Chapter 6. Structural & Non-Structural Shorelines

The ART project area shoreline is a diverse mixture of built and natural features. The northern portion of the project area, along the shoreline of Emeryville, Oakland, Alameda and San Leandro, is fairly urbanized with a predominance of engineered shoreline structures (Figure 1). In contrast, the southern portion of the project area, along the shoreline of Hayward and Union City, is less urbanized with non-engineered structures, natural shorelines and wetlands situated between the Bay and the built environment.

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 (Figure 2). 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., tidal and managed marshes) – dissipate wave energy, improve water quality and provide ecological habitat value

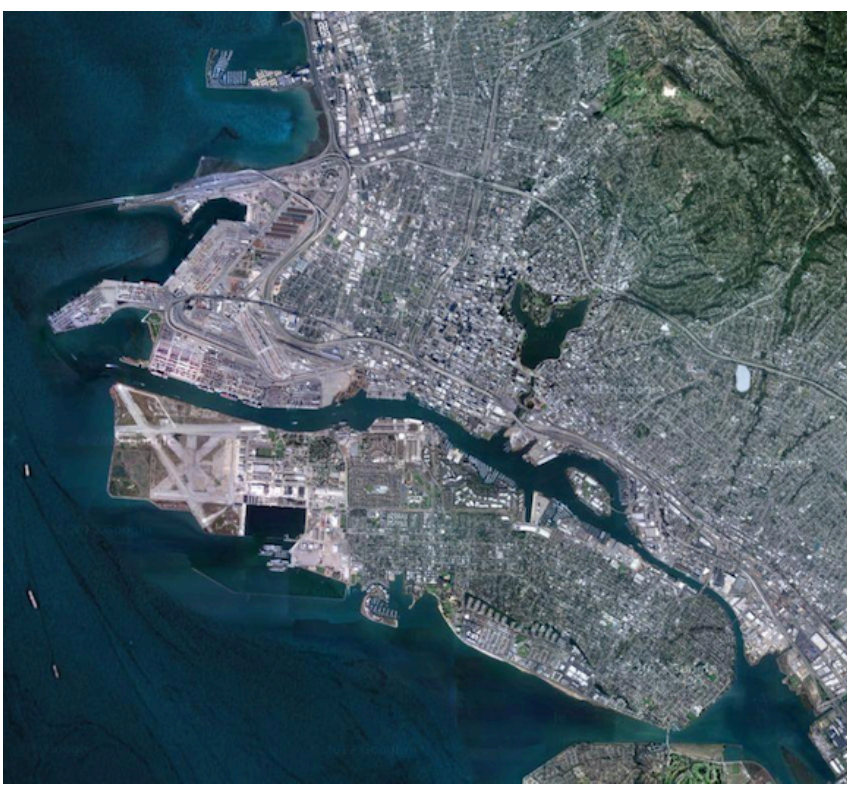


Figure 1. The northern project area is an urbanized shoreline that includes the Port of Oakland, EBMUD's main treatment plant, and the toll plaza for the San Francisco-Bay Bridge. Shoreline categories mapped onto northern ART project area include Engineered Shoreline Protection and Natural Shoreline/Beach.

An overview of the vulnerability of the three structural and one of the non-structural shoreline categories is provided below based on an evaluation conducted by a coastal engineering team for the Adapting to Rising Tides Transportation Vulnerability and Risk Assessment Pilot Project (AECOM, 2011); a similar overview of wetland shorelines is provided in Chapter 7. A more detailed assessment of the vulnerability and risk of individual shoreline assets will require specific information about the design, condition, ownership, current operation and maintenance and planned capital improvements of each asset or shoreline segment.

Figure 2. Shoreline categories in the ART project: 1) Engineered flood protection - levee with gate leading to LaRiviere Marsh (Source: Don Edwards San Francisco Bay National Wildlife Refuge); 2) Engineered shoreline protection - revetment along Emeryville's Marina Park; 3) Non-structural, natural non-wetland shoreline - Crown Beach (Source: Flickr Commons, Ingrid Taylor); and 4) Non-engineered berm in Eden Landing by Mallard, Hayward (Source: AECOM).

Exposure

Exposure is the extent to which an asset – such as an engineered flood protection structure, shoreline protection, or non-engineered berm – experiences a specific climate impact such as storm event flooding, tidal inundation, or elevated groundwater. The exposure of structural shoreline assets in the ART project area to two sea level rise projections and three Bay water levels was evaluated using a planning-level overtopping potential analysis.

The two sea level rise projections, 16 inches (40 cm) and 55 inches (140 cm), correlate approximately to mid- and end-of-century. These two sea level rise projections were coupled with three Bay water levels: the highest average daily high tide represented by mean higher high water (MHHW), hereafter "high tide" or "daily high tide"; the 100-year extreme water level, also known as the 100-year stillwater elevation (100-year SWEL), hereafter "100-year storm" or "storm event"; and the 100-year extreme water level coupled with wind-driven waves, hereafter "storm event with wind waves", or "wind waves." These water levels were selected because they represent a reasonable range of potential Bay conditions that will affect flooding and inundation along the shoreline.

Exposure of structural shoreline assets was determined using a potential overtopping analysis, which is more fully described in Chapter 2 and Appendix B. "Overtopping potential" refers to the condition where the water surface elevation exceeds the elevation of the shoreline feature that controls inland inundation. This analysis provides a high-level assessment of the structural shoreline assets that may not be of adequate height to prevent inland inundation by Bay waters under the various scenarios evaluated; it does not account for the physics of wave setup and runup, the condition of the shoreline asset, or the potential failure of the asset due to scour, undermining or a breach after the initial overtopping occurs

Results of the potential overtopping analysis are provided below for three representative shoreline areas, and are summarized for the project area as a whole in Chapter 2.

