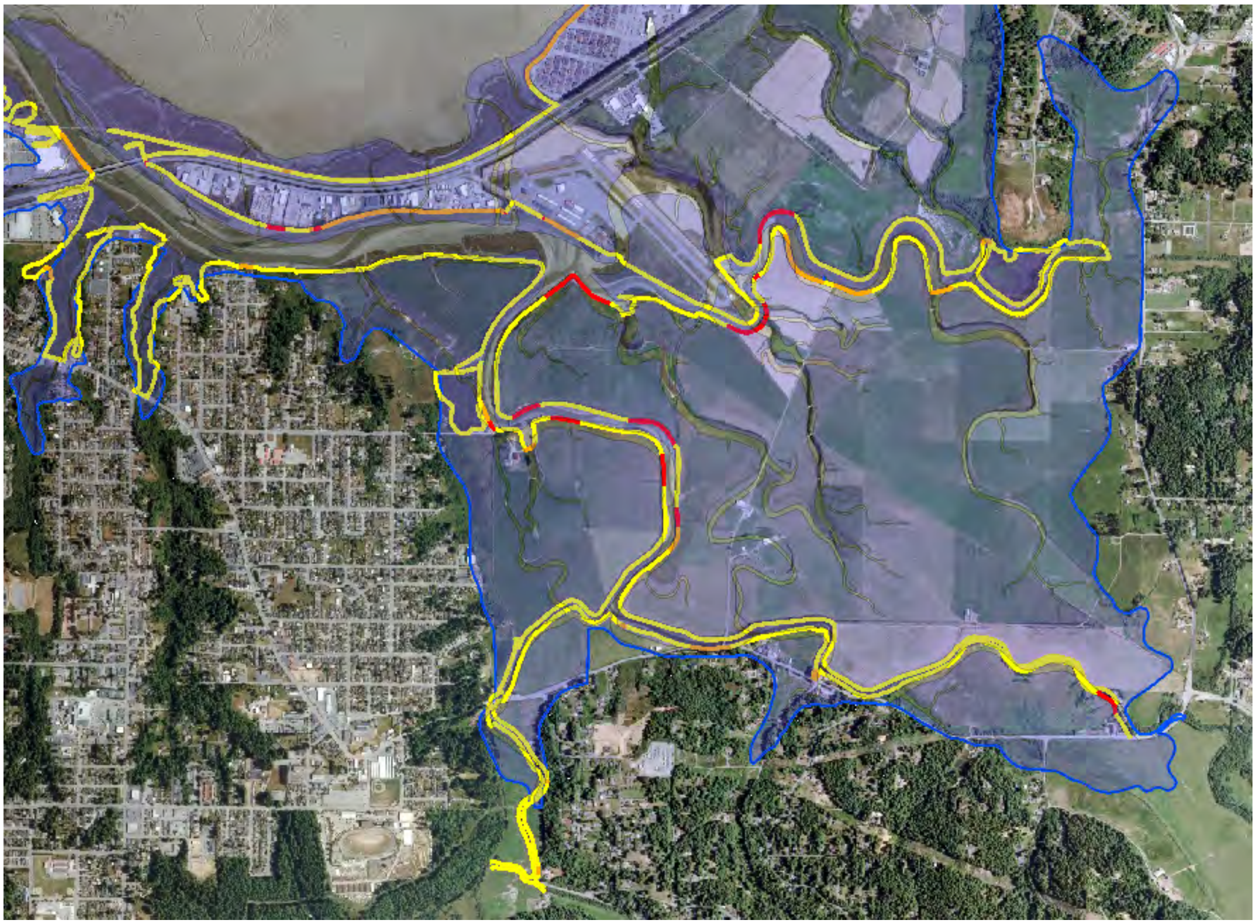

Figure 88. Eureka Slough shoreline cover: fortified (brown), vegetated (yellow), and exposed (red), with the 1870 tidal inundation area (blue).

Segregating Eureka Slough and the bottom land surrounding the slough into hydrologically connected areas will facilitate assessment of what land uses, infrastructure, or resources, may be at risk if the exposed shoreline were to fail to hold back tide water. On the north shoreline of Eureka Slough, three units (210, 113, and 21 feet in length) are exposed on the Jacobs Avenue dike, and on the airport dike, one unit of 98 feet is exposed. Continuing on the north shoreline, now in Fay Slough, there is one unit of 826 feet that is exposed. The land north of these shorelines was historically tidally interconnected and sloped towards the Bay. Shoreline failure on Fay Slough could flood agricultural and wildlife refuge lands to Highway 101, quite possibly the highway, towards commercial land at Indianola Cut-off, the airport and adjoining commercial area, and commercial and residential land in the Jacobs Avenue area. A breach in the airport dike could affect the airport and Jacobs Avenue area. A breach in the Jacobs Avenue dike may flood just that area.

On the south shoreline of Fay Slough, there are three dike units (95, 888, and 1,183 feet in length) that are exposed. On the north shoreline of Freshwater Slough, there are three dike units (402, 869, and 265 feet in length) that are exposed. Failure of any of these dike units would lead to flooding of a large agricultural area and a few residences. The City of Eureka's water transmission pipe traverses this area as does PG&E's gas transmission pipe and electrical transmission towers.

On the south shoreline of Freshwater Slough, there is one dike unit of 442 feet that is exposed. If this shoreline unit were to fail, flooding of agricultural land and Myrtle Avenue could occur.

