Chapter 7. Natural Shorelines

The shoreline of the ART project area is a diverse mix of built and natural features. To assess the vulnerability and risk of such a diverse and varied shoreline a simplified categorization approach was developed. This approach used publically available data (e.g., EcoAtalas, BAARI, NOAA ESI), aerial photo interpretation and best professional judgment to classify the outboard (i.e., bay edge) shoreline into five categories (AECOM, 2001). The categories were defined based on the primary function and the ability to inhibit inland inundation. The five categories include three structural and two non-structural shoreline types:

Structural shorelines

- Engineered flood protection (e.g., levees and flood walls) – protect inland areas from inundation
- Engineered shoreline protection structures (e.g., revetments and bulkheads) – harden the shoreline to reduce erosion and prevent land loss
- Non-engineered berms – protect marshes and ponds from wave erosion and provide flood protection to inland development

Non-structural shorelines

- Natural, non-wetland shorelines (e.g., beaches) – dissipate wave energy and provide recreational and ecological habitat value
- Wetlands (e.g., managed wetlands and tidal marsh) – dissipate wave energy, improve water quality and provide ecological habitat value

The vulnerability and risk of three structural and one non-structural shoreline category (natural, non-wetland areas, e.g. beaches) is discussed in Chapter 6. The vulnerability and risk of wetland shorelines is discussed separately in this Chapter because a different type of analysis is necessary when evaluating dynamic shoreline systems such as wetlands.

There are a number of different kinds of wetland systems in the ART project area. These include systems where the marsh edge is fully exposed to the bay (e.g., the Emeryville Crescent); systems that transition from tidal mudflat, to fringing marsh, to managed marsh (e.g., at the confluence of San Lorenzo Creek and the Bay); and systems that are a mosaic of tidal marsh, managed marshes and managed ponds (e.g., within the Hayward Regional Shoreline, Figure 1). These wetland systems are generally managed to preserve or restore ecosystem services such as wave energy dissipation, flood protection, water filtration and carbon sequestration. In addition they provide ecological benefits and habitat for a number of species of conservation concern.

Figure 1. Snowy Egrets at the Hayward shoreline (Source: Flickr, Jonas Flanken)

Rather than the approach used to assess the other asset categories in the ART project area, the vulnerability and risk of tidal marshes and managed marshes (Table 1) was evaluated in collaboration with PRBO Conservation Science (PRBO) using their online decision support tool

(PRBO tool)[1]. This approach was taken because wetlands are dynamic nearshore systems, and their response to changes in mean sea level rise will depend on a number of physical and biological factors including mineral sediment supply and organic matter accumulation. The sea level rise maps developed for the ART project that were used to evaluate the exposure of other assets do not account for potential changes in nearshore dynamic processes that are likely to occur with sea level rise (see Chapter 2 for more details on the mapping and analysis conducted). For example, neither organic matter accumulation nor sediment deposition and resuspension rates are considered even though these processes could alter the hydrodynamic or bathymetric condition in the Bay. Therefore, the PRBO tool was used to assess how tidal and managed marshes may change over the next 100 years in response to changes in mean sea level.

Table 1. Current size and habitat composition based on elevation relative to the daily high tide (MHHW) in NAVD88 of the twelve fully tidal and five managed marshes evaluated in the ART project area.

Location	Manager	Tidal Status[1]	Marsh Name	Current Acres[2]	Habitat composition (percentage by type) based on elevation relative to MHHW				
					Mudflat	Low Marsh	Mid Marsh	High Marsh	Upland
Eastshore State Park	EBRPD	Full	Emeryville Crescent	54	6	12	52	14	16
Martin Luther King Regional Shoreline	EBRPD	Full	Damon Marsh	9	5	12	76	3	4
		Full	Arrowhead Marsh	40	38	49	13	0	0
		Full	MLK - New Marsh	66	26	18	9	3	45
San Leandro	Citation Homes	Full	Citation Marsh	115	32	37	17	1	13
	EBRPD	Full	Robert's Landing	194	46	11	24	8	12
Hayward Regional Shoreline	EBRPD	Full	Oro Loma Marsh	274	33	41	16	5	5
	HARD	Managed	Frank's Tract	54	85	7	2	1	5
	HARD	Managed	West Winton	41	12	52	31	3	2
	EBRPD	Full	Triangle Marsh	8	28	41	25	1	4
	EBRPD	Full	Cogswell Marsh	195	6	7	35	36	17
	HARD	Full	HARD Marsh	79	18	33	32	3	14
	EBRPD	Managed	Hayward Marsh	212	1	47	37	2	12
	HARD	Managed	Oliver Salt Ponds	98	41	35	15	2	7
Eden Landing	CA DFG	Managed	Eden Landing Ecological Reserve (ELER)	2709	10	17	45	11	18
		Full	ELER Baumberg Tract	742	30	28	34	3	6
		Full	ELER Whales Tail, northern	278	4	2	4	22	68

[1] Tidal status indicates if the system is a fully tidal (full) or a managed marsh.
[2] Data from PRBO tool.

[1] San Francisco Bay Sea-Level Rise Website: A PRBO online decision support tool for managers, planners, conservation practitioners, and scientists (Hereafter, PRBO SLR tool). Available at: www.prbo.org/sfbayslr.

PRBO Tool

The PRBO tool is a publically available resource that evaluates through predictive modeling the vulnerability and resilience of tidal marshes throughout the entire San Francisco Bay region. The marsh accretion model and results that form the basis of the tool have been published in a peer-reviewed journal (Stralberg et al., 2011), and the conservation prioritization and tidal marsh bird and vegetation response to sea level rise are presented in a technical report to the California State Coastal Conservancy (Veloz et al., 2012).

The response of wetlands, and in particular tidal marshes, to sea level rise depends on a number of physical and biological factors, including the rate of sea level rise, the current elevation relative to the tidal frame, mineral sediment availability either from the Bay or nearby tributaries, and the rate of organic matter accumulation (Stralberg et al., 2011). The model depicts the future marsh condition by taking into account marsh accretion dynamics and incorporating spatial variation at a scale relevant for local decision-making. These factors are incorporated into the predictive modeling as follows:

- Sea Level Rise Rate: Two non-linear sea level rise rates - 0.52 meters (20.4 inches) or 1.65 meters (65 inches) over the next hundred years (2010 – 2110).
- Sediment Availability: Assumed low and high suspended sediment concentration (SSC) values that vary by biogeomorphic subregion[2] (0 to 300 milligrams per liter (mg/L))
- Organic Material: Assumed low and high organic matter (OM) accumulation rates that varies by biogeomorphic subregion (1 to 3 millimeter per year (mm/yr)).

The vulnerability and risk of wetlands in the ART project area was assessed based on the higher of the two sea level rise rates in combination with low/high sediment availability. The OM accumulation rate used was 1 mm/yr as the biogeographic subregions that include the ART project area are only represented by a single rate.

- The high rate of sea level rise, 1.65 m over 100 years, which corresponds to approximately 16 inches at 2050 and 55 inches at 2100.
- An assumed low SSC of 50 mg/L, and an assumed high SSC of either 100 or 150 mg/L (Table 2).

Table 2. Assumed low and high suspended sediment concentration (SSC) for wetlands in the ART project based on a biogeomorphic subregions identified by Stralberg et al. (2011).