Sensitivity and Adaptive Capacity

The sensitivity and adaptive capacity of structural and non-structural natural shorelines in the ART project area were assessed for four potential climate impacts that could occur due to sea level rise and storm events:

- Permanent or frequent inundation by the daily high or extreme tide
- More frequent or intense floods
- Elevated groundwater levels and saltwater intrusion
- Potential for overtopping and erosion

Sensitivity is the degree to which an asset would be physically or functionally impaired if exposed to a climate impact. Adaptive capacity is the ability for an asset to accommodate or adjust to a climate impact and maintain or quickly resume its primary function. A high level summary of the sensitivity and adaptive capacity of the three structural and one non-structural shoreline categories (natural, non-wetland shoreline) is presented below.

Structural Shorelines

<u>Engineered flood protection</u>
The primary function of engineered flood protection structures, such as levees and flood walls, is to protect inland areas from inundation. They are designed to meet a specific level of protection with respect to freeboard[1], embankment protection, foundation stability, and settlement. Levees and flood walls are generally designed, at a minimum, to provide protection from the extreme coastal storm event (100-year stillwater elevation with wind waves).

[1] Freeboard is safety factor, expressed in feet above a flood level, which compensates for unknown factors such as wave action, bridge openings, and hydrological effects (for more information see www.fema.gov/plan/prevent/floodplain/nfipkeywords/freeboard.shtm).

The flood protection provided by levees and flood walls is sensitive to sea level rise. As sea level rises, flood levels will increase and wave conditions will change, potentially reducing the amount of freeboard provided and increasing the potential for overtopping and inland inundation. Without improvements to maintain minimum freeboard there will be a progressive reduction in the level of protection provided as sea level rises (Figure 3).

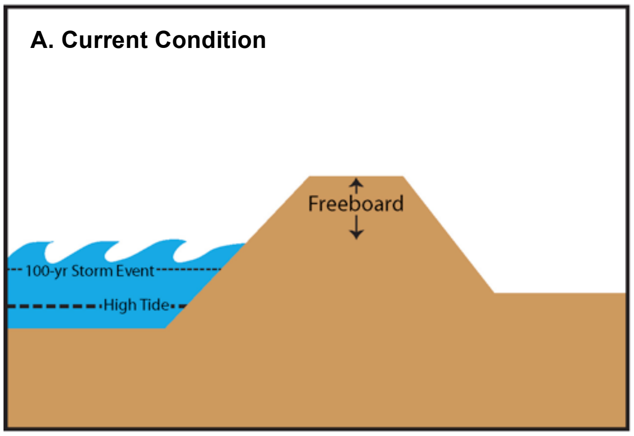
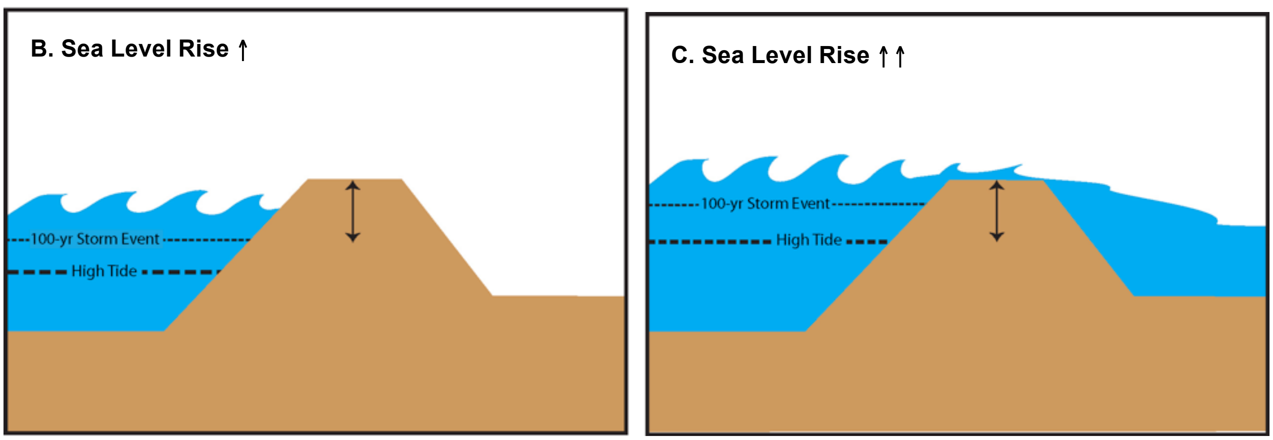
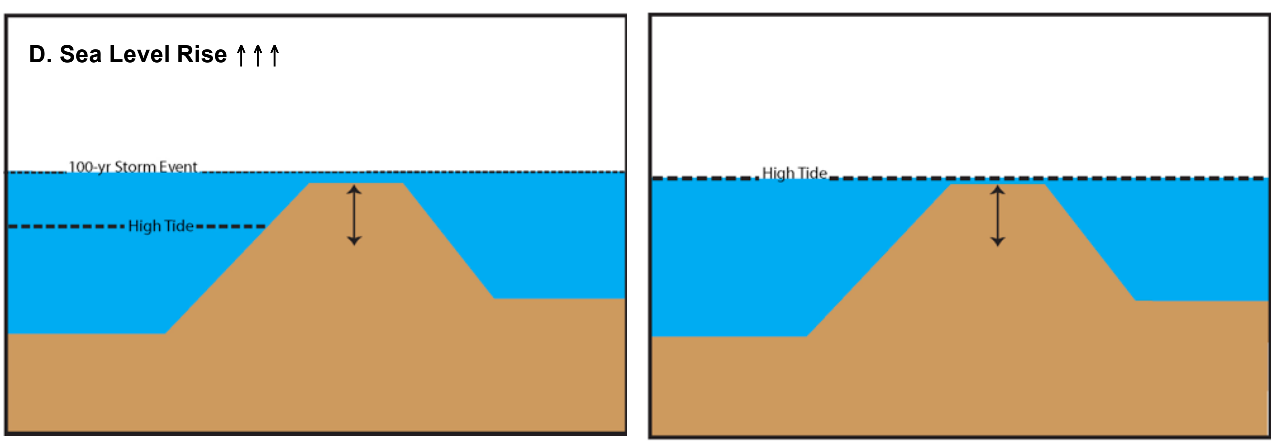


Figure 3. Engineered flood protection structures such as levees that currently have adequate freeboard will progressively lose their capacity to prevent flooding of inland areas as sea level rises unless they are improved or upgraded. Panel A represents current Bay water levels, while B - E show progressively higher Bay water levels as sea level rises.