On the west shoreline of Freshwater Slough, there are three dike units (451, 432, and 154 feet in length) that are exposed. If these dike units are breached, the agricultural area and a few residences north of Ryan Slough and south of Parks Street could flood.

One foot of sea level rise will increase the length of diked shoreline that is overtopped from 689 to 2,155 feet (Table 38). One to two feet of sea level rise will initiate wide spread dike overtopping; from 2,155 to 12,467 feet. The next increment of sea level rise of two to three feet will nearly triple the length of overtopped diked shoreline (12,467' to 36,395'). Six feet of sea level rise will overtop 97.5% of the diked shoreline. South of Eureka Slough are First, Second, and Third Sloughs, interspersed with residential and commercial uses, mostly on upland slopes. At the Slough shoreline, overtopping will occur but, due to the topography, there is little area to flood.

	Length (feet) of shoreline at or below specified elevation					
EUREKA SLOUGH	**ELEVATION**					**TOTAL**
SHORELINE STRUCTURE	**MMMH**	**8.74'**	**9.74'**	**10.74'**	**13.74'**	**LENGTH**
Dike	689	2,155	12,467	36,395	73,728	75,588
Railroad	18	131	295	461	563	551
Fill	828	2,720	4,172	5,133	6,057	6,059
Fortified	-	3	69	145	161	163
Total	**1,535**	**5,009**	**17,003**	**42,134**	**80,509**	**82,361**

Table 38. Cumulative lengths of shoreline by structure at increasing sea level elevations, and the total length of shoreline structure.

Breaching or overtopping of the shoreline on Eureka Slough has the potential to flood the following land uses, infrastructure, and resources, that are located within the historic tidal inundation footprint of 1870:

Land Uses:

North of Eureka and Fay Slough Shorelines

- Natural resources: DFG Fay Slough Wildlife Reserve,
- Agricultural,
- Commercial,
- Residential,
- Public facility: county airport

South of Fay Slough and East of Freshwater Slough Shorelines

- Agricultural,
- Natural resources,

South of Freshwater Slough

- Agricultural,
- Residential,
- Commercial

West of Freshwater Slough

- Agricultural,
- Natural Resources,

South of Eureka Slough

- Agricultural,
- Natural Resources,
- Residential,
- Commercial,
- Public Facility,

Infrastructure:

North of Eureka and Fay Slough Shorelines

- Recreational: DFG Fay Slough Wildlife Reserve, trails,
- Transportation: Interstate Highway 101, county roads, Jacobs Avenue, county airport,
- Drainage: numerous tidegates and culverts.

South of Fay Slough and East of Freshwater Slough Shorelines

- Transportation: County road,
- Utilities: City of Eureka water transmission pipes, PG&E gas transmission line, and PG&E electrical transmission towers,
- Drainage: numerous tidegates and culverts.

South of Freshwater Slough

- Transportation: County road,
- Drainage: tidegates, culverts, and causeway.

West of Freshwater Slough

- Transportation: County roads, service streets in Eureka and HCSD,

- Utilities: HCSD wastewater pump station,
- Drainage: numerous tidegates and culverts.

South of Eureka Slough

- Transportation: service streets in Eureka and HCSD,
- Utilities: HCSD wastewater pump station,
- Drainage: numerous tidegates and culverts.

Cultural Resources:

- Wiyot Tribe historical and archeological village sites.