<table>
<tr><th>Assumed Low SSC</th><th>Assumed High SSC</th><th colspan="2">Marsh Name</th></tr>
<tr><td rowspan="2">50 mg/L</td><td>100 mg/L</td><td colspan="2">Arrowhead Marsh
Damon Marsh
Emeryville Crescent
MLK - New Marsh
Robert's Landing</td></tr>
<tr><td>150 mg/L</td><td>Citation Marsh
Oro Loma Marsh
Frank's Tract
West Winton
Triangle Marsh
Cogswell Marsh</td><td>HARD Marsh
Hayward Marsh
Oliver Salt Ponds
Eden Landing Ecological Reserve (ELER)
ELER Baumberg Tract
ELER Whales Tail (northern portion)</td></tr>
</table>

[2] The ART project area is within two of the 15 biogeographic subregions identified by Stralberg et al. 2011. Each subregion was assigned a high and low value for sediment supply and organic accumulation based on a combination of USGS monitoring reports, observed accretion rates from restored sites, and expert opinion in order to account for variability within the bay.

The PRBO model results for the high rate of sea level rise were evaluated for the assumed low and assumed high SSC for two time frames, mid-century (2050) and end-of-century (2090). While results from the PRBO model for these four cases provide the most realistic evaluation of sea level rise currently feasible, like any model, there are caveats and limitations. For example, the model does not include the influence of waves, which may cause erosion and marsh retreat along the bay edge and conversion of low marsh to mudflat. Consequently, projected habitat areas may be overestimates of future habitat potential, especially for low marsh. The assessment of vulnerability and risk using the PRBO model results, or any other modeled results, should be used in high-level planning exercises that will guide where future studies are needed to support robust decision making, and not as definitive results or answers (TNC and NOAA, 2011).

Sensitivity and Adaptive Capacity

The vulnerability of wetlands in the ART project area is assessed based on sensitivity and adaptive capacity, and not on an evaluation of exposure. The sea level rise mapping and analysis used to evaluate exposure of other assets in the subregion is not appropriate for tidal marshes or beaches, which are dynamic systems already within the tidal range that will likely exhibit a complex response to sea level rise (Figure 2).

Figure 2. Hayward shoreline near San Lorenzo Creek. (Source: Panoramio)

The PRBO tool was used to evaluate the sensitivity and adaptive capacity of twelve tidal marshes and five managed marshes in the ART project area. These two types of wetlands were considered separately because managed wetlands, which are shown in the PRBO tool as “diked,” are areas that are or were at one time separated from the Bay. These areas remain under some level of management to control tidal and/or freshwater flows. Diked, managed wetlands tend to be at lower elevations than fully tidal wetlands due to subsidence, and they typically do not support coastal salt marsh vegetation found in fully tidal marshes. The PRBO tool uses the current elevation of these diked managed areas to predict the type of marsh habitat that could be supported if these areas were returned to tidal action. Each of these systems is managed differently (e.g., for flood protection or for ongoing, planned, or future restoration should resources become available). The tool, which was developed to evaluate future restoration potential, assumes the dikes are removed and wetlands fully revegetated at the start of the model run in 2010. Therefore, results for the managed marshes in the ART project areas should be interpreted in light of the potential to restore them to full tidal action in the future.

Historically, tidal marshes in the Bay have kept pace with low rates of sea level rise by accumulating mineral sediment and organic material (i.e., vertical accretion), and/or by migrating landward where the slope of the land is suitable and there are no inland barriers (i.e., upland transgression). However, as sea level rises, suspended sediment concentrations in the Bay decline (Schoellhamer, 2011), and with hardened shorelines and development adjacent to wetlands, there is less potential that tidal marshes will remain resilient to accelerating rates of sea level rise. While some wetland may persist, others will downshift in habitat type (e.g., change to a lower elevation habitat) and many could drown (e.g., become intertidal mudflat).

Sensitivity and adaptive capacity were evaluated for the fully tidal and managed marshes based on select information from the PRBO tool. To complete this analysis, first ART project staff identified the "footprint" of each tidal or managed marsh site based on a parcel data layer provided by Alameda County in combination with aerial photo interpretation. Then, for each site footprint PRBO staff summarized information from the PRBO tool including the current habitat composition; changes in future projected habitat based on elevation modeling; the conversion of uplands to wetlands based on elevation modeling, and changes in landscape conservation priority ranking based on Zonation, a spatial conservation planning tool (Stralberg et al., 2011, Veloz et al. 2012).

In general, tidal or managed marsh sites that either maintained their initial habitat composition or downshifted to lower elevation marsh habitats were assessed as having lower sensitivity to sea level rise. Marsh sites that transitioned to intertidal mudflat, especially if either by mid-century or under the assumed high suspended sediment supply scenario, were assessed as being highly sensitive. Additionally, sites that were able to maintain marsh habitat through upland transgression were assessed as having higher adaptive capacity, and those that either maintained or improved landscape conservation priority ranking were noted to have greater resilience as they would likely continue to provide critical functions such as maintaining biodiversity even in the face of sea level rise.

Tidal Marsh Sensitivity and Adaptive Capacity

Twelve fully tidal marshes in the ART project area were evaluated. These include one marsh in Eastshore State Park, three in Martin Luther King Regional Shoreline, two in San Leandro, four in the Hayward Regional Shoreline, and two in Eden Landing Ecological Reserve (Table 1).

<u>Vertical Accretion</u>
Tidal marshes are evaluated in the PRBO tool based on the potential for maintaining elevation relative to sea level rise through the accretion of mineral sediment and organic matter. Tidal marshes in the ART project area (as well as regionally) are sensitive to sediment availability. Under the low sediment scenario (50 mg/L), by 2050 five of the fully tidal marshes in the ART project area will downshift in habitat type (e.g., from mid to low marsh, or upland to mid marsh), two will persist as mid marsh, and five will transition to mudflat (Table 3). By 2090, all of the marshes are predicted to transition to mudflat.

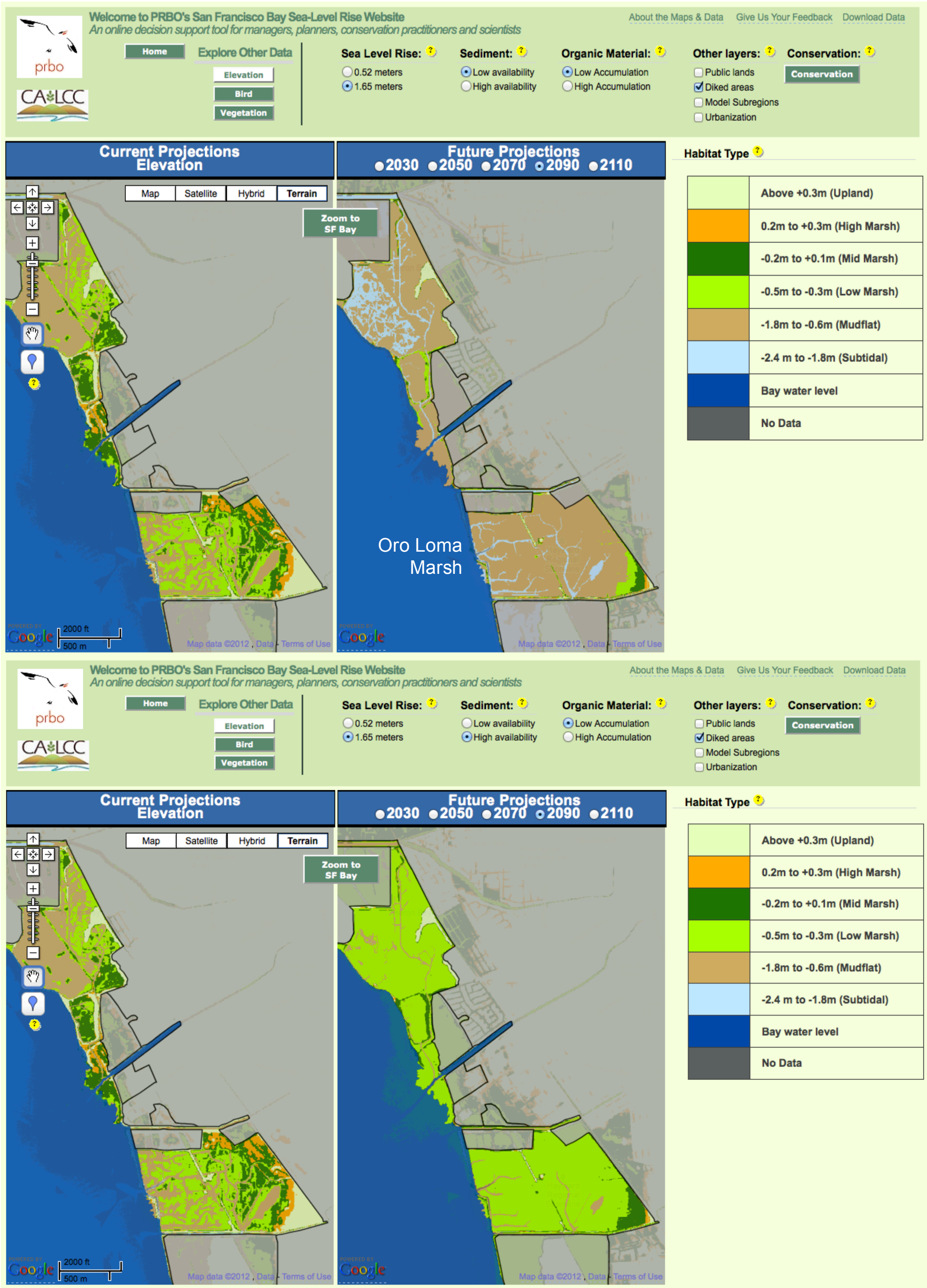
Under the high sediment scenario (either 100 or 150 mg/L), by 2050, all of the marshes except Arrowhead will persist as either mid or low marsh, and three will downshift in habitat type from upland to mid marsh or mid to low marsh. By 2090, all will persist as either mid or low marsh, except Arrowhead and Damon Marsh, both which downshift to mudflat (Table 3 and Figure 3).

