

Humboldt Bay
Shoreline Inventory, Mapping
and
Sea Level Rise
Vulnerability Assessment

Addendum:

Shoreline Vulnerability Ratings

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July, 2013

Introduction

The Humboldt Bay shoreline vulnerability rating is a quantitative measure of vulnerability that was developed as an addendum to the Humboldt Bay Shoreline Inventory, Mapping, and Sea Level Rise Vulnerability Assessment (Laird 2013). The vulnerability rating uses combinations of shoreline attributes (cover type and relative elevation to modeled mean monthly maximum high water) to rank a shoreline segment's vulnerability to erosion and/or overtopping due to extreme tides, storm surges, and future sea level rise. Shoreline segments were given a rating between 2 and 10, 2 being the least vulnerable and 10 being highly vulnerable. Ranking shoreline vulnerability will assist in identifying assets at risk of flooding in the near-term from existing coastal hazards of shoreline erosion or overtopping.

Methodology

The 2013 inventory and mapping of existing shoreline conditions on Humboldt Bay contain three elements: structure, cover, and elevation. A GIS database containing spatial data of existing shoreline conditions has been created for these three attributes. These attributes were selected to quantify existing shoreline conditions and to support a vulnerability assessment of existing shoreline and tidal conditions and under various sea level scenarios (Laird 2013).

Structure types of dikes and railroads were extracted from the shoreline mapping dataset for the vulnerability rating analysis because they are the most prevalent structures and most vulnerable to extreme tides, storm surges, and sea level rise. If these structures fail, they will expose thousands of acres of former tidelands to risk from flooding. Dike and railroad shoreline segments were given a value between 1 and 3 based on their cover type (0). Fortified shoreline segments are considered to be the least vulnerable to erosion and exposed segments are considered to be the most vulnerable.

Cover	Index Value
Fortified	1
Vegetated	2
Exposed	3

Table 1. Vulnerability index values based on cover type.

As a product of the Humboldt Bay Shoreline Inventory, Mapping, and Sea Level Rise Vulnerability Assessment, relative elevations to the modeled mean monthly maximum tidal water surface (MMMWW) were assigned to 1 meter segments of the bay shoreline.

Humboldt Bay Shoreline Vulnerability Rating

Using these relative elevations we rated each segment of shoreline using the values in Table 2.

Relative Elevation (ft)	Index Value
<1	7
1-2	6
2-3	5
3-4	4
4-5	3
5-6	2
>6	1

Table 2. Vulnerability index values based on relative elevation to MMMW.

Shoreline cover and relative elevation values were added together to assign a final rating between 2 and 10 to each individual 1 meter shoreline segment in Table 3. Relative shoreline elevations of <1 to 2 feet have been given high vulnerability rating because they are within current tidal elevations during annual extreme high tides and storm surges on Humboldt Bay. Relative shoreline elevations of 2 to 4 feet are rated moderately vulnerable at this time as they represent extreme high tide elevations with 1 to 2 feet of sea level rise, which is not expected until 2050 or later. Relative shoreline elevations of 4 to >6 feet are considered the least vulnerable at this time. Shoreline elevations of <1 to 2 feet are ranked highly vulnerable regardless of the shoreline cover conditions, with a vulnerability index of 7 to 10. Relative shoreline elevations of 2 to 4 feet are ranked moderately vulnerable but shoreline conditions of vegetated and exposed at relative elevations of 2 to 3 attain a combined vulnerability ratings of 7 and 8, which is a high vulnerability ranking, likewise at the relative elevation of 3 to 4 feet the exposed shoreline cover condition results in a highly vulnerable rating of 7. The same staggered vulnerability ranking occurs at 4 to 5 feet and 5 to 6 feet due to shoreline cover conditions causing higher vulnerability ranking than what would be if we just considered relative elevation.