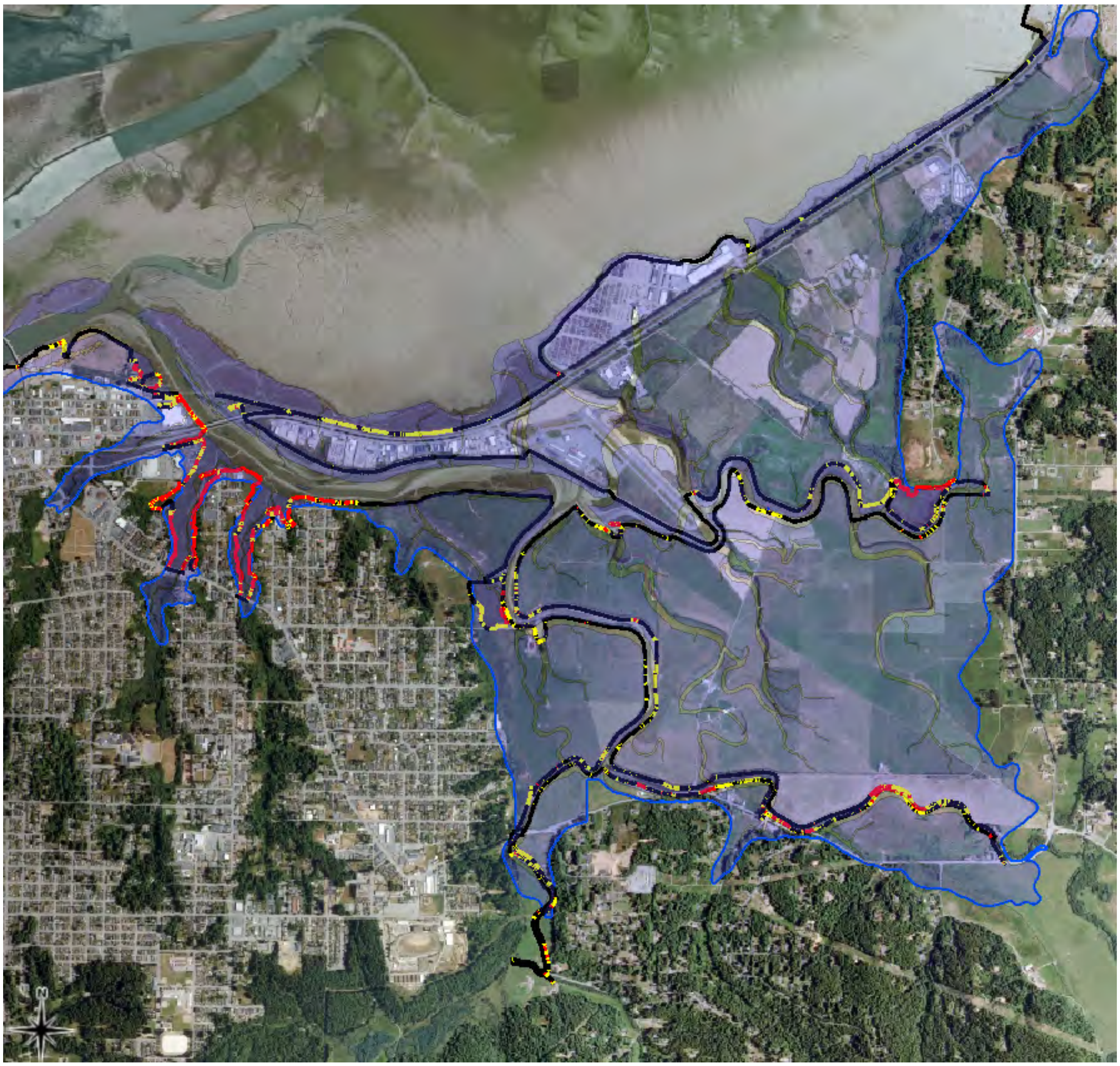

Figure 89. Eureka Slough, shoreline areas overtopped by 1 foot of sea level rise (red), and 2 feet (yellow), and the 1870 tidal inundation footprint (blue).

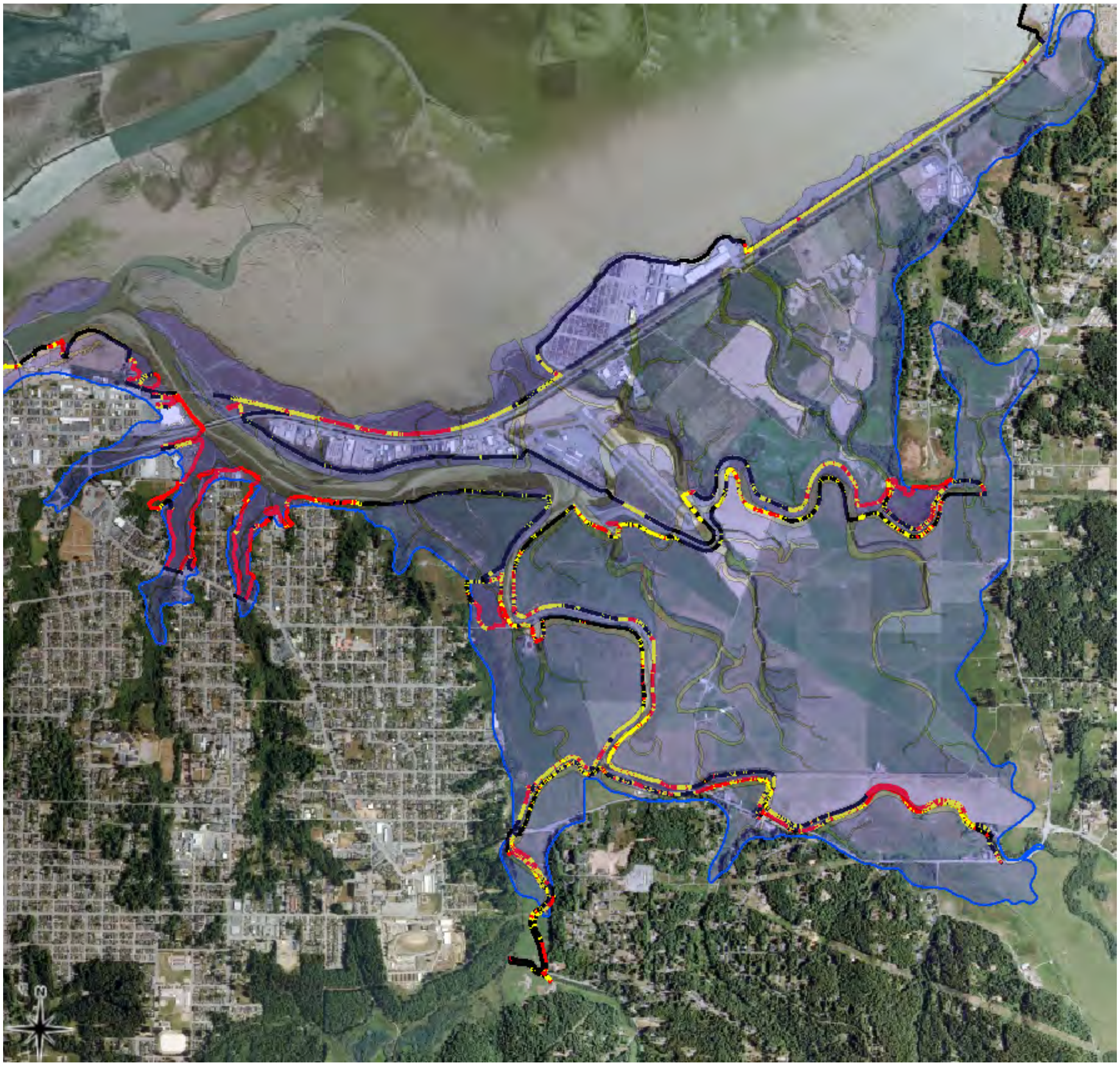

Figure 90. Eureka Slough, shoreline areas overtopped by 2 foot of sea level rise (red), and 3 feet (yellow), and the 1870 tidal inundation footprint (blue)..