Structure does not have adequate minimum freeboard but is not overtopped.

Structure is overtopped by the 100-year storm event only if there are wind waves.



Structure routinely overtopped by the 100-year storm event regardless of wave condition.

Structure routinely overtopped at high tide.

The structural integrity of engineered flood protection structures is also sensitive to sea level rise. As sea level rises, wave conditions are also likely to change. Larger and more frequent storms could result in erosion of levee embankments or flood wall footings. Larger waves could cause overtopping of these structures, causing levee crest and backside erosion and possibly even failure. Inadequately maintained structures will have increased sensitivity to sea level rise.

Additionally, the entire ART project area has high seismic vulnerability and moderate to very high liquefaction susceptibility. Liquefaction during earthquakes could cause damage to structural shoreline assets, including levees and flood walls. Engineered flood protection structures have varying tolerances to seismic events, and elevated groundwater could increase the potential for liquefaction and lateral spreading, increasing the potential for damage during an earthquake.

The adaptive capacity of engineered flood protection structures will vary depending on a number of factors, including design, condition, routine maintenance, and the availability of funds for planning and operations.

Structures with the greatest adaptive capacity include:

- Those either located or designed in a manner that allows for improvement or upgrade to accommodate rising water levels and wave conditions. For example, levees that can be increased in height that have sufficient room to increase the overall footprint.
- Those with dedicated maintenance funding and permit authorizations allowing ongoing maintenance or improvements.
- Those that are already included in long-range capital improvement planning.

Structures with the least adaptive capacity include:

- Those that cannot be expanded due to physical or environmental constraints. If there is insufficient room to expand the levee footprint, improvements may necessitate a combination of approaches, e.g., adding a flood wall on top of a levee.
- Those without dedicated funds or without permit authorizations for ongoing maintenance or improvement.

<u>Engineered shoreline protection</u>

The primary function of engineered shoreline protection structures, such as revetments and bulkheads, is to harden the shoreline to reduce shoreline erosion and prevent land loss. The discussion below focuses on revetments since this is the most common engineered shoreline protection in the ART project area; bulkheads at the Port of Oakland are discussed in the Seaport assessment chapter[2].

In general, revetments consist of an armoring of erosion-resistant material (such as concrete or riprap) placed on an existing slope or an engineered embankment to protect the area from waves. Revetments are sensitive to degradation from erosion and overtopping depending on their design and condition. For example, armor is sized to remain in place given present wave action. Sea level rise may increase wave heights and velocities, resulting in mobilization of the armor layer. Additionally, overtopping could undermine the foundation and weaken the revetment. Lastly, if waves exceed design conditions, the toe could undercut and the entire structure could be compromised and potentially unravel.

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[2] Bulkheads at the Port of Oakland are mostly unanchored (gravity) structures and therefore have some form of shoreline erosion protection beneath, e.g., riprap or stone. Adapting to Rising Tides: Transportation Vulnerability and Risk Assessment Pilot Project, November 2011, Chapter 2.

The adaptive capacity of revetments will depend on their size and location. Generally, revetments have moderate adaptive capacity since they can be upgraded over time to accommodate changing conditions. Improvements may include placing additional armoring or increasing the size of armor to cope with increasing currents and waves. It is also possible to increase the height of a revetment in response to higher high tides, extreme water levels or wave heights. If the size of the revetment is increased, the amount of toe protection may also need to be increased, which could be challenging if the structure is, for example, located in an environmentally sensitive area with high resource values. The maximum height of a revetment is limited by the height of the slope it is protecting; therefore it may be necessary to combine revetments with an engineered flood protection structure if additional protection is required.

Non-engineered berms

The primary function of non-engineered berms is to separate managed marshes and ponds from the Bay, although they also protect developed shorelines in some locations (Figure 4). These berms are essentially mounds of bay mud, which have not been engineered to meet specific design criteria. They provide some level of "ad hoc" flood protection to inland areas, especially if they are adjacent to expansive wetlands, which themselves help attenuate waves and reduce flooding. For example, in the southern portion of the project area, the expansive network of former and resorted salt ponds at Eden Landing and non-engineered earth berms provides a buffer between the Bay and inland developed areas. If the most outboard berms are overtopped, the ponds behind them, which are generally lower than the Bay, will fill. Because the ponds would provide flood storage, the next inland berm would not overtop unless the pond either reached capacity or there were wind waves that caused an additional rise in water level. If the system of pond and berms is adequate, Bay water levels could recede before the most inland berms are overtopped, protecting inland areas from inundation or flooding.

Figure 4. Non-engineered berm with riprap on outboard side (Source: Google Earth).

Non-engineered berms are sensitive to sea level rise and storm events, in particular to the erosive forces of currents and waves. Some berms are maintained on a regular schedule. Those that are adjacent to the Bay are maintained more often than those further inland as they exposed to more erosive tides, currents and waves. However, many berms are only maintained if erosion is observed or as failures occur. The ability to improve non-engineered berms to accommodate rising sea level and storm conditions is limited. Many berms cannot support the placement of additional material and therefore are already at a maximum height. In addition, the current maintenance practice in many locations is to excavate adjacent bay mud and place it on top of the berm. Once this supply of material is exhausted, suitable material will need to be imported. This will greatly affect that ability to cost-effectively maintain these structures, and will limit their ability to be modified to accommodate or adjust to sea level rise.

Non-Structural Shorelines

<u>Natural, non-wetland shorelines</u>

Natural non-wetland shorelines such as beaches can dissipate wave energy, protecting inland areas from large waves. They may also provide varying levels of flood protection depending on the extent of beach, topographic relief, and height of the associated dune system, if there is one.