Humboldt Bay Shoreline Vulnerability Rating

Relative Elevation	Index Value	Cover Index Value	Vulnerability Rating
<1	7	1-2-3	8-9-10
1-2	6	1-2-3	7-8-9
2-3	5	1-2-3	6-7-8
3-4	4	1-2-3	5-6-7
4-5	3	1-2-3	4-5-6
5-6	2	1-2-3	3-4-5
>6	1	1-2-3	2-3-4

Table 3. Combined shoreline vulnerability index values create high-moderate-low vulnerability ratings.

Dike and Railroad Grade Shoreline Vulnerability Ratings

Shoreline vulnerability rating results for dike and railroad shoreline segments are shown in Tables 4 through 6 below.

Sum of Length (miles)	Vulnerability Rating									Total
	Low								High	
Area	2	3	4	5	6	7	8	9	10	
Arcata Bay	0.68	0.88	0.98	1.41	2.82	3.38	1.88	0.26	0	12.3
Eureka Bay	0.67	0.41	0.03	0.14	0.4	0.34	0.19	0.09	0	2.26
South Bay	0.01	0.07	0.15	0.82	2.25	3.81	1.34	0.43	0.12	9
Mad River Slough	0.04	0.34	0.68	1.68	2.43	1.9	1.74	0.62	0.12	9.54
Eureka Slough	0	0.46	0.98	1.85	3.93	4.63	1.98	0.58	0.03	14.44
Elk River Slough	0.08	0.13	0.06	0.05	0.2	0.48	0.74	1.49	0	3.23
Total	1.48	2.28	2.88	5.94	12.03	14.54	7.87	3.47	0.28	50.78

Table 4. Dike and railroad shoreline vulnerability rating for Humboldt Bay summarized as length in miles.

Humboldt Bay Shoreline Vulnerability Rating

The total length of diked and railroad shoreline that is rated highly vulnerable is 26.2 miles. Eureka Slough has the greatest length of shoreline ranked highly vulnerable 7.2 miles; South Bay 5.7 miles, Arcata Bay 5.5 miles, Mad River Slough 4.4 miles, Elk River Slough 2.7 miles, and Eureka Bay 0.6 miles.

Percent of Length	Vulnerability Rating									Total
	Low								High	
Area	2	3	4	5	6	7	8	9	10	
Arcata Bay	5.60%	7.20%	8.00%	11.50%	23.00%	27.40%	15.30%	2.10%	0.00%	100.00%
Eureka Bay	29.70%	18.00%	1.40%	6.10%	17.60%	15.10%	8.40%	3.80%	0.00%	100.00%
South Bay	0.10%	0.80%	1.70%	9.10%	25.00%	42.30%	14.90%	4.80%	1.40%	100.00%
Mad River Slough	0.40%	3.50%	7.20%	17.60%	25.40%	19.90%	18.20%	6.50%	1.30%	100.00%
Eureka Slough	0.00%	3.20%	6.80%	12.80%	27.30%	32.10%	13.70%	4.00%	0.20%	100.00%
Elk River Slough	2.50%	4.10%	1.70%	1.70%	6.20%	14.90%	22.80%	46.10%	0.10%	100.00%
Total	2.90%	4.50%	5.70%	11.70%	23.70%	28.60%	15.50%	6.80%	0.60%	100.00%

Table 5. Dike and railroad shoreline vulnerability rating for Humboldt Bay summarized as percent of total.

The total length of diked and railroad shoreline that is rated highly vulnerable is 51.5 %. Elk River Slough has the greatest percentage, 83.9%, of diked and railroad shoreline ranked highly vulnerable; South Bay 62.0%, Eureka Slough 49.8%, Mad River Slough 45.9%, Arcata Bay 44.8%, and Eureka Bay at 27.3%.