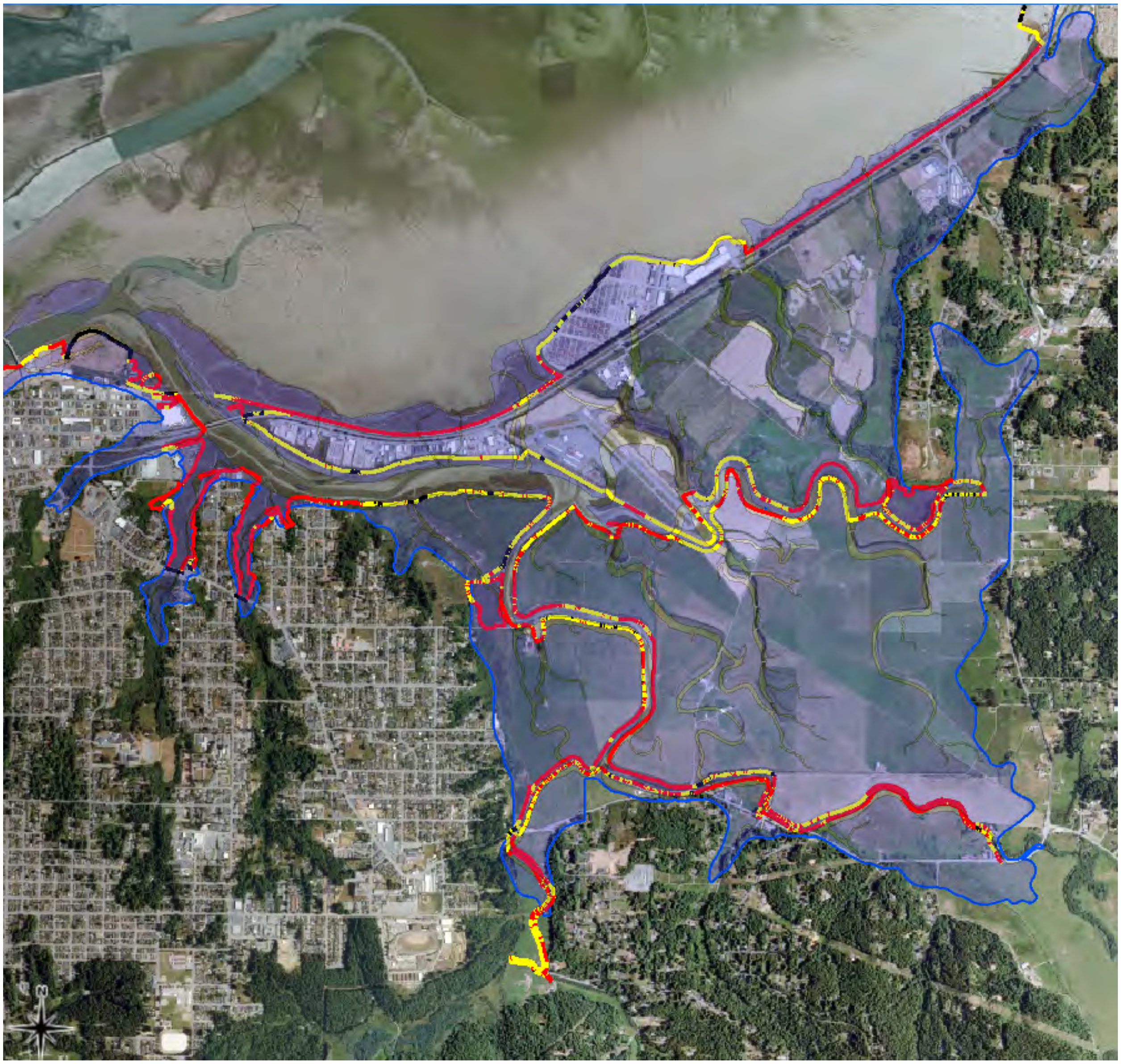

Figure 91. Eureka Slough, shoreline areas overtopped by 3 feet of sea level rise (red), and 6 feet (yellow), and the 1870 tidal inundation footprint (blue).

g) Elk River Slough

The shoreline of Elk River Slough is 9.7 miles long. 45% (35,306 feet) of the shoreline is composed of artificial structures, and only 100 feet of the artificial shoreline are exposed (Figure 92). The dominant artificial shoreline structures are dikes (43.4%, 15,334 feet) and roadway (9.7%, 3,443 feet). The diked shoreline is 57.4% (20,273 feet) vegetated, and only 74 feet are exposed. The majority of the shoreline on Elk River Slough, 55%, is made of natural channel banks. The upper 4,850 feet of the tidal reach of Elk River Slough is a natural channel that traverses the floodplain.

Figure 92. Elk River Slough shoreline cover: fortified (brown), vegetated (yellow), and exposed (red).