In the ART project area, the most significant natural shoreline is the beach and sand dunes at the Robert M. Crown Memorial State Beach in Alameda[3]. Although the beach and dunes provide some protection from large waves, the beach is maintained with imported sand and engineered sand-retaining structures. Sea level rise and storm events could require more frequent replenishment or additional sand retention features at Crown Beach. Additionally, the dunes may need to be protected to help preserve the adjacent roadway. Shoreline interventions such as hardening, groins, or berms can interrupt the natural process of sediment transport, thereby increasing the sensitivity of the beach system to sea level rise and storm events.

Beach and dune complexes that are not naturally self-sustaining have low adaptive capacity, as they generally do not have the inherent ability to either accommodate or adjust to changes in water level, storm, and wave conditions without a significant amount of resources. In addition to the financial costs of such resources, there are also regulatory requirements that add to the complexity of either maintaining or improving the beach and dunes.

Representative Geographic Areas

To better understand both the vulnerability of the structural shorelines in the project area, and the potential risk to the inland areas and assets they protects, three representative geographic areas were selected for a more in-depth evaluation (Figure 5). Each of the three areas is comprised of a different combination of structural and non-structural shoreline assets and protects regionally significant services and facilities. The three areas selected include:

- San Francisco-Oakland Bay Bridge Peninsula and the Port of Oakland
- Bay Farm Island and the Oakland International Airport
- Hayward Area Shoreline

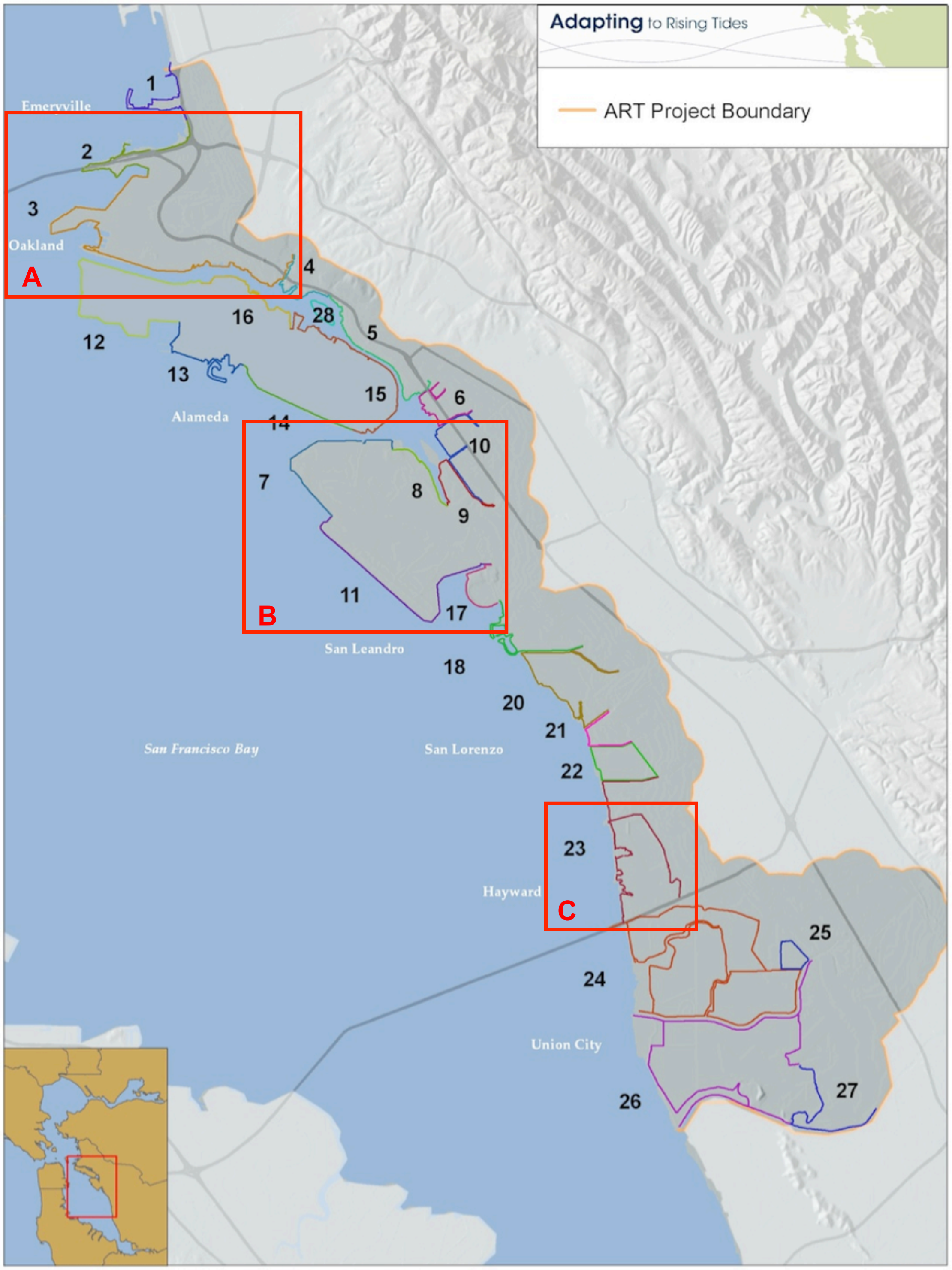
The assessment of the representative geographic areas also informs an understanding of the likelihood that the inland assets they protect will be exposed to inundation. In the following discussion, the exposure of each of the representative geographic areas, the vulnerability of the structural assets that comprises them, and the magnitude of the potential consequences on the inland areas is discussion. Where it was available, information is provided about the specific locations where exposure of the shoreline may occur and the types of vulnerable services and facilities nearby that could also be exposed.

Exposure of the three representative geographic areas was evaluated using the results of the overtopping potential analysis described in Chapter 2. Each of the areas is comprised of one or more shoreline system. Shoreline systems are contiguous reaches of structural and non-structural assets that together prevent inundation of inland areas. The systems were aligned to the feature that most likely prevents inland inundation, and therefore are mostly comprised of structural assets such as engineered flood protection, engineered shoreline protection and non-engineered earth berms, although in some locations the feature controlling inundation was a roadway or rail embankment. In areas where the shoreline was a natural feature, for example a tidal marsh or beach, the shoreline system was aligned landward at the feature controlling inland inundation (see Chapter 2 for a more complete description of the analysis).

