Oakland/Alameda Resilience Study

August 2016

Adapting to Rising Tides Program Introduction and Overview

In 2011, the San Francisco Bay Conservation and Development Commission (BCDC) and NOAA's Office for Coastal Management (NOAA OCM) brought together local, regional, state and federal agencies and organizations, as well as non-profit and private associations for a collaborative planning project along the Alameda County shoreline to identify how current and future flooding will affect communities, infrastructure, ecosystems and economy.

Since then, the ART Program has continued to both lead and support multi-sector, cross-jurisdictional projects that build local and regional capacity in the San Francisco Bay Area to plan for and implement adaptation responses. These efforts have enabled the ART Program to test and refine an adaptation planning method (ART Approach) that builds a process with the following characteristics:

- Collaborative by Design. Climate change, similar to hazard planning, requires planning across jurisdictions, geographies, sectors, and time frames to address complex, cross-cutting issues. ART emphasizes convening and closely collaborating throughout a planning process with a stakeholder working group representing the diverse values, viewpoints and responsibilities relevant to the project, to build relationships that lead to future collaborations.

- A Transparent Process. To build a strong, actionable case for adaptation, the ART approach adheres to transparent decision-making throughout the planning process. ART Design Your Project guidance and supplies help maintain transparency and support clear communication to stakeholders about decisions and project outcomes, including resilience goals developed and agreed upon by the working group, and evaluation criteria that clearly reflect priorities and objectives.

- Sustainability from Start to Finish. A core aspect of ART is consideration of the relevance and implications of all aspects of sustainability in each step of the planning process, from who is included in the initial working group list to what evaluation criteria are selected to evaluate adaptation responses. ART uses four sustainability frames:

Sustainability From Start To Finish

A Core Component of ART is consideration of the relevance and implications of all aspects of sustainability throughout a project. Four Sustainability frames are incorporated into each step of the planning process, beginning with the development of the initial working group list, all the way to the selection of criteria to evaluate adaptation responses. ART frames these components of sustainability as:

SOCIETY AND EQUITY

Effects on communities and services on which they rely, with specific attention to disproportionate impacts due to inequalities.

ECONOMY

Economic values that may be affected such as costs of physical and infrastructure damages or lost revenues during periods of recovery

ENVIRONMENT

Environmental values that may be affected, including ecosystem functions and services, and species biodiversity.

GOVERNANCE

Factors such as organizational structure, ownership, management responsibilities, jurisdiction, mandates, and mechanisms of participation that affect vulnerability to impacts.

Throughout the region, the ART Program is integrating adaptation into local and regional planning and decision-making in multiple ways:

- **Leading collaborative adaptation planning projects** that build a comprehensive understanding of climate vulnerability and risk, develop effective and equitable adaptation responses, identify opportunities for implementing these responses and build capacity across the region to increase resilience.
- **Assisting adaptation planning efforts** with consistent staff support that includes recommendations, tools and approaches for selecting climate impact scenarios, tools, approaches and data to identify vulnerabilities and consequences, assist with selecting adaptation responses through the use of evaluation criteria and help with process and meeting design, review of work products and more.
- **Providing the ART Portfolio** which combines a comprehensive set of online resources, including how-to guides, tools and findings, with Help Desk support from experienced ART Program staff to enable users to make use of Portfolio resources to efficiently and effectively assess and plan for climate impacts.
- **Building regional capacity for adaptation** by working with local, regional, state and federal agencies to find funding, and develop capacity and support at all scales for this work.
- **Advocating for adaptation** through communicating findings, issues, processes and needs to state and federal agencies to ensure that grant and other assistance programs are informed by and responsive to conditions in the Bay Area.

Figure 1: This is an example of a graphic used by ART Program staff in an engagement exercise with a stakeholder working group to explore functional and physical linkages among community assets and services, built infrastructure and natural shorelines that contribute to their climate vulnerability.

ART in Alameda County

In 2011, the Adapting to Rising Tides Alameda County Project assessed sea level rise vulnerability and consequences across the Alameda County shoreline from Emeryville to Union City. The ART Alameda Project analyzed assets in twelve sectors: airport, community land use, contaminated lands, energy, infrastructure, pipelines and telecommunications, ground transportation, hazardous materials, nonstructural shorelines/natural areas, parks and recreation, seaport, stormwater, structural shorelines and wastewater. The impacts of sea level rise and storm events on these asset categories were evaluated, and the climate vulnerability and risk of representative and specific assets were determined. The ART Project staff and working group used the vulnerability and consequence assessment to identify key issues and develop adaptation responses and implementation options to improve the project area's climate resilience.