Table 3. Predicted change in average habitat type based on modeled average elevation relative to MHHW NAVD88* for assumed high and low sediment scenarios in combination with a high rate of sea level rise and low rate of OM accumulation.

Marsh Name	Current (2010)	Low SSC		High SSC	
		2050	2090	2050	2090
Emeryville Crescent	Mid Marsh	Mid Marsh	Mudflat	Mid Marsh	Low Marsh
Damon Marsh	Mid Marsh	Low Marsh	Mudflat	Low Marsh	Mudflat
Arrowhead Marsh	Low Marsh	Mudflat	Mudflat	Mudflat	Mudflat
MLK - New Marsh	High	Mid Marsh	Mudflat	Mid Marsh	Low Marsh
Citation Marsh	Mid Marsh	Low Marsh	Mudflat	Mid Marsh	Low Marsh
Robert's Landing	Low Marsh	Mudflat	Mudflat	Low Marsh	Low Marsh
Oro Loma Marsh	Low Marsh	Mudflat	Mudflat	Low Marsh	Low Marsh
Triangle Marsh	Low Marsh	Mudflat	Mudflat	Low Marsh	Low Marsh
Cogswell Marsh	Mid Marsh	Mid Marsh	Mudflat	Mid Marsh	Low Marsh
HARD Marsh	Mid Marsh	Low Marsh	Mudflat	Mid Marsh	Low Marsh
ELER Baumberg Tract	Low Marsh	Mudflat	Mudflat	Low Marsh	Low Marsh
ELER Whale's Tail**	Upland	Mid Marsh	Mudflat	Mid Marsh	Low Marsh

*Elevation based on LIDAR elevations with +/- 2 – 3 cm vertical accuracy.
**The current habitat type at ELER Whale's Tail is identified in the PRBO tool as "upland" which is not strictly correct. This error is due to inaccuracies in the LIDAR for this site that was used to develop the predicted current and future habitat types.

Figure 3. By 2090, if sediment availability is at the assumed low level, most of Oro Loma Marsh will become mudflat, and the small portion of high marsh and uplands in the southeast corner of the system will downshift to low and mid marsh (above). If sediment availability is high, the majority of the system will persist as low marsh, and high marsh and uplands will downshift to mostly mid marsh (below).



Upland Transgression

The capacity for upland transgression is evaluated in the PRBO tool as the potential for wetlands to expand into adjacent natural, not diked, upland areas. This is expressed as the acres of uplands converted to wetlands (i.e., low marsh, mid marsh and high marsh). For this analysis only uplands within the marsh site (identified as described above) were considered.

The total amount of uplands available for conversion across the twelve tidal marshes evaluated ranges from none (e.g., Arrowhead Marsh) to 190.6 acres (e.g., ELER Whale's Tail, Table 4). Under the low sediment scenario, by 2050 only one marsh, ELER Whale's Tail, is predicted to convert most of the available uplands, while two marshes, Damon and Robert's Landing, are predicted to convert more than half of the available uplands. There is no difference in the amount of uplands converted by 2050 between the assumed high and low sediment scenarios (Table 4). This is because conversion is limited by the availability of uplands at an elevation relative to sea level that will support marsh habitat rather than by sediment availability.

By 2090, most of the marshes will have converted half or more of the available uplands, with two exceptions, the Emeryville Crescent and Citation Marsh. The upland areas adjacent to these two sites are not at a suitable elevation to support marsh habitat (e.g., along the embankment of Powel Street along the north edge of the Crescent). Sediment availability is predicted to affect the amount of uplands converted to wetlands by 2090, with slightly more conversion occurring with a high sediment supply (Table 4). For example, Damon Marsh, Triangle Marsh and ELER Whale's Tail convert 100 percent of the upland area to wetlands under the high sediment scenario. In addition to the amount of uplands converted, sediment availability also determines the type of habitat the upland coverts to, and whether the converted uplands can persist as wetlands or will downshift to mudflat.

Table 4. Predicted acres of uplands converted to wetlands based on modeled average elevation relative to MHHW NAVD88 for assumed high and low sediment scenarios in combination with a high rate of sea level rise and low rate of OM accumulation. The data below constrains the uplands to adjacent natural, not diked areas within the identified marsh site footprint.

Marsh Name	Current Upland Acres (2010)	Percent Uplands Converted			
		Low SSC		High SSC	
		2050	2090	2050	2090
Emeryville Crescent	8.5	27	36	27	47
Damon Marsh	0.3	66	77	66	100
Arrowhead Marsh	0.0	--	--	--	--
MLK - New Marsh	29.5	13	80	13	84
Citation Marsh	14.5	11	32	11	35
Robert's Landing	22.5	55	73	55	88
Oro Loma Marsh	12.7	36	59	36	76
Triangle Marsh	0.3	16	94	16	100
Cogswell Marsh	32.3	45	62	45	86
HARD Marsh	11.2	39	85	39	96
ELER Baumberg Tract	45.6	43	78	43	90
ELER Whale's Tail	190.6	97	NA	97	100

For many of the tidal marshes evaluated, there is minimal opportunity for upland transgression due to existing development patterns. Damon Marsh, for example, is a small mid marsh dominated system that is constrained by the Interstate 880 corridor and existing land uses, including recreational and commercial facilities (Figure 4). Within the marsh site there are only 0.3 acres of uplands available, and most will convert to wetland as sea level rises. Further landward migration would require changes in the existing adjacent land uses, and would ultimately be constrained by I-880.