Nearly the entire length of Martin Slough, which is diked, and a substantial length of the diked shoreline on Elk River Slough (2,180 feet) are overtopped by MMMW of 7.74 feet. In addition, 4,938 feet of natural shoreline (no structure) on the west and east banks of Elk River, at the upper reach of tidal influence, are also overtopped at MMMW elevation. Flooding at this tidal stage affects predominantly agricultural lands. One foot of sea level rise (EHT) will substantially increase overtopped diked shoreline from 2,180 to 7,865 feet (Table 39), and will overtop the remaining 3,747 feet of the east bank of the natural channel in the upper tidal reach. Flooding of the agricultural lands in Martin Slough and lower Elk River Valley, as well as Pine Hill Road, occurs regularly at EHT. At two feet of sea level rise, 11,750 feet (76.6%) of diked shoreline is overtopped, and flooding on both sides of Highway 101, NCRA right-of-way, and Elk River Road, will occur south of Elk River and Martin Sloughs. Overtopping of the fore dunes of Elk River Spit is extensive (87.7%) at two feet. It is not known how sediment circulation in Humboldt Bay, particularly across from the entrance, will change with rising sea levels or what impact that might have on Elk River Spit. Much of the shoreline fronting Hilfiker Lane and City of Eureka wastewater treatment facility is overtopped at two feet and the entire shoreline at three feet. At three feet of sea level rise, the dike on the north bank of Elk River Slough between Highway 101 and the NCRA Bridge south of the City of Eureka's Wastewater Treatment Facility, is overtopped; and 92.4% of the diked shoreline on Elk River and Martin Sloughs is overtopped.

	Length (feet) of shoreline at or below specified elevation					
ELK RIVER SLOUGH	**ELEVATION**					**TOTAL**
SHORELINE STRUCTURE	**MMMH**	**8.74'**	**9.74'**	**10.74'**	**13.74'**	**LENGTH**
Dike	2,180	7,865	11,750	14,170	15,349	15,334
None	4,938	10,854	13,867	15,573	16,010	15,919
Fore dune	3,000	6,772	8,113	9,104	9,251	9,246
Road	75	196	332	1,162	3,046	3,443
Railroad	-	-	13	144	858	1,714
Total	**10,193**	**25,687**	**34,075**	**40,152**	**44,514**	**45,656**

Table 39. Cumulative lengths of shoreline by structure at increasing sea level elevations, and the total length of shoreline structure.

Breaching or overtopping of the shoreline on Elk River Slough has the potential to flood the following land uses, infrastructure, and resources that are located within the historic tidal inundation footprint of 1870:

<u>Land Uses:</u>

<u>West of Highway 101</u>

- Natural resources,
- Agricultural,
- Public recreation.
- Public facility.

- Industrial

East of Highway 101

- Agricultural,
- Residential.

Infrastructure:

West of Highway 101

- Recreational: City of Eureka's Hiksari Trail,
- Transportation: Interstate Highway 101, county roads and City of Eureka service streets, and NCRA railroad,
- Utilities: City of Eureka Wastewater Treatment Facility, PG&E's gas transmission line,
- Drainage: numerous tidegates and culverts.

East of Highway 101

- Transportation: Interstate Highway 101, county roads,
- Utilities: PG&E's gas transmission line, PG&E electrical transmission towers,
- Drainage: numerous tidegates and culverts.

Resources:

- Wiyot Tribe historical or archeological village sites.