[3] This park is evaluated in parks and recreation assessment chapter.

Figure 5. Three representative geographic areas include (A) the San Francisco-Oakland Bay Bridge Peninsula and the Port of Oakland; (B) Bay Farm Island and the Oakland International Airport; and (C) the Hayward Area Shoreline.

ART Shoreline Systems



Data Source: AECOM

The potential overtopping analysis is summarized below for the shoreline systems that are within each of the three representative geographic areas. The overtopping potential results are presented as the percent of the total length overtopped, and the average and maximum depth of overtopping (see Table 1 and 2). These results are discussed in detail in the sections that follow[4].

Table 1. Percent of length overtopped for each system within the representative areas. Total length of each system provided as a reference.

System #	System Length (miles)	Percent of Length Overtopped					
		16“ SLR			55” SLR		
		High Tide	Storm Event	Storm Event + Wind Waves	High Tide	Storm Event	Storm Event + Wind Waves
San Francisco-Oakland Bay Bridge Peninsula/Port of Oakland (13.9 total miles)							
2	4.4	4	45	73	54	72	99
3	9.5	1	12	45	18	41	100
Bay Farm Island/Oakland International Airport (10 total miles)							
7	3.5	0	6	64	21	66	94
8	1.6	0	74	100	94	100	100
11	4.9	0	0	54	1	50	100
Hayward Shoreline (7.6 total miles)							
23	7.6	10	30	98	68	98	100

Table 2. Average depth of overtopped (rounded to nearest half foot increment) for each shoreline system within the three representative areas.

System #	Average Depth of Overtopping					
	16“ SLR			55” SLR		
	High Tide	Storm Event	Storm Event + Wind Waves	High Tide	Storm Event	Storm Event + Wind Waves
San Francisco-East Bay Bridge Peninsula/Port of Oakland						
2	1	1.5	4	2	4	6
3	1	1.5	2.5	2	2.5	4
Bay Farm Island/Oakland International Airport						
7	0	1	2.5	1	2	5
8	0	1	4	2	4	7
11	0	1.5	2	1	2	4
Hayward Shoreline						
23	2	2	3.5	2	3.5	7

[4] It is important to note that while the overtopping potential analysis summarized below can identify the location and depth of inundation at the shoreline it does not provide a complete picture of the consequences that an overtopping event will have on inland areas. Even if a short length of shoreline is overtopped, potentially large inland areas could be inundated. Additionally, if the overtopping results in a structural failure of a shoreline asset, larger areas could be inundated at deeper depths, resulting in greater consequences.

<u>San Francisco-Oakland Bay Bridge Peninsula/Port of Oakland</u>

The San Francisco-Oakland Bay Bridge Peninsula/Port of Oakland area extends from Temescal Creek in Emeryville though the Oakland Outer, Middle and Inner Harbors, to the west side of Lake Merritt Channel ending at 1st Avenue in Oakland. This shoreline area is protected by two shoreline systems, #2 and #3 (Figure 6).

- System #2 includes the Emeryville Crescent wetlands and riprap revetment engineered shoreline protection. This system protects the San Francisco-East Bay Bridge Peninsula, including the toll plaza.
- System #3 includes riprap revetment engineered shoreline protection as well as the bulkheads located at the Port of Oakland. This system protects the Port of Oakland, Jack London Square and Laney College/Lake Merritt BART station neighborhood.

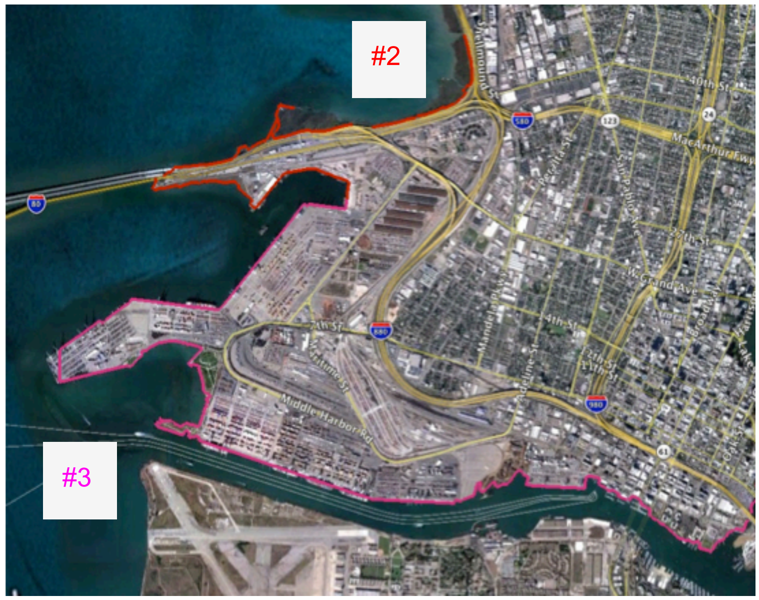


Figure 6. The San Francisco-Oakland Bay Bridge Peninsula and Port of Oakland area is comprised of two shoreline systems, #2 in red and #3 in pink. (Source: Google Earth)

Together, these two systems protect the neighborhood of West Oakland and key regional infrastructure including Interstate 880 and 80, the Union Pacific Rail Yard, two BART stations and the East Bay Municipal Utility District (EBMUD) main wastewater treatment plant.

With 16 inches of sea level rise, less than 5% of either system #2 or #3 will potentially overtop at high tide (Table 1). However both systems will be significantly affected by storm events. During a storm event approximately half of system #2 could potentially be overtopped at depths averaging 1.5 feet (Figure 7). The majority of the overtopping will occur on the north side of system #2, in the vicinity of the Bay Bridge toll plaza. In comparison, 12% of system #3 could potentially be overtopped at an average depth of 1.5 feet during a storm event. Overtopping would increase to 45% and 2.5 feet if there were wind waves. The overtopping of system #3 will mostly occur at Oakland Middle Harbor along 7th street, at Jack London Square, and along the west side of the Lake Merritt Channel.