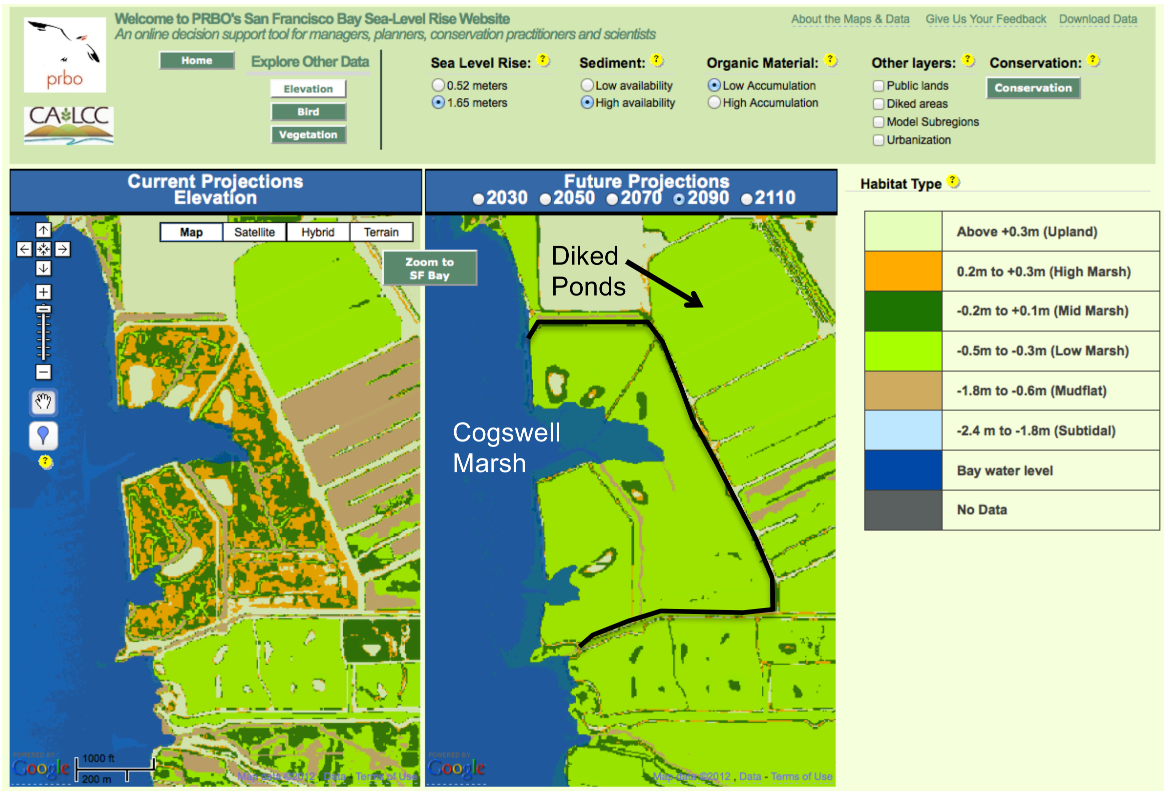
Figure 4. Migration of Damon Marsh would require changes in existing land uses, and would ultimately be constrained by the I-880 corridor. (Source: Google Maps)

In the southern portion of the project area where the Bay shoreline is less developed and the marshes are less constrained, many wetlands are adjacent to levees and dikes, and therefore the uplands are currently unavailable for transgression. For example, Cogswell Marsh is a mid and high marsh dominated system within the Hayward Regional Shoreline (Figure 5 and Table 3). The marsh adjoins some uplands of suitable elevation (32.3 acres) that could be converted to wetlands. Almost half of the uplands (14 acres) are predicted be converted to mid marsh by 2050. By 2090, 62 to 86% of the uplands (20 to 28 acres) are predicted to convert depending on sediment availability (Table 4).

Figure 5. Migration of Cogswell Marsh would require removal of dikes protecting the Hayward out-of-service oxidation ponds, and would ultimately be constrained by industrial land uses. (Source: Google Maps)

Further migration of the Cogswell Marsh is currently constrained by the levees that protect the City of Hayward's out-of-service wastewater oxidation ponds. Using the viewer function of the PRBO tool, rather than the data extracted in Table 4, it is possible to observe that if the levees were removed and the marsh was allowed to migrate landward, with low sediment availability (e.g., 50 mg/L) the ponds could convert to mudflat, whereas with a high sediment (e.g., 150 mg/L) the ponds could convert to low marsh (Figure 6). Ultimately, the landward migration of Cogswell Marsh will be constrained by exiting land uses, including Hayward's wastewater treatment plant and a number of industrial and commercial facilities.

Figure 6. By 2090, converted uplands at Cogswell Marsh are predicted to be a mixture of low and mid marsh if sediment availability is high in combination with a high rate of sea level rise and low rate of OM accumulation. Although small areas of uplands will remain, further landward migration could require the removal of dikes that protect the adjacent out-of-service wastewater oxidation ponds.



Landscape Conservation Priority Ranking

The current and predicted future habitat value of the fully tidal marshes in the ART project area was evaluated using the PRBO tool's landscape conservation priority ranking. The rankings are based on an analysis using Zonation, a spatial conservation planning software tool that takes into account the habitat value for multiple bird species under a combination of sediment availability and sea level rise rates to create a hierarchical prioritization of the landscape (Veloz et al., 2012). The conservation priority is based on current and future marsh conditions and informs whether tidal marsh habitat is resilient to sea level rise, i.e., habitat quality will remain high enough to support tidal marsh bird species.

The landscape conservation priority rankings are based on the predicted density of five bird species[3] for six time periods (2010, 2030, 2050, 2070, 2090 and 2110) for the combination of low and high sea level rise and low and high SSC rates. In addition, the analysis assumed that all dikes had been removed. This "no dike" assumption allows undeveloped natural areas that are not currently exposed to full tidal action to become tidal in the model, and therefore become a source of habitat for tidal marsh bird species.

While the two sea level rise and two sediment availability rates were used in combination with all time periods to determine the future conservation priority, the model down-weighted areas

[3] Predicted bird abundance was evaluated for Black Rail, Clapper Rail, Marsh Wren, Common Yellowthroat, and Song Sparrow.

if there was high uncertainty in the predicted densities of bird species. The results are therefore more strongly driven by the near-term (2010 to 2050), where there is less uncertainty, rather than the longer-term (2070 to 2100) future condition, where uncertainty is much higher. In addition, areas with consistent high bird species density across scenarios are ranked higher by Zonation, resulting in a more robust prioritization that is less sensitive to the uncertainty in future conditions.

In the PRBO tool, conservation priorities are divided into six categories[4], with a higher conservation priority rank indicating a greater potential to support tidal marsh birds. In the ART project area, the average conservation priority rank ranges fall within the first four categories (Table 5). All marshes except one (MLK-New Marsh) increase in conservation priority rank in the future scenario, suggesting that the tidal marsh function of providing habitat for the bird species evaluated is resilient to sea level rise, at least in the near-term.

Table 5. Current and future conservation priority rank for the fully tidal marsh systems in the ART project area (Very low = 0-0.30; Low = 0.31-0.5; Medium low = 0.51-0.75; Medium high = 0.76 - 0.90).

	Conservation Priority Rank	
Marsh Name	**Current**	**Future**
Emeryville Crescent	Low	Medium Low
Damon Marsh	Low	Medium High
Arrowhead Marsh	Low	Medium High
MLK - New Marsh	Low	Low
Citation Marsh	Very Low	Medium Low
Robert's Landing	Very Low	Medium Low
Oro Loma Marsh	Very Low	Low
Triangle Marsh	Very Low	Low
Cogswell Marsh	Very Low	Low
HARD Marsh	Very Low	Low
ELER Baumberg Tract	Very Low	Low
ELER Whale's Tail	Very Low	Low

Representative Tidal Marsh Systems

To understand how the physical and biological factors evaluated using the PRBO tool can inform the sensitivity and adaptive capacity of specific tidal marshes, two representative systems are discussed in greater detail below. The discussion also incorporates input provided by resource managers who have intimate knowledge of the sites. Together, information from the PRBO tool and best professional judgment provides insight as to the vulnerability and risk these marshes may face as sea level rises.