Sum of Length (miles)	Vulnerability Rating									Total
	Low								High	
	2	3	4	5	6	7	8	9	10	
Arcata Bay										
Dike	0.68	0.86	0.9	1.15	0.67	0.59	0.73	0.2	0	5.78
Railroad	0	0.02	0.08	0.26	2.15	2.78	1.16	0.06	0	6.52
Eureka Bay										
Dike	0	0.32	0.01	0	0.01	0.05	0.1	0.09	0	0.58
Railroad	0.67	0.09	0.02	0.13	0.39	0.29	0.09	0	0	1.68
South Bay										
Dike	0.01	0.06	0.11	0.69	1.65	3.28	1.28	0.43	0.12	7.63
Railroad	0	0.01	0.04	0.13	0.61	0.53	0.06	0	0	1.38
Mad River Slough										
Dike	0.04	0.27	0.52	1.51	2.29	1.88	1.74	0.62	0.12	8.99
Railroad	0	0.07	0.16	0.17	0.13	0.01	0	0	0	0.55
Eureka Slough										
Dike	0	0.46	0.98	1.84	3.92	4.6	1.95	0.55	0.03	2.91
Railroad	0	0	0	0	0.02	0.03	0.03	0.02	0	0.32
Elk River Slough										
Dike	0	0.01	0.01	0.05	0.16	0.46	0.73	1.49	0	14.33
Railroad	0.08	0.13	0.04	0.01	0.04	0.02	0	0	0	0.11
Total	1.48	2.28	2.88	5.94	12.03	14.54	7.87	3.47	0.28	50.78

Table 6. Dike and railroad shoreline vulnerability rating for Humboldt Bay summarized as length in miles by structure type.

Humboldt Bay Shoreline Vulnerability Rating

The total length of diked shoreline that is rated highly vulnerable is 21.0 miles and for railroad shoreline 5.1 miles. Eureka Slough has the greatest length of diked shoreline rated highly vulnerable, 7.13 miles; South Bay 5.1 miles, Mad River Slough 4.4 miles, Elk River Slough 2.7 miles, Arcata Bay 1.5 miles, and Eureka Bay 0.3 miles. Arcata Bay has the greatest length of railroad shoreline rated highly vulnerable, 4.0 miles; South Bay 0.6 miles, Eureka Bay 0.4 miles, Eureka Slough 0.01 miles, and Elk and Mad River Sloughs negligible lengths of railroad bridge ramps that are vulnerable. The distribution of shoreline vulnerability ratings is depicted in Figure 1.



Figure 1. Diked and railroad shoreline vulnerability rating for Humboldt Bay; red-high, yellow-moderate, and green-low.

Humboldt Bay Shoreline Vulnerability Rating

The vulnerability ratings have also been charted as column graphs below.