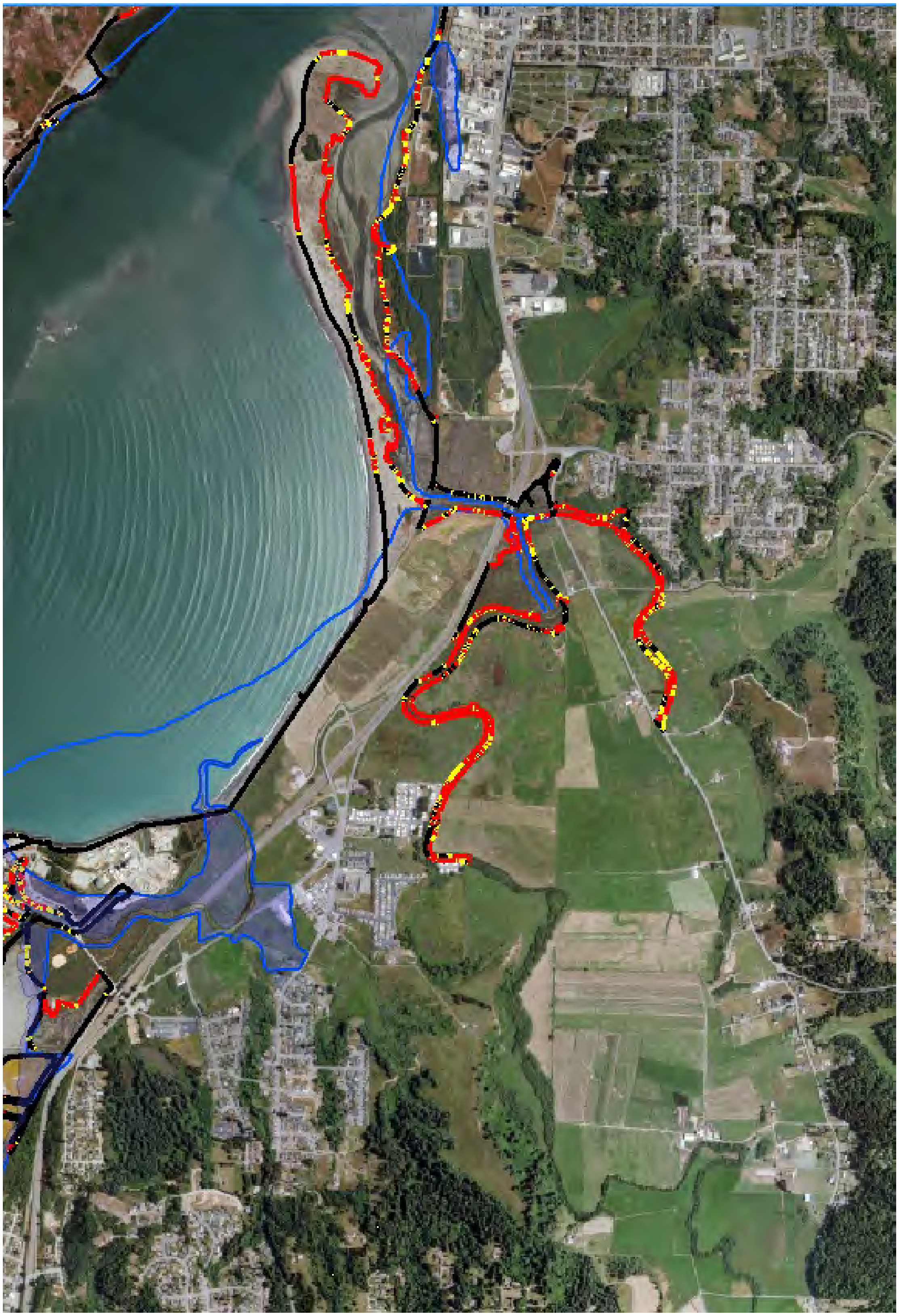

Figure 93. Elk River Slough shoreline areas overtopped by 1 foot of sea level rise (red), and 2 feet (yellow).

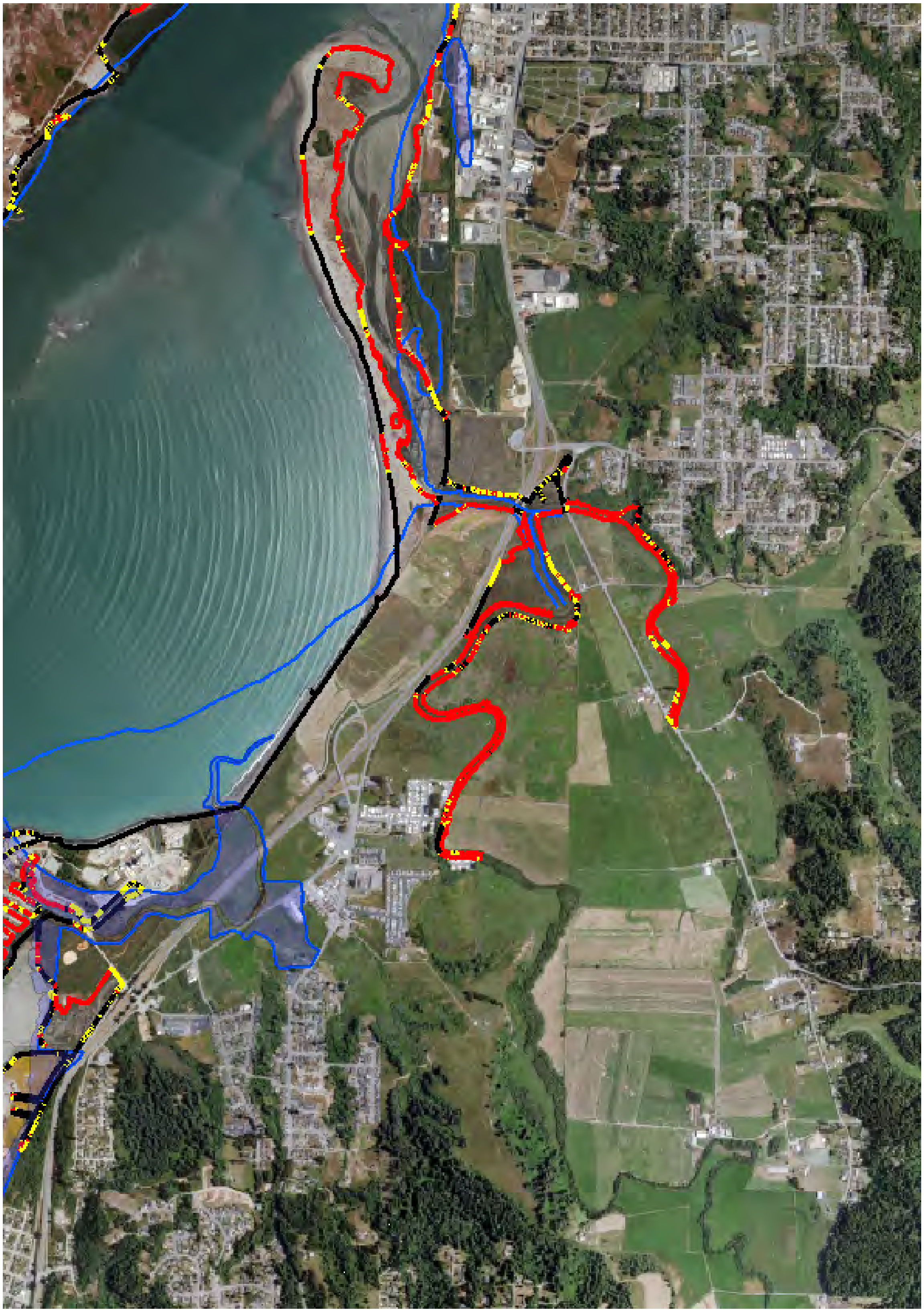

Figure 94. Eureka Slough shoreline areas overtopped by 2 foot of sea level rise (red), and 3 feet (yellow).