Emeryville Crescent

The tidal marsh at the Emeryville Crescent is owned by the State of California and managed by the East Bay Regional Park District (EBRPD). It is located between the Emeryville Peninsula (Powell Street), Interstate 80, and the San Francisco-Oakland Bay Bridge in Eastshore State Park (Figure 7). The marsh sits at the mouth of Temescal Creek, and is comprised of coastal salt marsh habitat, a few small natural sand beach formations, and intertidal mudflats that serve as foraging areas for shorebirds.

[4] Conservation priority ranking are divided into six categories: 0.00-0.30; 0.31-0.50; 0.51-0.75; 0.76-.090; 0.91-0.95; and 0.96-1.00

The marsh is currently a mid marsh dominated system with some low and high marsh, and an upland edge along Powell Street to the north (Table 1). The system is predicted to persist as mid marsh until at least 2050 (Table 2); however, if sediment supply is low there will be more mudflat, and if supply is high more mid marsh. By 2090, much of the marsh will transition to mudflat if sediment supply is low, and low marsh if supply is high.

Currently, inundation at high tide can displace the birds and wildlife using the marsh, and can leave behind a wrack line of trash and debris. More frequent or permanent tidal inundation due to sea level rise will exacerbate this situation, forcing birds and wildlife to forage and nest closer to Powell Street and Interstate 80, potentially reducing nest success. Additionally, the small sand beach areas and intertidal mudflat shore bird foraging areas could be reduced or eliminated as more areas in the marsh are inundated for longer periods of time.

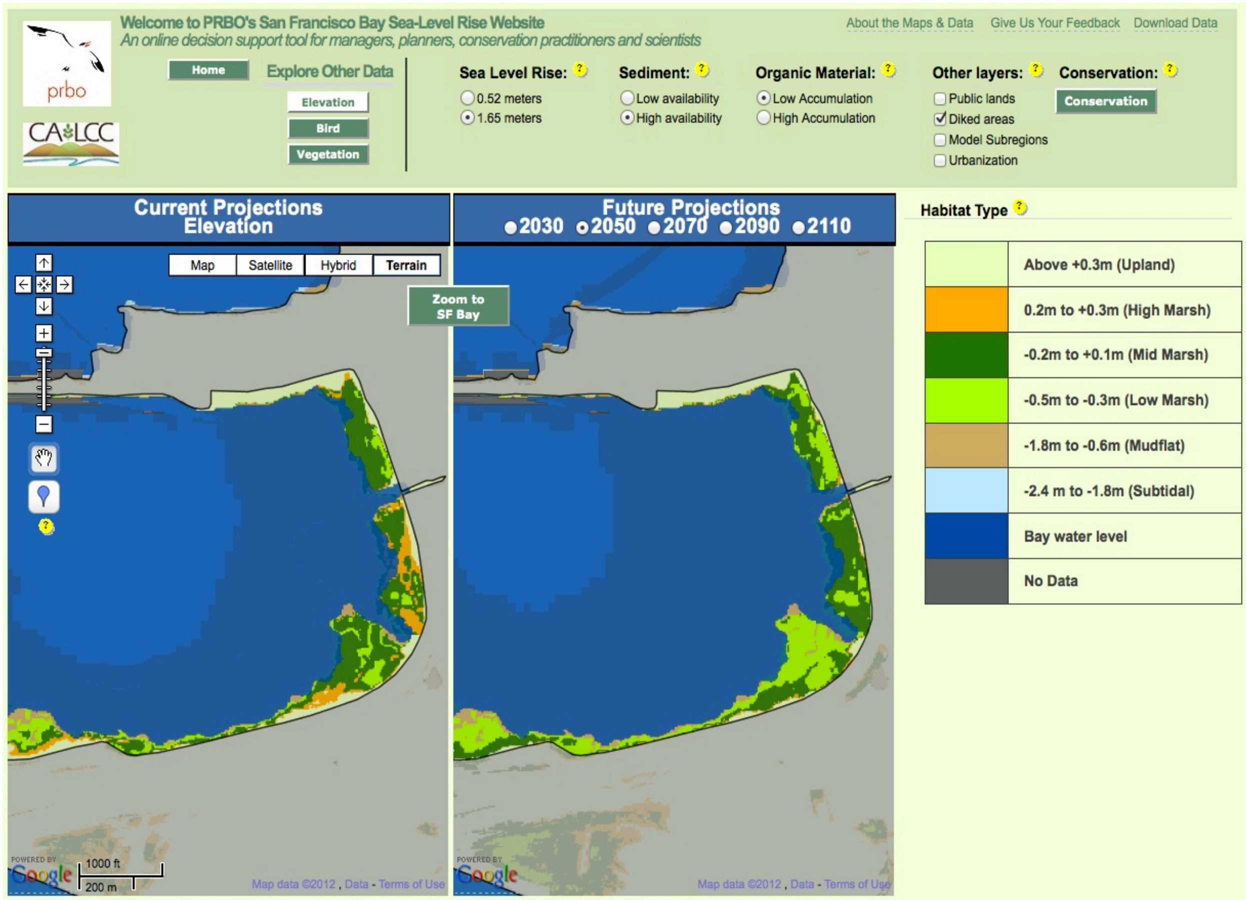
Figure 7. Emeryville Crescent is where Temescal Creek joins the Bay. The marsh is constrained by I-80 to the east and south, and Powell Street to the north. (Source: Google Maps)

Storm event flooding may have the greatest likelihood of causing damage to the upland area north of the marsh adjoining Powell Street. This area, which is partially protected by a loose mixture of broken concrete, metal slag and asphalt, is currently eroding. In addition, the low-lying upland areas adjacent to Powell Street currently flood during wet weather. Storm events could increase the potential for continued shoreline erosion, causing loss of adjacent upland habitat in areas already impacted by either high or extreme tides.

The Emeryville Crescent marsh has limited adaptive capacity. While there are some upland areas that could convert to wetlands (2 to 4 acres, 27 to 47 percent of the 8.5 acres available, see Table 4), much of these uplands are located along the Powell Street the embankment, and are not of appropriate elevation to support future marsh habitat. Further upland transgression is restricted by the I-80 corridor, development that surrounds this system, and ongoing management practices to protect the shoreline from erosion (Figure 8).

Improving the resilience of this marsh to sea level rise or storm events would likely be costly; however, it is a well-known natural shoreline area with an engaged public that could support its protection. This marsh is located adjacent to the San Francisco-Oakland Bay Bridge and toll plaza, a regionally significant transportation asset that will likely need to be protected. Holistic solutions for this area will need to consider potential impacts and opportunities for mutual benefits to both the built and the natural environment, including the capacity for the tidal marsh system to reduce inland flooding and shoreline erosion.

Figure 8. Predicted change in marsh habitat based on modeled average elevation relative to MHHW NAVD88 at the Emeryville Crescent by 2050 under a high rate of sea level rise, low rate of OM accumulation, and high sediment availability. Areas that are currently “diked” are shown in grey.



<u>Oro Loma Marsh</u>
Oro Loma Marsh is a 364-acre restored salt pond at the northern end of the EBRPD managed Hayward Regional Shoreline. The marsh is located in a fairly well developed portion of the ART project shoreline south and west of San Lorenzo (Figure 9). Despite being surrounded by levees, it is a fully tidal marsh, with Bockman Channel to the north, Sulfur Creek to the south, the Southern Pacific Railroad right-of-way to the east, and the Bay Trail on the bayside levee to the west. In addition to providing shoreline recreational access, this segment of the Bay Trail serves as emergency vehicle access from Grant Avenue in San Lorenzo, if, for example, the railroad is under repair or in case of a derailment. Lastly, there is a utility corridor that transects the middle of the marsh that includes a PG&E distribution and transmission line, an abandoned Shell Oil gas line, and the East Bay Dischargers (EBDA) effluent pipeline.