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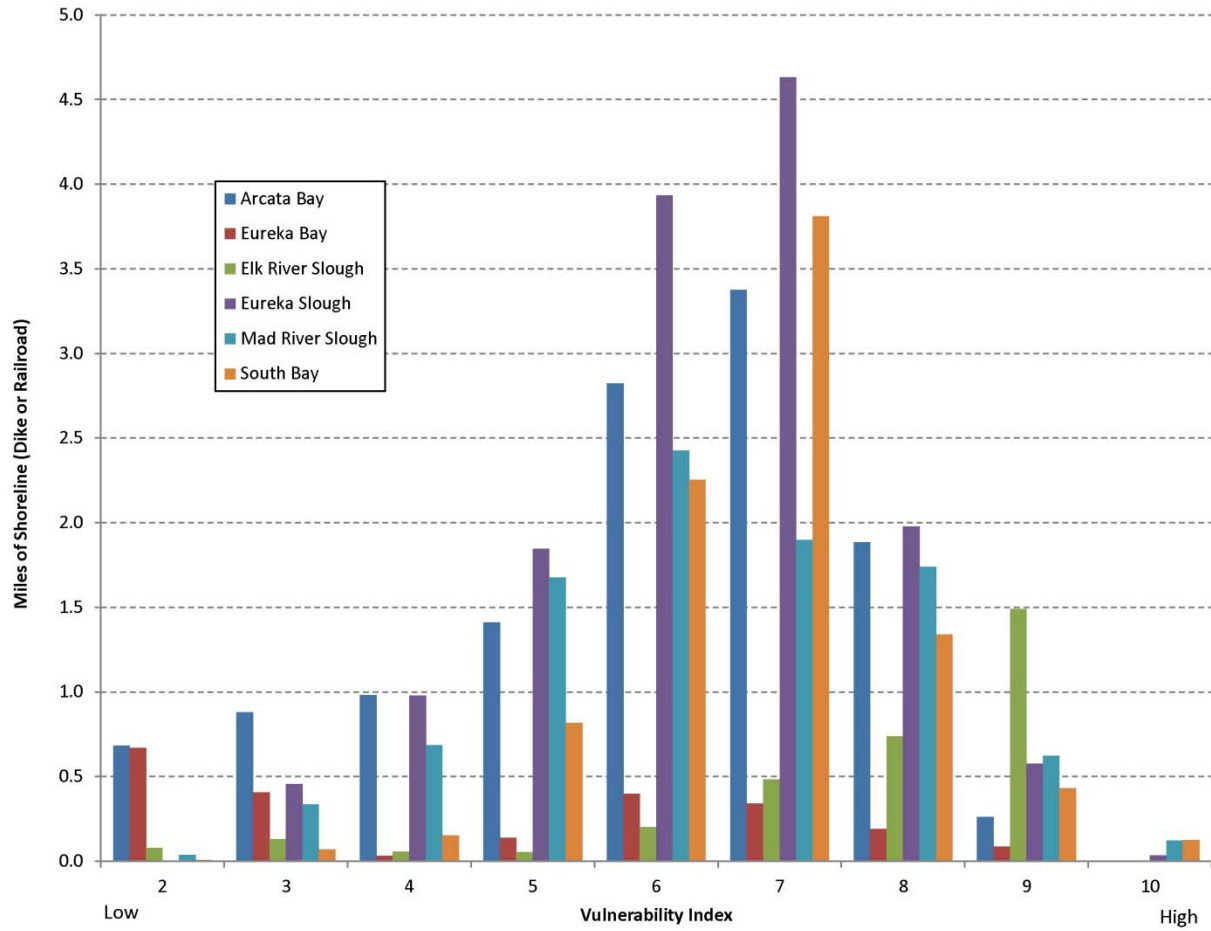


Figure 2. Diked and railroad shoreline vulnerability rating for Humboldt Bay charted by length in miles.