With 55 inches of sea level rise 50% of system #2 will overtop at high tide, and over 75%will overtop during a storm event. The average depth of overtopping will increase from 2 feet at high tide to 4 feet during a storm event. System #3 is less exposed, with 18% overtopping at high tide, and 41% during a storm event (Figure 8). Both systems will be entirely overtopped by a storm event with wind waves by average depths of 4 to 6 feet.

Figure 7. Approximately half of system #2 will overtop during a storm event with 16 inches of sea level rise (areas shown in blue). If there are wind waves during the storm the average depth of overtopping will increase from 1.5 to 4 feet. The overtopping generally occurs on the north side of the Bay Bridge toll plaza and along the Interstate 80 approach.

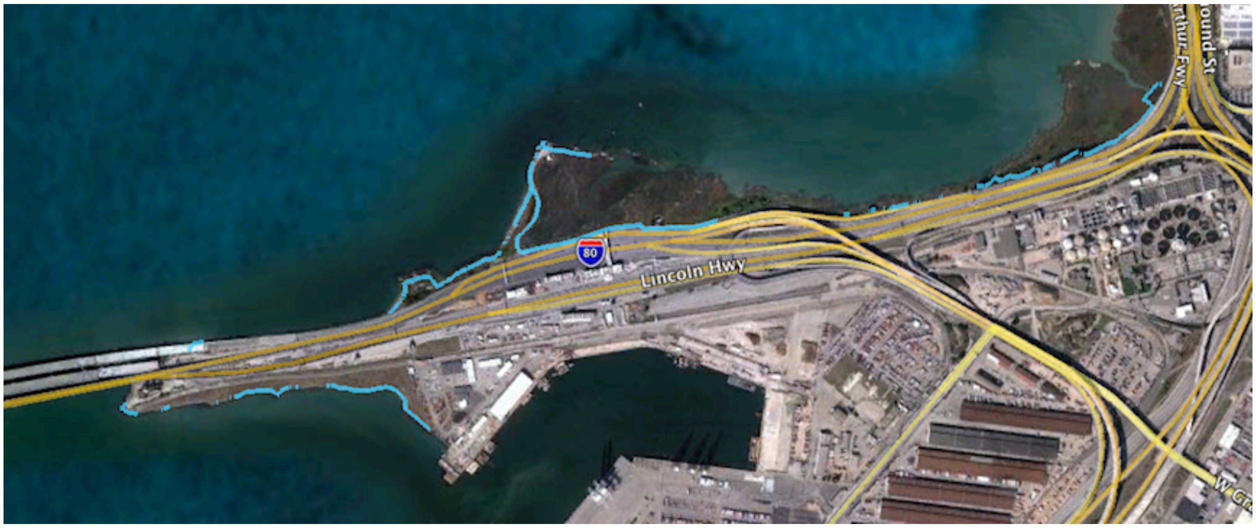


Figure 8. Almost half of system #3 will overtop during a storm event with 55 inches of sea level rise. In this case, Oakland Middle Harbor will overtop with 2 feet of inundation (areas shown in teal). If there are wind waves during the storm overtopping will occur along the entire system.

The San Francisco-Oakland Bay Bridge Peninsula/Port of Oakland area is mostly comprised of engineered shoreline protection, which can be sensitive to degradation from overtopping and erosion depending on the design and condition. Engineered shoreline protection does however have some adaptive capacity, because it can be upgraded or modified to accommodate increased water levels, currents and waves if the structure is not already at its maximum height. In addition, there are bulkheads at the Port of Oakland, which is fairly unique to the ART project shoreline. The bulkheads are mostly unanchored (gravity) structures with shoreline erosion protection beneath, e.g., riprap or stone. Also, critical infrastructure for Port operations is located beneath the bulkheads, for example electrical conduit for shore-side power. Therefore, while the bulkheads may not be sensitive it is possible that erosion protection and infrastructure beneath them could be adversely affected by sea level rise and storm events.

Overall, this representative geographic area is highly sensitive to storm events. System #2 which protects the Bay Bridge toll plaza is more exposed then system #3, and is likely to be more sensitive as it includes the Emeryville Crescent wetlands (see Chapter 7). The consequences of a failure in either system #2 or #3 will be very high, as they each protect regionally significant infrastructure, as well as the residential, commercial and industrial land uses within West Oakland (See Chapter 5).

Bay Farm Island/Oakland International Airport

The Bay Farm Island/Oakland International Airport area is comprised of three shoreline systems that protect Bay Farm Island and the Oakland International Airport (OAK), including (Figure 9).

- System #8 includes engineered flood protection structures (levees) and non-engineered earth berm. This system protects the eastern side of Bay Farm Island, including Shoreline Park along Doolittle Drive from Swan Way to Harbor Bay Parkway.
- System #7 is comprised of engineered flood protection structures (levees). This system protects the north side of Bay Farm Island, including Shoreline Park from Harbor Bay Parkway on Doolittle Drive to the OAK perimeter dike just past North Loop Road.
- System #11 is comprised of engineered flood protection structures (levees). This system protects OAK from North Loop Road along the north side of Airport Canal, to Davis Street. It also protects the Metropolitan Golf Links and San Leandro's Wastewater Treatment Plant.

Figure 9. The Bay Farm Island/Oakland International Airport shoreline area is comprised of three systems, #8 in purple, #7 in red, and #11 in orange. (Source: Google Earth)

With 16 inches of sea level rise none of the systems will be overtopped at high tide (Table 1). However, during storm events, 74% of system #8, which is one of the shortest systems in the ART project area, will be overtopped (Figure 10). In contrast 6% of system #7, which protects the northern portion of Bay Farm Island, will overtop, and none of system #11, the OAK perimeter dike, will overtop. Airport services and facilities could be exposed during a storm event with 16 inches of sea level rise from the overtopping of system #8 rather than from the airport's perimeter levee.