Adaptation responses were developed for specific assets, asset categories, and jurisdictions and at all assessment scales- with responses from asset scale to federal scale. Additionally, the ART Alameda Project identified five key issues that were critical to the region and needed further assessment. These five issues, also called overarching vulnerabilities because it was determined that they applied to the region and not just the study area and they needed to be addressed at a broader than local scale, were:

- **Certain Land Uses**
  Certain types of land uses are particularly vulnerable because of the specific functions they serve, and because they are difficult to protect, evacuate, or rebuild. If these land uses are damaged or their function is disrupted there can be significant consequences on public health and safety. Many of the plans, policies and practices that guide land use and capital investments do not consider sea level rise or storm events, and action at the local, regional, state and federal levels will be necessary to ensure that as the region grows that these land uses, and the people who rely on them, are not put at risk.
- **Population Characteristics**
  There are particular characteristics that can make individual members of a community, or a community as a whole, especially vulnerable to sea level rise and storm events. These include lacking the financial means, the physical capacity, necessary information, or access to services to prepare for and respond to flooding or other hazards. Past disasters have demonstrated the consequences on public health and safety, as well as the local and regional economy, of not factoring specific community characteristics and needs into emergency and land use planning and policy making.
- **Networked Infrastructure**
  Networked infrastructure that is connected as a continuous corridor or as a series of contiguous segments is particularly susceptible to disruption because it is generally only as resilient as its weakest link. Disruptions to one segment can cause cascading secondary impacts in adjoining segments or even farther away, resulting in a system-wide failure. This is especially true for long and linear ground transportation assets in the ART Alameda project area such as the Bay Trail and the regional rail system, as well as the utility infrastructure and the system of shoreline protection along the Bay's edge. Disruption of networked infrastructure can cause widespread economic and community consequences. The people and property that are protected by, or rely on these systems should be included in planning and funding decisions regarding maintenance, repair or upgrade.
- **Information Gaps**
  There were significant gaps in the quality and availability of information needed to understand the social and physical dimensions of vulnerability and risk for every asset category assessed. For example, there is a growing but still very limited understanding of how natural, dynamic shoreline systems will respond to sea level rise, a lack of centrally coordinated, up-to-date, accurate information about hazardous material sites and contaminated lands, and limited access and availability of information on the ownership, location and condition of energy, pipeline, telecommunication, and stormwater infrastructure. These information challenges make it difficult to accurately characterize the vulnerability of shoreline communities and assets, and pose a barrier to further action.
- **Emergency Preparedness and Response**
  Emergency plans, policies and practices in the ART Alameda project area and elsewhere do not consider storm events that could affect areas not currently at risk of flooding, or the contingencies and secondary impacts associated with widespread or longer lasting future storm events. Most

plans do not identify or address the specific needs of particularly vulnerable community members, and the information necessary to improve these plans is not always available, correct, up-to-date, or easily accessible. In addition, those that own or manage community assets, such as transportation and utility infrastructure that are critical during an emergency or disaster, do not have control over the lands that provide access to their facilities or the shoreline that protects them. Targeted information gathering and coordinated and, in some cases, shared decision making will all be necessary to avoid the widespread consequences of not addressing the future flood risks.

These findings led us directly to the future projects that we determined the program would focus on, including the Oakland/Alameda Resilience Study, which includes all of the vulnerabilities and consequences described above.

Oakland/Alameda Resilience Study

Working Group Members

Alameda County Flood Control and Water Conservation District
Association of Bay Area Governments
Bay Area Rapid Transit
Bay Farm Island Homeowners Association
Bay Trail
Caltrans
California Coastal Conservancy
Capitol Corridor Passenger Rail
City of Alameda-Public Works
City of Oakland-Fire Department Emergency Planning
City of Oakland-Planning
City of Oakland-Sustainability
East Bay Municipal Utilities District
East Bay Regional Park District
Federal Emergency Management Administration
Metropolitan Transportation Commission
Pacific Gas and Electric
Port of Oakland