Humboldt Bay Shoreline Vulnerability Rating

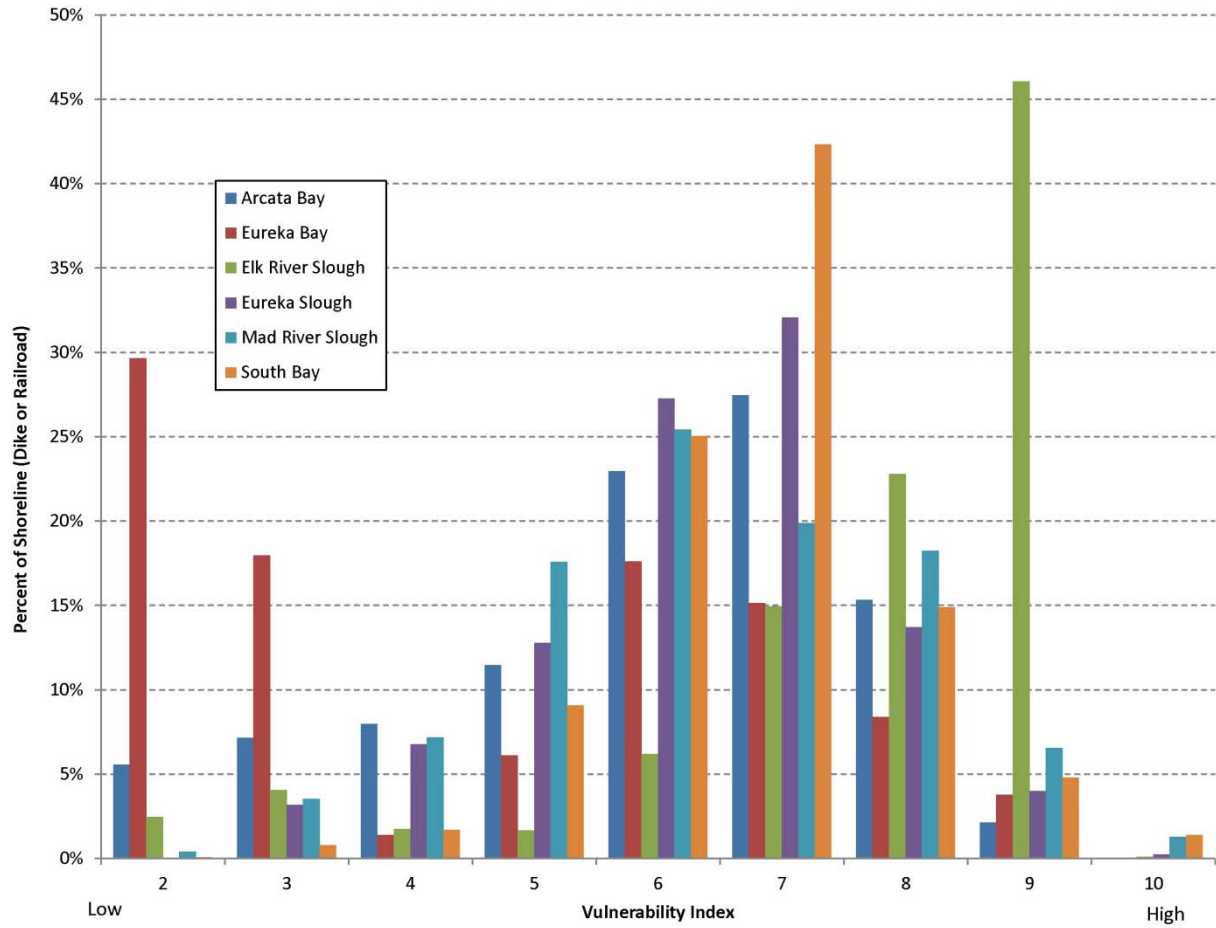


Figure 3. Diked and railroad shoreline vulnerability rating for Humboldt Bay charted as percent of total.

Humboldt Bay Shoreline Vulnerability Rating



Figure 4. Diked and railroad shoreline vulnerability rating for Arcata Bay; red high, yellow moderate, and green low.



Figure 5. Diked and railroad shoreline vulnerability rating for Eureka Bay; red high, yellow moderate, and green low.



Figure 6. Diked and railroad shoreline vulnerability rating for South Bay; red high, yellow moderate, and green low.