If there are wind waves during the storm event overtopping of system #8 increases to 100%, and average depths will increase from 1 foot to 4 feet (Table 2). For system #7, overtopping increases from 6% to 64%, and average depths will increase from 1 foot to 2.5 feet. The portion of system #7 potentially overtopped is along the northern end of Bay Farm Island, along Shoreline Park (Figure 11). This section of shoreline was categorized as a non-engineered earth berm because it is not heavily armored, and is not mapped as a levee/flood protection structure. This area of shoreline is therefore more sensitive to sea level rise and storm events

Figure 10. With 16 inches of sea level rise all of system #8 will overtop during a storm event with wind waves (areas shown in blue). This system, which is only 1.6 miles long, could lead to inundation at the airport well before the OAK perimeter dike is vulnerable.

Figure 11. With 16 inches of sea level rise more than half of system #7 will overtop during a storm event with wind waves (area shown in purple). Along Shoreline Park and the Bay Trail, overtopping depths will potentially be 2.5 feet on average. In addition, as sea level rises this section of shoreline will be exposed to erosion from wind-driven waves and will require additional protection.

than areas identified as engineered flood protection structures (e.g., levees). System #11, the OAK perimeter dike, will have more than half of its length overtopped during a storm event with wind waves with an average depth of 2 feet. This potential overtopping is located on the south side of the island along the Airport Canal (Figure 12).

With 55 inches of sea level rise all of system #8 is overtopped. Average depth of overtopping is 2 feet at high tide, 4 feet during a storm event, and 7 feet if there are wind waves. Only 20% of system #7 and 1% of system #11 are overtopped at high tide; however, this increases to over 50% during a storm event, and almost 100% if there are wind waves. The depth of overtopping within these two systems increases from 1 foot at high tide, to 2 feet during a storm event, to at least 4 feet if there are wind waves.

The Bay Farm Island/Oakland International Airport shoreline area is mostly comprised of engineered flood protection structures. However, the northern portion of Bay Farm Island within system #8 is protected by a non-engineered structure (Figure 13). Engineered flood protection is designed to protect inland areas from flooding, and is not as sensitive to overtopping and erosion (depending on the design and condition). Non-engineered structures are very sensitive to changing tides, currents and wave condition, and are likely to be adversely affected by sea level rise and storm events. Additionally, they have limited capacity to be easily, simply or in a low-cost manner improved to better protect inland areas.

Overall, this area is highly sensitive to storm events. System #8, which is a relatively small system in length, is sensitive to storm event overtopping. This system helps to protect regionally significant infrastructure including the services and facilities necessary for the operation of the airport. In addition, the portion of system #7 along northern Bay Farm Island that is non-engineered earth berm is also sensitive and plays a role in protecting the residences on Bay Farm Island and the northern portion of the airport. Lastly, there is a portion of system #11 along the Airport Canal that is sensitive to storm events. Failure of any one of these three systems could have significant consequences on the region, not only due to the loss of airport operations but also the loss of access to jobs, impacts on commercial, industrial and residential land uses, and potential disruption of utility infrastructure such as the San Leandro wastewater treatment plant.

Figure 12. With 16 inches of sea level rise, 54% of system #11 will potentially overtop during a storm event with wind waves to an average depth of 2 feet (area shown in purple). This potential overtopping is located on the south side of the island along the Airport Canal.

Figure 13. The northern portion of Bay Farm Island, from the Bay Farm Island Bridge to Aughinbaugh Way, is protected by a non-engineered earth berm structure, and is vulnerable storm events with sea level rise.

Hayward Regional Shoreline

The Hayward Regional Shoreline area extends from the south side of Sulphur Creek to the Hayward-San Mateo Bridge. It is protected by one shoreline system, #23 (Figure 14).

- System #23 is comprised of non-engineered berm along the bayshore, and engineered flood protection structures along Sulphur Creek and Depot Road. This system protects key industrial and commercial job centers on Depot and Cabot Roads, access to the Hayward-San Mateo Bridge, Hayward's Wastewater Treatment Plant, and the East Bay Dischargers Authority (EBDA) Hayward Effluent Pump Station.

Figure 14. The Hayward Regional Shoreline area is comprised of one system, #23 shown in orange below.

The Bay Trail is located on the bayshore levee that protects the Hayward Regional shoreline, including a closed landfill, four managed marshes including the Hayward Marsh, and for fully tidal marshes including Triangle, Cogswell and the HARD marsh (see Chapter 7). It also includes the levee along Depot Road, inboard of Hayward Wastewater Treatment Plant's out-of-service oxidation ponds and sludge drying beds, the inboard levee along Hayward Marsh, and the levee along the south side of Sulphur Creek.

With 16 inches of sea level rise at high tide, 10% of system #23 will be overtopped by 2 feet on average. During a storm event 30% of the system will be overtopped by 2 feet, and if there are wind waves almost the entire length of the system, 98%, will be overtopped by 3.5 feet (Table 1 and 2). The majority of the overtopping during a storm event is along the engineered flood protection structures on Depot Road, and along the bayshore non-engineered berms that protect the marsh systems (Figure 15).

Figure 15. With 16 inches of sea level rise, 30% of system #23 will overtop with an average depth of 2 feet during a storm event (areas shown in blue). The overtopping is mostly along Depot Road adjacent to industrial and commercial businesses.

With 55 inches of sea level rise, 68% of system #23 will be overtopped by an average of depth 2 feet at high tide. The majority of this overtopping is along the engineered flood protection structures on Sulphur

Figure 16. With 55 inches of sea level rise, almost 70% of system #23 will overtop with an average depth of 2 feet (area in dark blue). The majority of overtopping will occur along Sulphur Creek and Depot Road levees, and along the Bayshore non-engineered earth berms.

Creek and Depot Road, and along the bayshore non-engineered berms that protect the managed and fully tidal marsh systems (Figure 16). During a storm event nearly the entire system will be overtopped whether or not there are wind waves. The average depth of overtopping will, however, increase from 3.5 feet during a storm event to 7 feet during a storm with wind waves (Table 2).