Because the marsh is a restored salt pond, it is at a fairly low elevation relative to MHHW and is dominated by low marsh and mudflat. Under the low sediment scenario, most of the marsh will downshift to mudflat by 2050 and will persist as mudflat by 2090. However, some marsh habitat in the portions of the system farthest from the Bay will remain (see Figure 10). Under the high sediment scenario, the marsh is predicted to persist as low marsh (Table 3).

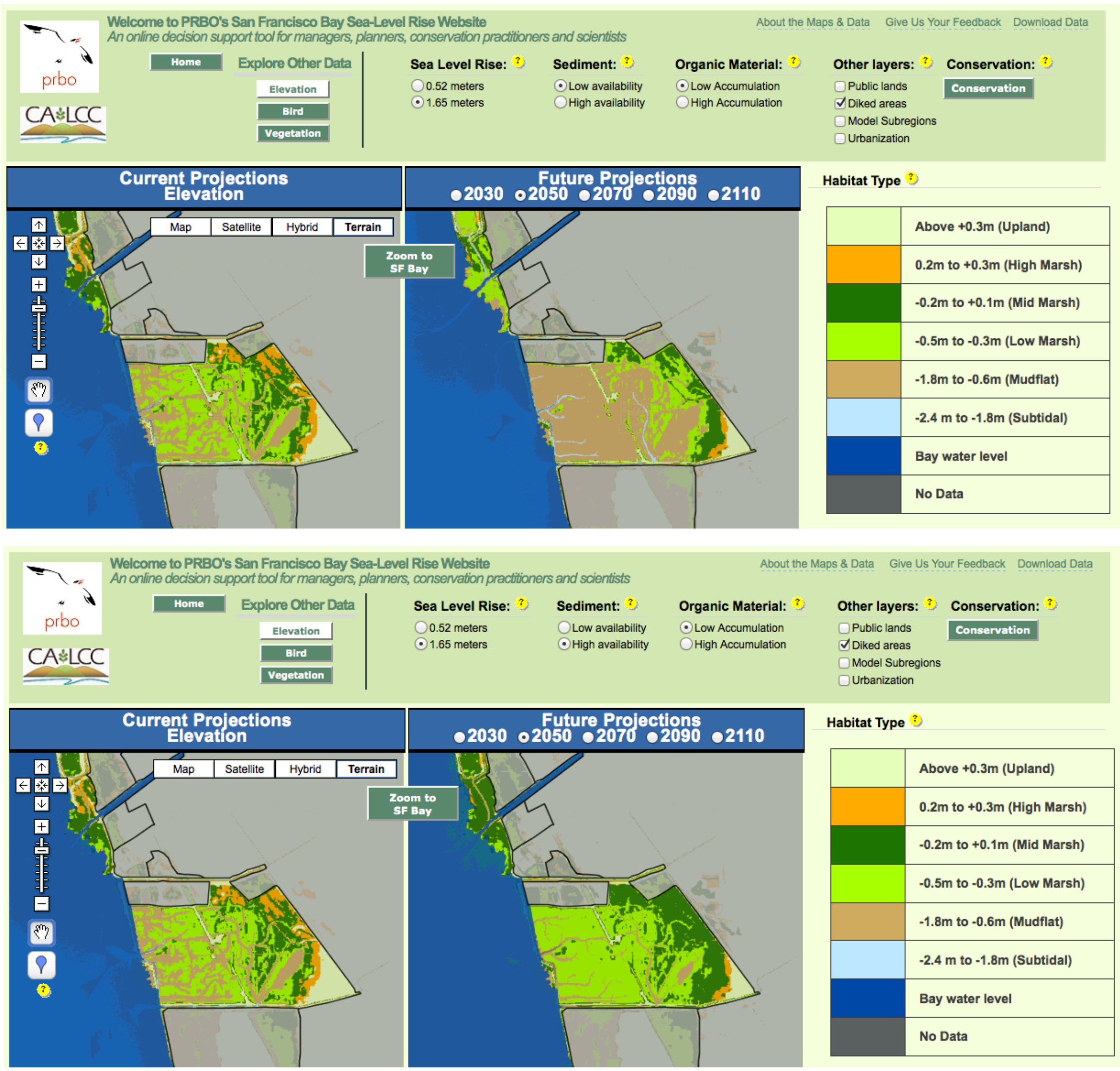
Currently, during storm events, especially those with wind waves, the bayside levee overtops, causing the Bay Trail to be unusable due to water damage and debris accumulation. More frequent overtopping during storm events could damage the bayside levee, not only affecting the Bay Trail but also the marsh it protects.

The marsh has limited adaptive capacity to accommodate or adjust to sea level rise or storm events. Upland migration opportunities are limited. While there are very few acres of upland in the southeast corner of the marsh, the marsh is surrounded by levees, and the adjacent inland areas are fairly urbanized. In addition, infrastructure either crosses (e.g., PG&E and EBDA utility lines) or bounds the marsh (e.g., the railroad right-of-way). These assets may be vulnerable to sea level rise, storm events and elevated groundwater, and will require further study to determine if they should be relocated or reinforced. Finally, while the bayside levee is actively maintained by EBRPD, it has proven difficult to obtain the necessary permits to raise or strengthen the levees protecting the Bay Trail and the marsh.[5]

Figure 9. Oro Loma Marsh is within the Hayward Regional Shoreline. The Bay Trail alignment follows the bayside levee. (Source: Google Maps)

[5] EBRPD obtains permits on an annual basis to repair the outer bay trail levee; however only small segments of repair are completed at a time due to permit conditions.

Figure 10. Predicted change in marsh habitat based on modeled average elevation relative to MHHW NAVD88 at Oro Loma Marsh by 2050 under a high rate of sea level rise, low rate of OM accumulation, and low (upper image) and high (lower image) sediment supply assumptions. Areas that are currently "diked" are shown in grey.



Managed Marsh Sensitivity and Adaptive Capacity

The ART project area contains five managed marshes. Four are within the Hayward Regional Shoreline, including Frank's Tract, West Winton, Hayward Marsh, and the Oliver Salt Ponds. The fifth is within the Eden Landing Ecological Reserve (ELER) at the southern end of the project area, which is a mixture of fully tidal and managed wetlands. The two ELER wetlands that have been restored to tidal action, Baumberg Tract and Whale's Tail, are considered in the previous tidal marsh section.

Hayward Marsh is somewhat unique compared to the other four systems (Figure 11). It is comprised of five managed ponds (3 freshwater and 2 brackish). The marsh receives secondary treated wastewater from Union Sanitary District and is subject to a National Pollution Discharge Elimination Permit (NPDES) from the Regional Water Quality Control Board. Flow through the ponds is controlled by a series of weirs, valves, and channels, which allow for the operation and management of the system[6]. Lastly, in the southeast corner of the marsh there is a 25-acre preserve that provides habitat for the federally endangered Salt Marsh Harvest Mouse.

Figure 11. Hayward Marsh is a mixture of fresh and brackish ponds, with internal channels and islands. It relies on secondary treated wastewater from Union Sanitary District as a freshwater input. (Source: Google Earth)

<u>Vertical Accretion</u>

The PRBO tool evaluates through predictive modeling how resilient managed (diked) systems would be if in fact they were restored to full tidal action. There are a number of assumptions and caveats to this analysis; for example, initial habitat predictions are based solely on current elevations and not existing vegetation. The future predictions assume that in year 2010 these systems were returned to tidal action with the initial predicted habitat composition. It does not consider the time it would take for tidal marsh vegetation to colonize the area, nor any potential differences in mineral sediment or organic matter accumulation rates that would occur while vegetation was colonizing.