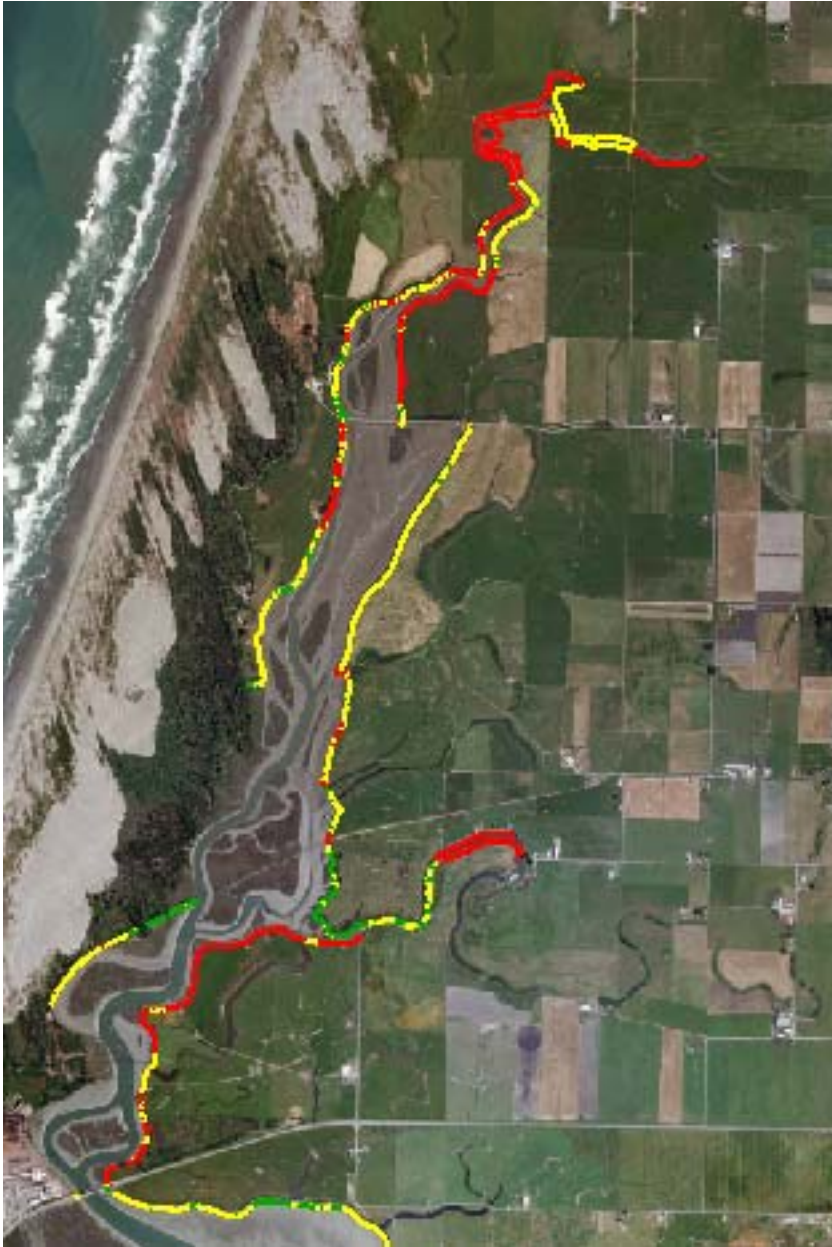


Figure 7. Diked and railroad shoreline vulnerability rating for Mad River Slough; red high, yellow moderate, and green low.



Figure 8. Diked and railroad shoreline vulnerability rating for Eureka Slough; red high, yellow moderate, and green low.



Figure 9. Diked and railroad shoreline vulnerability rating for Elk River Slough; red high, yellow moderate, and green low.

Humboldt Bay Shoreline Vulnerability Ratings

Shoreline vulnerability rating results for the entire shoreline of Humboldt Bay is shown in Tables 7 through 10 below.

The total length of shoreline that is rated highly vulnerable is 59.5 miles. South Bay has the greatest length of shoreline ranked highly vulnerable 15.2 miles; Eureka Slough 12.5 miles, Arcata Bay 10.0 miles, Elk River Slough 8.4 miles, Mad River Slough 7.7 miles, and Eureka Bay 5.2 miles.

Sum of Length (miles)	Vulnerability Rating								
	Low								High
Area	2	3	4	5	6	7	8	9	10
Arcata Bay	0.8	1.4	1.6	2.3	3.9	4.5	2.8	2.6	0.1
Eureka Bay	2.1	1.7	1.4	1.9	3.0	2.1	1.8	1.3	0.5
South Bay	0.0	0.6	0.5	1.7	3.7	5.5	3.7	5.0	1.0
Mad River Slough	0.1	0.4	0.8	1.8	2.7	2.6	2.6	2.4	0.1
Eureka Slough	0.0	0.7	1.1	2.1	4.4	5.7	3.4	3.4	0.0
Elk River Slough	0.1	0.3	0.2	0.2	0.5	1.2	1.8	5.2	0.2
Total	3.2	5.2	5.7	10.0	18.2	21.5	16.1	19.9	2.0

Table 7. Humboldt Bay shoreline vulnerability ratings summarized as length in miles by hydrologic unit.