Focus on Oakland/Alameda

At the conclusion of the ART Alameda Project, the ART team and working group members recognized the need for more detailed assessments and plans for the transportation, parks, vulnerable populations and housing sectors as well as for particular geographic areas. This finding led to projects analyzing the geographic areas along the Hayward Shoreline, the Bay Bridge touchdown in the East Bay and the Oakland/Alameda Study Area and sectors and issues such as housing, transportation, parks and recreation and vulnerable populations. The Oakland/Alameda study area (Figure 2) was selected for further investigation because of its critical transportation assets, the types of land uses present, including residential development and the Oakland International Airport, the community's characteristics, the role and need for emergency services in the study area which is essentially an island, and the significant current and future flood risk. The study area is all of Bay Farm Island, including portions of the City of Alameda and the Port of Oakland, as well as the Coliseum area and its adjacent neighborhoods in Oakland. The study area contains the Coliseum BART station and tracks, the Coliseum Amtrak station and Union Pacific Railroad tracks, Interstate 880, the Coliseum complex, Oakland International Airport, Martin Luther King Jr. Regional Shoreline, utilities and infrastructure, and many community land uses including housing, schools and fire stations.

Figure 2: Oakland/Alameda Study Area

The Oakland/ Alameda Resilience Study Overview

The Oakland/Alameda Resilience Study built its assessment on findings from the ART Alameda Project, ABAG's Resilience Program, the ART Program transportation assessments conducted in partnership with the Metropolitan Transportation Commission (MTC), Caltrans and Bay Area Rapid Transit (BART)[i], and the ART/ABAG Stronger Housing, Safer Communities Project. These projects provided hazard data, assessment methodologies, and preliminary vulnerability findings. In addition, partners and stakeholders from the ART Alameda Project continued their participation in the Oakland/Alameda Resilience Study. The working group for the study consisted of local governments, park and recreation staff, utility agencies, the Port of Oakland, community representatives and regional, state and federal agencies. These working group members provided information for the assessment, refined the assessment outcomes, attended field trips and work sessions, and communicated study findings to their home agencies. Their participation in the study was and continues to be critical to the success of the study.

The ART Program used the Oakland/Alameda Resilience Study to further evaluate several issues that were identified as overarching issues in the ART Alameda Project, such as certain land uses, community characteristics, networked infrastructure and emergency response. Additionally, the study is the first project that ABAG and the ART Program evaluated and developed responses for both flooding and seismic hazards together, identifying approaches and methods for combining this work. The study also provided the ART Program with an opportunity to evaluate current and future flood risk from multiple sources, including coastal, watershed, flood control channels, stormwater systems and groundwater rise. The findings from the study area verified how important it is to evaluate these hazards together and that the risks, consequences and potential adaptation options can change dramatically when the flooding from multiple sources is analyzed. The work in the study area has identified a need to conduct this kind of work around the region and provides a replicable process that can be used in other communities.

Phase I: Scope, Organize, Assess and Define

Vulnerability and Risk Assessment Findings

The Oakland/Alameda Resilience Study began by scoping the project area, developing a work plan and a working group and stakeholder list, and gathering existing research. The kickoff working group meeting was held in November 2013. Following the ART Planning Process (Figure 3), ART staff and the working group determined the scope of the study including its geographic boundaries, sectors and assets to include, and stakeholders to invite. The working group also developed resilience goals, shown in Figure 4, which include aspects of the economy, the environment, society and equity, and governance.