Based on this analysis, the four managed systems within the Hayward Regional Shoreline would have varying capacities to persist over time depending on their initial elevation and the availability of mineral sediment (Table 6). Based on the assumed average initial elevations used in the PRBO tool, if returned to tidal action Frank's Tract would support mudflat, West Winton and Oliver Salt Ponds low marsh, and Hayward Marsh and ELER mid marsh.

With low sediment availability, by 2050, Frank's Tract would remain mudflat, West Winton and Oliver Salt Ponds would downshift to mudflat, and Hayward Marsh and ELER would downshift to low marsh. By 2090, all of the systems would transition to mudflat. With high

[6] http://www.ebparks.org/parks/hayward

sediment availability, by 2050 Frank's Tract would gain elevation to become, on average, a low marsh, while the other four systems would retain their initial marsh habitat. By 2090, all four systems would on average be at low marsh (Table 6 and Figure 12).

Figure 12. Frank's Tract and West Winton modeled predicted change in habitat to a uniform low marsh (based on elevation relative to MHHW) under high sediment availability in 2090.

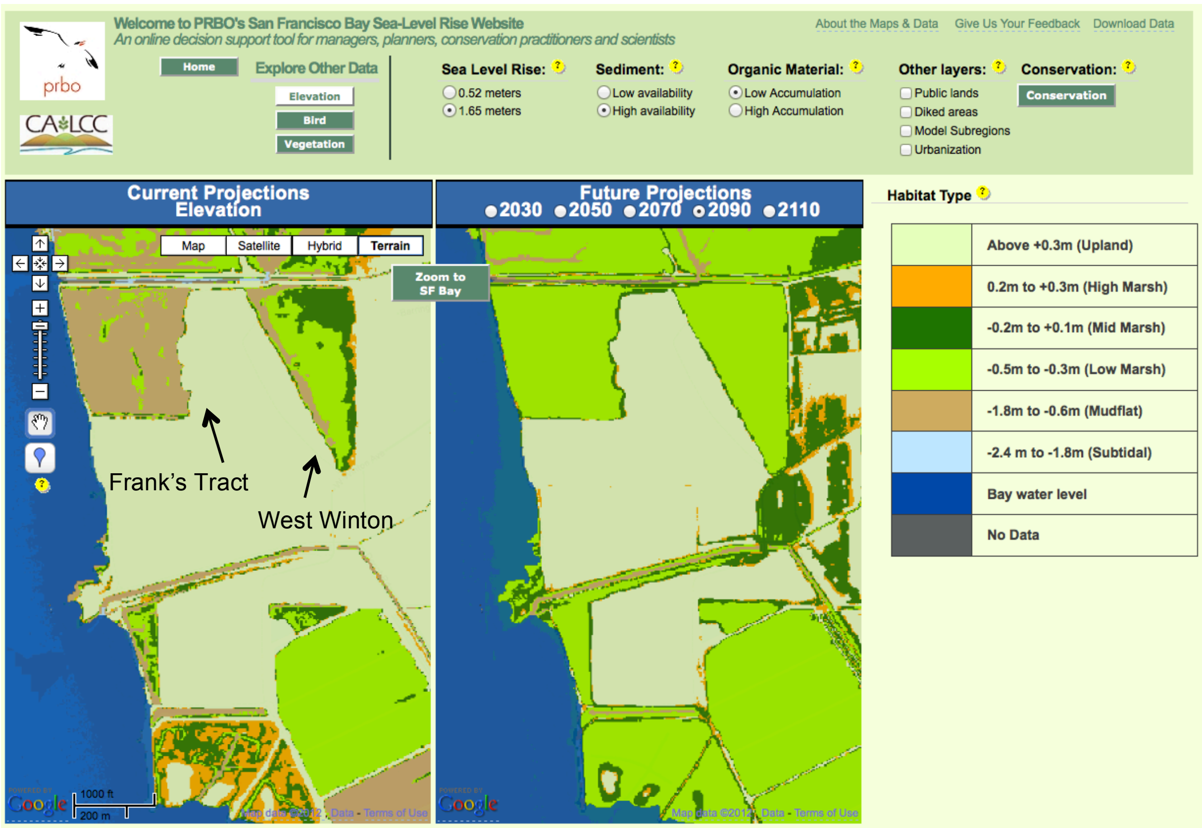


Table 6. Predicted change in average habitat type based on modeled average elevation relative to MHHW NAVD88 for assumed high and low sediment scenarios in combination with a high rate of sea level rise and low rate of OM accumulation.

	Assumed Initial	Low SSC		High SSC	
Marsh Name	**(2010)**	**2050**	**2090**	**2050**	**2090**
Frank's Tract	Mudflat	Mudflat	Mudflat	Low marsh	Low marsh
West Winton	Low marsh	Mudflat	Mudflat	Low marsh	Low marsh
Oliver Salt Ponds	Low marsh	Mudflat	Mudflat	Low marsh	Low marsh
Hayward Marsh	Mid marsh	Low marsh	Mudflat	Mid marsh	Low marsh
ELER	Mid marsh	Low marsh	Mudflat	Mid marsh	Low marsh

Upland Transgression

The potential for upland transgression, or the conversion of uplands to wetlands, for three of the five systems (Frank's Tract, West Winton, and Oliver Salt Ponds) if they were returned to tidal action is limited, mostly due to the minimal amount of upland habitat within these sites, and their location adjacent to existing urban development.

Under either the low or high sediment availability scenario, by 2050 the five systems are predicted to convert about half of the uplands available (Table 7). By 2090, all of these marshes will convert all available uplands to wetlands. As demonstrated by Hayward Marsh, the conversion of uplands does not always indicate a landward migration of wetland habitat. Upland areas within Hayward Marsh are islands that sit within the pond system. The conversion of these upland islands may not help to sustain the marsh system overall, but will provide habitat to tidal marsh species and will serve as tidal refugia for sensitive species for a period of time.

Table 7. Predicted acres of uplands converted to wetlands based on modeled average elevation relative to MHHW NAVD88 for assumed high and low sediment scenarios in combination with a high rate of sea level rise and low rate of OM accumulation. The data below constrains the uplands to adjacent natural, non-diked areas within the identified marsh footprint.

Marsh Name	Current Upland Acres (2010)	Percent Uplands Converted			
		Low SSC		High SSC	
		2050	2090	2050	2090
Frank's Tract	2.6	20	79	20	86
West Winton	1.0	47	48	47	68
Hayward Marsh	26.0	29	73	29	81
Oliver Salt Ponds	6.7	54	80	54	91
Eden Landing Ecological Reserve	485.9	47	71	47	87

Overall, if these managed systems were restored to full tidal action they would be sensitive to sea level rise and storm events given that they are at fairly low starting elevations. In addition, once restored to tidal action colonization of vegetation in these systems could be sensitive to changes in tidal regime or high-energy storm events.

If the dikes were *not* removed and all five wetlands were maintained as managed systems, they would be sensitive to potential overtopping and erosion of the shoreline structures that currently protect them from full tidal action. Additionally, tide control structures or gates used to maintain water surface elevations could be sensitive to higher Bay water levels, and may be difficult to operate or maintain if the frequency or intensity of storm events increases.

Specifically, for the Hayward Marsh, the levees are already in need of repair, and if there was damage to the levee system, the marsh may have to discontinue receiving treated wastewater to remain in compliance with the current NPDES permit. Furthermore, the freshwater and brackish ponds for this wetland provide final polishing to the secondary treated wastewater, and this function is sensitive to changes in salinity due to inundation or storm flooding. Lastly, the complexity of the operations, management, and permit compliance of the Hayward Marsh system means that there is less capacity to simply, easily, or in a low cost manner accommodate or adjust to changes from sea level rise or storm event impacts.