The total length of shoreline that is rated highly vulnerable is 58.5 %. Elk River Slough has the greatest percentage, 86.3%, of shoreline ranked highly vulnerable; South Bay 69.5%, Eureka Slough 60.2%, Mad River Slough 56.5%, Arcata Bay 50.1%, and Eureka Bay at 36.2%.

Percent of Length	Vulnerability Rating								
	Low								High
Area	2	3	4	5	6	7	8	9	10
Arcata Bay	3.9%	7.0%	7.9%	11.7%	19.4%	22.7%	13.9%	13.2%	0.4%
Eureka Bay	13.4%	11.0%	8.9%	11.8%	18.7%	13.4%	11.4%	8.3%	3.1%
South Bay	0.2%	2.9%	2.4%	7.8%	17.1%	25.0%	16.7%	23.1%	4.8%
Mad River Slough	1.0%	3.2%	6.2%	13.5%	19.6%	18.7%	19.4%	17.3%	1.1%
Eureka Slough	0.1%	3.3%	5.3%	10.0%	21.2%	27.2%	16.4%	16.4%	0.2%
Elk River Slough	0.9%	3.0%	2.0%	2.3%	5.5%	12.5%	18.8%	53.3%	1.8%
Total	3.1%	5.1%	5.6%	9.9%	17.9%	21.2%	15.8%	19.6%	1.9%

Table 8. Humboldt Bay shoreline vulnerability ratings summarized as percent of length by hydrologic unit.

The total length in miles of shoreline by structure and hydrologic unit is presented in Table 9 and 10 below. Eureka Slough has the greatest length of shoreline by structure rated highly vulnerable, 7.1 miles of dike; South Bay 5.1 miles of dike, Mad River Slough 4.4 miles of dike, Arcata Bay 4.0 miles of railroad, Elk River Slough 3.0 miles of natural bank-no structure and 2.7 miles of dike, and Eureka Bay 1.3 miles of fortified shoreline and 1.3 miles of natural bank-no structure.

Humboldt Bay Shoreline Vulnerability Rating

Sum of Length (miles)	Vulnerability Rating								
	Low								High
	2	3	4	5	6	7	8	9	10
Arcata Bay									
Bridge Abutment	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bulwark	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Dike	0.7	0.9	0.9	1.2	0.7	0.6	0.7	0.2	0.0
Fill	0.0	0.3	0.2	0.1	0.2	0.4	0.5	0.7	0.0
Fortified	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
None	0.0	0.0	0.0	0.0	0.0	0.0	0.1	1.6	0.1
Pond	0.1	0.1	0.4	0.5	0.6	0.3	0.0	0.0	0.0
Railroad	0.0	0.0	0.1	0.3	2.2	2.8	1.2	0.1	0.0
Road	0.0	0.0	0.1	0.3	0.2	0.4	0.2	0.1	0.0
Boat Ramp	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Eureka Bay									
Building	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bulwark	0.0	0.1	0.1	0.1	0.2	0.1	0.1	0.0	0.0
Dike	0.0	0.3	0.0	0.0	0.0	0.1	0.1	0.1	0.0
Fill	0.0	0.0	0.1	0.1	0.2	0.4	0.2	0.1	0.1
Fore Dune	0.0	0.6	0.6	0.3	0.2	0.2	0.3	0.3	0.3
Fortified	1.3	0.3	0.6	0.9	1.2	0.7	0.6	0.0	0.0
Jetty	0.1	0.0	0.0	0.2	0.2	0.0	0.1	0.0	0.0
None	0.0	0.3	0.1	0.1	0.2	0.2	0.3	0.8	0.1
Railroad	0.7	0.1	0.0	0.1	0.4	0.3	0.1	0.0	0.0
Road	0.1	0.0	0.0	0.1	0.4	0.1	0.1	0.0	0.0
Tidegate	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Boat Ramp	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
South Bay									
Bridge Abutment	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bulwark	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.0
Cliff/Bluff	0.0	0.0	0.1	0.0	0.0	0.1	0.1	1.3	0.3
Dike	0.0	0.1	0.1	0.7	1.6	3.3	1.3	0.4	0.1
Fill	0.0	0.3	0.1	0.1	0.2	0.3	0.4	0.6	0.5
Fore Dune	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0
Fortified	0.0	0.0	0.0	0.4	0.4	0.2	0.3	0.1	0.0
Jetty	0.0	0.2	0.1	0.1	0.1	0.0	0.0	0.0	0.0
None	0.0	0.0	0.0	0.1	0.3	0.7	1.1	2.5	0.0
Railroad	0.0	0.0	0.0	0.1	0.6	0.5	0.1	0.0	0.0
Road	0.0	0.0	0.0	0.0	0.2	0.2	0.1	0.0	0.1
Tidegate	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Boat Ramp	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 9. Humboldt Bay shoreline vulnerability ratings summarized as length in miles for each type of shoreline structure and by hydrologic unit.