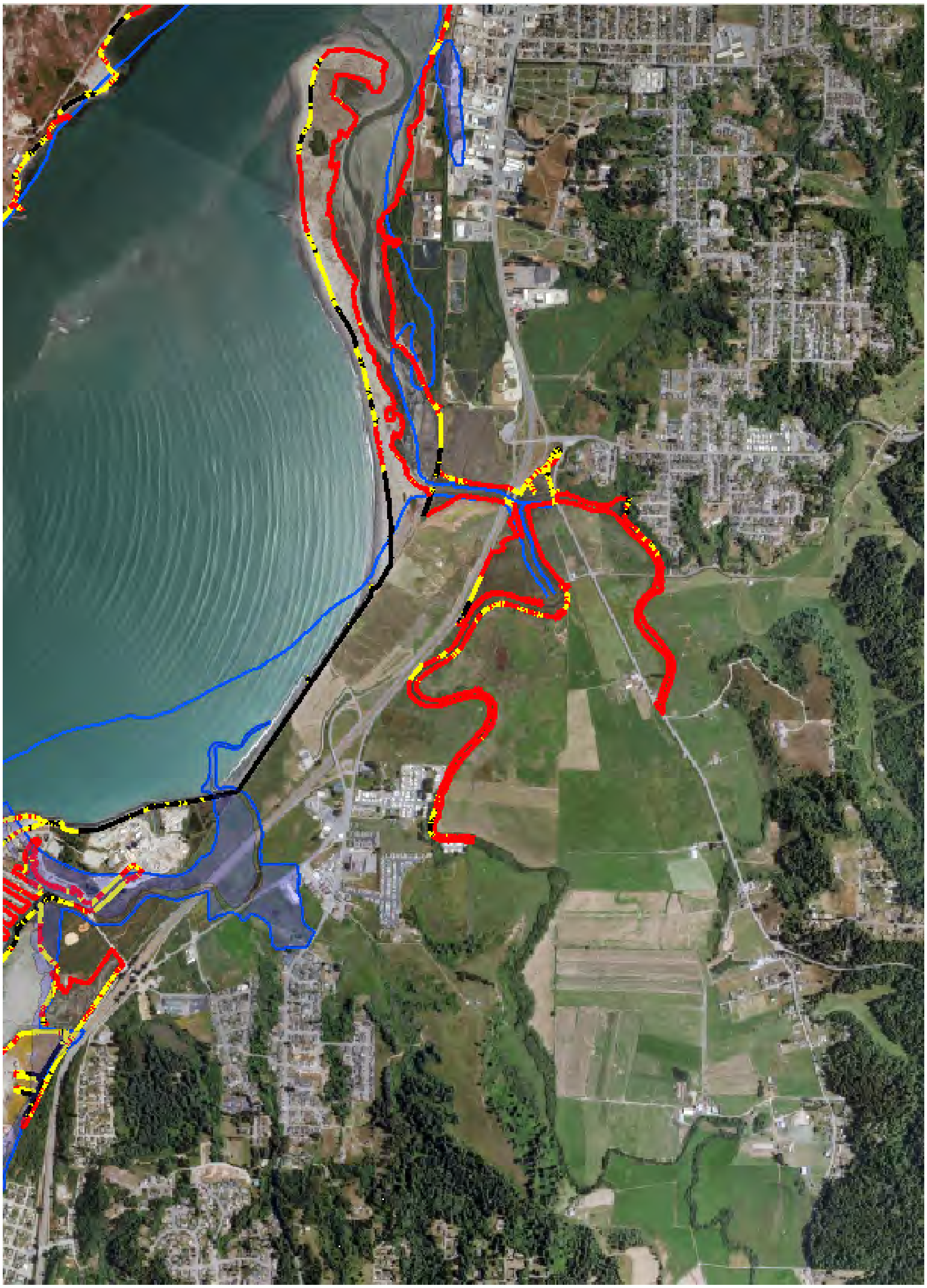

Figure 95. Eureka Slough shoreline areas overtopped by 3 feet of sea level rise (red), and 6 feet (yellow).

5 Conclusions

This project created the first comprehensive geo-spatial database of Humboldt Bay's shoreline. The database is based upon physical shoreline attributes of structure, cover, elevation, and the presence of salt marsh habitat. This database serves as a useful baseline to measure future changes in these shoreline attributes. NOAA's 2009 benthic habitat mapping of Humboldt Bay has been augmented to include the location of 57 additional areas of salt marsh habitat. This project also added 36 structures, 18 culverts, and 18 tidegates at 28 locations, to the USFWS's 2007 water control structure database.