Consequences

Consequences are the magnitude of the economic, social, environmental and governance effects if an impact occurs. Factors that inform the magnitude of the potential consequences include the severity of the impact on the asset itself in terms of operations, maintenance, and capital improvement costs, the size and demographics of the population affected, the types of natural resources affected, and the jurisdictional complexity to manage the asset.

The consequences of sea level rise and storm events on wetlands will be significant to the natural resource functions, species and habitats within them, and to the inland areas protected by them. These larger consequences to inland areas from sea level rise and storm events are detailed in other chapters within this report.

Economy

There are potential direct and indirect economic consequences related to the exposure of wetlands to climate impacts. Many of the tidal marshes in the ART project area have been restored, representing a significant financial investment. There will be direct economic consequences if sea level rise increased the cost of restoration, including the cost to maintain or improve restoration projects. In addition, there could be direct costs in repairing utilities located within wetlands. For example, there are multiple utilities that transect the fully tidal Oro Loma Marsh, including power, wastewater and an abandoned gas pipeline. Furthermore, Hayward Marsh is a restored freshwater and brackish marsh system that serves as a discharge location for secondarily treated wastewater. The disruption or loss of this managed system will potentially have significant economic impacts on the utility that relies on it (Union Sanitary District).

Indirect consequences include the loss of ecosystem services that wetlands provide, including erosion and flood control through wave attenuation as well as water filtration and carbon sequestration. While it is difficult to quantify the dollar value of these services, Heberger (2009) points out that over $60 billion in infrastructure is at risk of inundation under high rates of sea level rise, and that some of this loss could be prevented by protecting and restoring tidal marshes.

Society

The complete or partial loss of tidal or managed marsh systems will potentially place shoreline residents at risk of flooding. Additionally, all of the fully tidal marshes in the ART project area have either been restored or are in process of being resorted. The ability to continue, maintain or expand the restoration industry and the employment that it provides will become more uncertain as sea level rises. Finally, tidal and managed marsh systems offer opportunities to view wildlife, provide access to the Bay shoreline, and offer scenic and aesthetic benefits that other areas cannot. The loss of these functions will have consequences for the people that use these areas for outdoor enjoyment or recreation.

Environment

In general, tidal marshes are predicted to either downshift from high to low marsh habitat or be lost as they convert to unvegetated intertidal mudflat under the high sea level rise scenario evaluated here. The consequence of this habitat shift would be significant for the a number of species of conservation concern, including state-listed or federally threatened and endangered species such as Clapper Rail, Black Rail and Salt Marsh Harvest Mouse, which rely on tidal marsh habitat either for breeding or foraging. For example, the loss of mid marsh, which is the primary breeding habitat for many bird species, could cause a significant reduction in bird abundance.

As marshes are subjected to more frequent or longer duration tidal inundation, there will be a loss of high tide refugia for species such as Clapper Rail and Salt Marsh Harvest Mouse, causing increased losses to predation, drowning or exposure. Additionally, in marshes that are adjacent to inland development, such as the Emeryville Crescent, repeated high tide inundation could force wildlife onto higher ground near Powell Street and I-80, causing increased stress on these populations. Lastly, more frequent inundation especially around the confluence with Temescal Creek could change soil salinities, affecting the survival marsh plant species and changing the vegetation profile over time.

Finally, many marshes are co-located with utility assets and impacts to these utilities as a result of sea level rise and storm events could have secondary impacts on water and habitat quality.

<u>Governance</u>
While wetlands are often managed by single agencies, wetland restoration programs require the collaboration of many different entities, from local to federal agencies and non-governmental organizations to private landowners. There may be a wide variety of agencies and organizations involved with wetland restoration and protection, which presents challenges in the many phases of decision-making:

- Planning and funding (e.g., San Francisco Bay Joint Venture)
- Regulation (e.g., U.S. Fish and Wildlife Service, U.S. Army Corps of Engineers, San Francisco Bay Conservation and Development Commission, and San Francisco Bay Regional Water Water Quality Control Board
- Restoration design (e.g., Phillip Williams & Associates – Environmental Science Associates)
- Land management (e.g., National Parks Service, California Department of Fish and Game, and East Bay Regional Parks)
- Research (e.g., United States Geological Survey and PRBO Conservation Science)

The fact that there is no single, individual institutional decision-maker for wetland restoration and protection presents challenges for effective and timely management of these assets.

Key Findings

The vulnerability of twelve tidal marshes and five managed marshes in the ART project area was assessed in collaboration with PRBO Conservation Science using data from their sea level rise online decision support tool. The sensitivity and adaptive capacity of these marshes was assessed based on select information in this tool, including current habitat composition; changes in future projected habitat based on elevation modeling; the conversion of uplands to wetlands based on elevation modeling, and changes in landscape conservation priority ranking. These indicators of vulnerability were evaluated for PRBO's predictive modeling of a high rate of sea level rise, which corresponds to approximately 16 inches of sea level rise at 2050 and 55 inches at 2100, and two future assumed suspended sediment concentration rates (low and high) for two time periods (2050 and 2090).

The PRBO modeling results suggest that marshes are sensitive to a high rate of sea level rise, and that their capacity to persist over time will depend on sediment supply. Overall, within the ART project area marshes will downshift from higher to lower elevation habitat types, and eventually to mudflat. Under the more pessimistic sediment supply assumption (low availability), marshes are more sensitive to sea level rise. For example, under the low sediment scenario most of the marshes in the ART project area will not persist. Instead, they will transition to mudflat by 2050. Under the high sediment supply scenario all but one of the marshes will persist in 2050, with some downshifting in habitat type. By 2090 only one additional marsh will be lost to mudflat, while the remainder will downshift to low marsh habitat under the high sediment supply scenario.

Almost half of the uplands within the marsh system footprint will be converted to wetland habitat (low, mid or high marsh) by 2050 regardless of sediment supply. Under the high sediment supply scenario, approximately 75% of the uplands will convert to wetlands by 2050, with additional conversion by 2090. For many of the marshes in the ART project area there is minimal opportunity for upland transgression due to existing constraints such as adjacent land uses, including developed or diked areas, and the elevation of the available uplands.

Five managed marshes were assessed. If the existing dikes were removed, and these systems were restored to full tidal action, they would be sensitive to a high rate of sea level rise as they are at fairly low starting elevations. In addition, the colonization of vegetation in these areas to create marsh habitat once restored to tidal action could be sensitive to changes in tidal regime or high-energy storm events. If the dikes were *not* removed these systems would be sensitive to potential overtopping and erosion of the shoreline structures (non-engineered earth berms, etc) that currently protect them from full tidal action. Additionally, tide control structures or gates used to maintain water surface elevations could be sensitive to higher Bay water levels, and may be difficult to operate or maintain if the frequency or intensity of storm events increases.

The Hayward Marsh, which is unique compared to the other managed marshes in the ART project area, is sensitive to sea level rise, has limited adaptive capacity, and there will be high consequences if this system is exposed to sea level rise or storm events. The freshwater and brackish ponds in the marsh provide final polishing to the secondary treated wastewater, and this function is sensitive to changes in salinity. The marsh is protected by a series of levees that are already in need of repair and are therefore already sensitive to storm events. The complexity of the operations, management and permit compliance of both the operation of this marsh system and the maintenance and upgrade of the levees that protect it means there is limited capacity to simply, easily or in a low cost manner accommodate or adjust to changes from sea level rise or storm event impacts.

As marshes are exposed to more frequent or longer duration tidal inundation, there will be a loss of high tide refugia for species such as Clapper Rail and Salt Marsh Harvest Mouse, causing increased losses to predation or drowning. Additionally, for marshes that are adjacent to urbanized areas repeated high tide inundation could force wildlife to higher ground that is closer to people and infrastructure, causing increased stress on these populations.

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