Humboldt Bay Shoreline Vulnerability Rating

Sum of Length (miles)	Vulnerability Rating									Total
	Low								High	
	2	3	4	5	6	7	8	9	10	
Mad River Slough										
Bulwark	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Dike	0.0	0.3	0.5	1.5	2.3	1.9	1.7	0.6	0.1	9.0
Fill	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Fortified	0.1	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.3
None	0.0	0.1	0.0	0.0	0.1	0.3	0.7	1.7	0.0	2.8
Railroad	0.0	0.1	0.2	0.2	0.1	0.0	0.0	0.0	0.0	0.6
Road	0.0	0.0	0.1	0.1	0.1	0.3	0.2	0.1	0.0	0.9
Boat Ramp	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Eureka Slough										
Bridge Abutment	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Bulwark	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.0	0.0	0.3
Cliff/Bluff	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.9	0.0	1.3
Dike	0.0	0.4	1.0	1.9	3.9	4.6	1.9	0.6	0.0	14.3
Fill	0.0	0.0	0.0	0.1	0.1	0.2	0.4	0.4	0.0	1.2
Fortified	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
None	0.0	0.0	0.0	0.0	0.1	0.6	0.7	1.4	0.0	2.9
Railroad	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Road	0.0	0.1	0.0	0.0	0.1	0.1	0.1	0.1	0.0	0.7
Tidegate	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Boat Ramp	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Elk River Slough										
Bridge Abutment	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Bulwark	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cliff/Bluff	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.3	0.0	0.6
Dike	0.0	0.0	0.0	0.0	0.2	0.5	0.7	1.5	0.0	2.9
Fill	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.2
Fore Dune	0.0	0.0	0.0	0.0	0.0	0.1	0.3	1.3	0.1	1.8
Fortified	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.1
None	0.0	0.0	0.0	0.0	0.1	0.3	0.6	2.0	0.1	3.0
Railroad	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
Road	0.0	0.1	0.1	0.1	0.2	0.2	0.0	0.0	0.0	0.6
Tidegate	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	3.2	5.2	5.7	10.0	18.2	21.5	16.1	19.9	2.0	101.8

Table 10. Humboldt Bay shoreline vulnerability ratings summarized as length in miles for each type of shoreline structure and by hydrologic unit.

Reference

Laird, A., 2013
Humboldt Bay Shoreline Inventory, Mapping, and Sea Level Rise Vulnerability Assessment. <http://scc.ca.gov/webmaster/ftp/pdf/humboldt-bay-shoreline.pdf>