Since the 1880s, Humboldt Bay has had a historical legacy of diking and "reclaiming" nearly 9,000 acres of tidelands. There currently are reaches of earthen dikes on Humboldt Bay that are actively eroding, unmaintained, or with surfaces that are overtopped by MMMW or EHT elevations; these reaches are vulnerable to coastal hazards of erosion and flooding. Since 2000, Humboldt Bay has experienced periods of rising water elevations on the order of 1 to 1.75 feet during annual EHTs and when combined with either stormwater runoff or storm surges. Vulnerable shoreline structures, such as dikes, put land uses, infrastructure, and property that may be lower in elevation than the Bay, at risk from flooding. At great expense, fortification of diked shorelines has been a common response to recently breached or overtopped dikes, during EHTs that have flooded formerly protected lands. Unfortunately, for example, fortification and rehabilitation of dikes, at the cost of $900,000.00 to $2,000,000.00 per mile, on Arcata Bay by the City of Arcata and Reclamation District 768, did not significantly increase their dike's surface elevations. These recently repaired dikes now range in elevation from 10.74 to 13.74 feet, and would not offer protection from rising sea levels above 3 or 6 feet.

Increasing the elevation of a dike generally requires expanding the width of the dike's base, or footprint. The California Coastal Act (Act) does allow shoreline armoring to protect "existing structures" (Public Resource Code (PRC) Section 30235). Existing, is interpreted to mean those structures built before 1976, the date of the Act. However, increasing the height of a dike by expanding its base generally would require placing fill in a tidal wetland or coastal water, which under the Act, is not one of the allowable reasons for placing fill in a wetland or coastal water (Section 30233). Therein is the conundrum! While it may be physically feasible for dikes to be modified to retain higher tide elevations, it may not be, per regulations, feasible to fill coastal wetlands or waters in order to fortify and expand a dike's footprint and height. With artificial shorelines covering 75% of Humboldt Bay (76.7 miles), only 36% is fortified (27.6 miles). Increasing the amount of shoreline that is fortified is not likely to conform to coastal resource protection policies addressing sediment recruitment and the continued existence of benthic habitats like salt marsh. Former tidelands have been and continue to be productive areas for agriculture, but at some time in the future, rising tides or continued subsidence of the land will elevate groundwater and existing tidegates will no longer fully drain on ebbing tides. Eventually, rising tides and subsiding land may reclaim some of the nearly 9,000 acres of former tidelands as the Bay returns to its original footprint.

With rising sea levels, all tidal datums such as mean low water and mean high water, will increase; when the MMMW elevation rises 1 foot, then so too will EHT increase 1 foot to an average elevation of nearly 10 feet at the North Spit tide station (equivalent now to 2 feet of sea level rise), and the risk of flooding will become an annual event. Based upon existing conditions, a sea level rise of 1 foot plus EHT would expose approximately 11 miles of dikes (28%) to overtopping in all six hydrologic units of Humboldt Bay. A conservative estimate for California is that we could see 1 foot of sea level rise by 2050. Unfortunately, based upon the North Spit tide record, Humboldt Bay is also subsiding, resulting in the highest rate of sea level rise in California. Because of the effect of subsidence, Humboldt Bay could realize a relative sea level rise of 1 foot sooner than 2050. On Elk River, EHT events regularly flood the lower valley reaches that Martin, Swain, and Elk River Sloughs traverse. In 2003, during EHT and a storm surge that elevated water elevations 1.77 feet above MMMW, a breach of 230 feet of dike on Mad River Slough flooded approximately 600 acres of agricultural land. During the 2005/2006 New Years storms and EHT, with water elevations of 1.75 to 1.81 feet, overtopping of Reclamation District 768's dikes on Arcata Bay occurred in several locations, which led to FEMA granting the District 11 million dollars to fortify and rehabilitate 4.9 miles of their dikes.

While it is not known if sea level rise or subsidence will continue at the same rate as has been recorded at the North Spit tide station, it would be prudent for the Humboldt Bay region to initiate adaptation plans before water levels reach the two to three foot threshold when wide-spread shoreline failure of approximately 21 to 44 miles could occur, and land uses, infrastructure, and resources, currently protected, will be at risk of permanent flooding. In the long-term, with a 6 foot rise in water levels, nearly 94% of the dikes would fail to hold back rising tidewater. It is important for the land use authorities on Humboldt Bay who have the capability, to pro-actively adapt to sea level rise in an effort to reduce the risk from flooding of land uses, infrastructure, and resources.

There is time to plan and adapt to sea level rise, but the more time we wait, the more likely we will have to deal with extensive emergency flooding. This project constitutes the first phase of a multi-phase sea level rise adaptation planning effort for Humboldt Bay. To develop a sea level rise adaptation plan, it is necessary to understand the vulnerability to and risk from sea level rise (Russell 2012). In preparing a vulnerability assessment for Humboldt Bay, the local tidal record from the North Spit station should be utilized to develop relative rates of sea level rise that incorporate local rates of tectonic subsidence. The SCC is funding Phase 2 of the sea level rise adaptation planning effort, which will complete the vulnerability assessment begun in Phase 1 with the development of surface and ground water models to assess changes in water levels from anticipated increases in sea level. In Phase 2, maps will be produced of areas under existing conditions that are vulnerable to inundation from Humboldt Bay and from groundwater, and for different rates of sea level rise. Phase 1 identifies structures that are vulnerable and Phase 2 will identify areas that are currently at risk from coastal hazards such as erosion and overtopping of dikes and flooding of low lying areas as well as identifying areas at risk due to sea level rise.

Subsequent adaptation planning phases should include:

- conducting a risk analysis of the sensitivity of the region's land uses, infrastructure, and resources,
- conducting an economic assessment of at risk regional assets,
- conducting an assessment of the adaptive capacity of land use or land management authorities to respond to or cope with the effects of sea level rise,
- developing, vetting, and authorizing adaption strategies and plans,
- implementing adaptation strategies and plans,

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