The engineered flood protection structures along Suphur Creek and Depot Road may be sensitive to overtopping and erosion depending on their design and condition. In addition, the areas they protect include natural resource such as tidal and managed marshes, recreational access areas, and utility infrastructure. The opportunities to modify or improve the engineered flood protection systems to accommodate higher bay water levels, currents and waves may be limited by existing or potentially competing uses. The consequence of a failure of the Depot Road levee would be considerable as this segment of shoreline protects the Hayward wastewater treatment plant, and there is significant wastewater conveyance infrastructure owned by the East Bay Dischargers Authority (EBDA) between the out-of-service oxidation ponds and Depot Road.

The levees within the Hayward Regional Shoreline are maintained by East Bay Regional Parks are already affected by storm events. Not only are they sensitive to storm events, they have limited adaptive capacity as there are not enough resources to keep them maintained and there are limited opportunities as well as regulatory hurdles to making necessary improvements.

In addition to engineered flood protection structures, this area also includes a significant amount of non-engineered earth berms and some wetlands (e.g., Cogswell Marsh). Non-engineered berms, due to their design and construction, are sensitive to sea level rise and storm events and typically have limited capacity to be improved or modified. Non-engineered earth berms protect Hayward Marsh, a unique managed fresh and brackish marsh system that receives secondarily treated wastewater from Union Sanitary District. These berms are sensitive and have minimal adaptive capacity. Overtopping would lead to the degradation of these berms, compromising the function of the marsh. The failure of this portion of the shoreline would have significant economic and environmental consequences, and would require multi-jurisdictional, multi-agency coordination and collaboration that could be very challenging.

Consequences

Consequences are the magnitude of the economic, social, environmental, and governance effects if an impact occurs. Factors that inform magnitude include the severity of the impact on the asset 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 structural and non-structural shorelines will both be significant to the shoreline asset, and to the inland areas protected by that asset. The potential consequences on the aforementioned shoreline types are discussed below, the larger consequences to inland areas, including communities, facilities and services, are discussed elsewhere in this report.

Economy
There are significant costs associated with maintaining or improving structural shoreline assets. The repair and replacement of structural shorelines, where feasible, will require funding for design, permitting, materials, construction, and on-going maintenance. These costs will vary with the type and location of the asset, and access to adequate financing could be difficult for many of the public and private entities that own and maintain these shorelines.

Society
If the shoreline structures that protect inland areas from inundation erode, overtop, or fail, there will be significant consequences for communities, facilities and services. The consequences of the shoreline failing to protect inland assets are discussed in other chapters of this report, and are considered in the discussion of communities, facilities and services.

Environment
Natural non-wetland shorelines (beaches) and non-engineered berms offer both direct and indirect environmental value in promoting or supporting subtidal (e.g., eelgrass beds) and sandy beach habitat. These areas are also often the first line of defense against tides, currents and wind and wave erosion. The degradation and loss of these types of shorelines would threaten the species that rely on beaches and wetlands.

Governance
Shoreline assets in the ART project area are owned, maintained, financed and regulated by a complex system of public and private entities, including some of the following local, regional, state and federal agencies:

- Port of Oakland (shoreline protecting Oakland International Airport and the Seaport)
- Alameda County Flood Control and Water Conservation District (ACFCWCD) (shoreline throughout the ART project area)
- California Department of Transportation (shoreline protecting transportation assets such as the San Francisco-East Bay Bridge)
- U.S. Army Corps of Engineers (shoreline around navigable waters)

Specifically, in the southern portion of the ART project area, much of the shoreline is owned and maintained by East Bay Regional Parks District, Hayward Area Recreation and Park District, ACFCWCD, and the California Department of Fish and Game. Shoreline assets may also require coordination with agencies such as, but not limited to:

- San Francisco Bay Conservation and Development Commission
- San Francisco Bay Regional Water Quality Control Board
- California State Lands Commission

- U.S. Fish and Wildlife Service
- National Oceanic and Atmospheric Administration National Marine Fisheries Service

This complex mixture of ownership and regulatory authorities presents challenges in the logistics of effective and timely management of these assets in the face of climate change.

Key Findings

The representative shoreline areas illustrate the vulnerability and risk of not only the shoreline structures, but also the inland areas they protect. Much of the shoreline in the ART project area will overtop with 16 inches of sea level rise during a storm event, especially if coupled with wind waves. With 55 inches of sea level rise during a storm event the majority of the shoreline will overtop even in the absence of wind waves. The different structural shoreline categories have different sensitivities to sea level rise and storm events. For example:

- Engineered flood protection structures that are overtopped could suffer erosion of the crest and backside of levees and flood walls, thus weakening the structures and increasing the potential for failure.
- Engineered shoreline protection structures could be weakened, mobilizing the armor layer, eroding the foundation, and undermining the toe protection, thus decreasing the stability of the structure and increasing the potential for failure.
- Non-engineered berms are particularly sensitive to erosion and, given their non-engineered nature, have a limited range of possible height or stability improvements.

The adaptive capacity of these shorelines will vary depending on the type, design, location and ongoing operation and maintenance regime. Structures that have space to expand and be improved, have dedicated funding and are already maintained proactively, have the highest adaptive capacity. Natural non-wetland shorelines (beaches) that are not already self-sustaining have low adaptive capacity.

There are both direct and indirect consequences of sea level rise and storm event impacts on these shorelines. The direct impacts include the economic costs associated with maintaining or improving structural or non-structural shoreline assets. In addition, there are governance challenges in financing and coordinating maintenance or improvements since shorelines are owned, maintained, and regulated by private individuals and organizations as well as local, regional, state and federal agencies. The indirect impacts include the potential damages and loss of the communities, facilities and services that these shorelines protect. These consequences are detailed in the assessment of shoreline communities and assets elsewhere in this report.

References

Adapting to Rising Tides: Transportation Vulnerability and Risk Assessment Pilot Project. November 2011. Prepared by AECOM and Arcadis for the San Francisco Bay Conservation and Development Commission, Metropolitan Transportation Commission and the California Department of Transportation. Available at http://www.mtc.ca.gov/news/current_topics/10-11/sea_level_rise.htm.