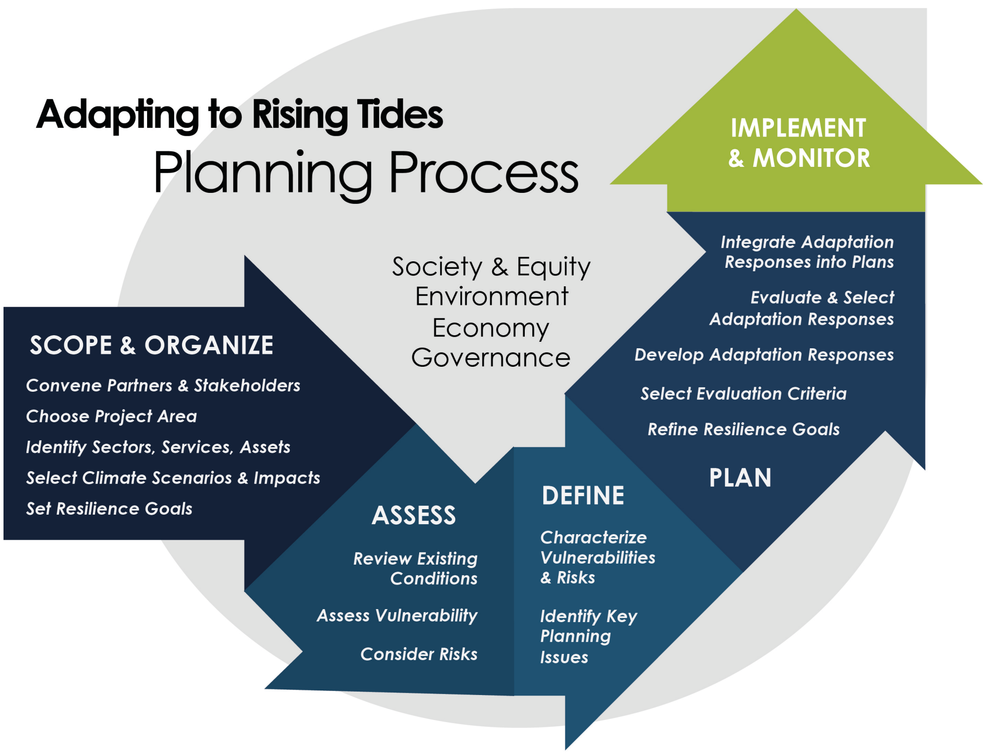


Figure 3. ART Planning Process

Oakland/Alameda Resilience Study

Project goals and objectives

- Demonstrate the benefits of multi-objective shoreline resilience planning that considers multiple hazards and sectors
- Identify shared elements of earthquake risk mitigation and sea level rise adaptation planning
- Consider vulnerabilities caused by dependencies and interdependencies
- Create partnerships with diverse stakeholders actively engage them in planning for multiple hazards with in the focus area

Figure 4. Working Group Resilience Goals and Objectives

This chapter completes section two of the ART Process, the vulnerability and risk assessment; it includes the vulnerability and risk assessment findings at the asset and study area scale. The following sections contain exposure information for coastal and fluvial flooding, as well as seismic risk. This exposure information, in conjunction with assessment findings about specific assets and land uses, provides the background information for identifying the vulnerabilities and developing the asset profile sheets found in Appendix A. At the conclusion of the assessment, ART Program staff and the working group developed six key planning issues for the study area.

Climate and Hazard Impacts and Scenarios

During the ART Alameda Project, the ART Program team began to work much more closely with the ABAG Resilience Program. Working group members wanted to ensure that the assessment considered current and future flood risk and seismic hazards together and would result in adaptation strategies that addressed both hazards. Based on this, the ART Program teamed up with ABAG's Resilience Program[ii]. By considering multiple hazards, this study identifies efficiencies, for example where data and information necessary to understand one hazard can inform another, and this approach simplifies and streamlines the planning process for stakeholders by seeking their participation in a single project that addresses multiple hazards. An integrated planning process also provides important insights into how adaptation and risk mitigation strategies for one hazard may be modified to address another, and may uncover where an action to mitigate one hazard could exacerbate the risk from a different hazard.

As part of the ART Transportation study[iii], exposure analysis for current and future flooding was conducted for Bay Farm Island, the Oakland Coliseum area and surrounding neighborhoods[iv]. This analysis considered six water levels for coastal flooding: 12", 24", 36", 48", 72", and 96". These water levels represent many possible combinations of astronomical and storm tides as well as future sea level rise. Using this total water level approach, as opposed to specific climate scenarios, allows for the analysis of intermittent and permanent flooding as well as multiple sea level rise projections. For example, the 36" water level, highlighted in green in Table 1, could be seen today given a 50-year (2% chance) water level. Thirty-six inches is also the State of California's predicted most-likely sea level rise estimate for 2100. Using a single water level and map to envision both storm event (temporary) and sea level rise (permanent) flooding helps property owners understand what their thresholds are for vulnerability. Different assets may have different vulnerabilities for the same flood threshold, e.g., a park may be resilient to temporary and intermittent flooding; after a short closure and cleanup, the park and trail could return to their full function. On the other hand, the Oakland airport terminals or a senior care facility would be severely damaged by even short-duration flooding and their repair would be costly and time-consuming. The vulnerability and risk assessment considered exposure to flooding and seismic hazards as well as the unique characteristics of assets and sectors that make them more or less vulnerable to hazards.

Sea Level Rise Scenario	**Daily Tide** ***Permanent Inundation***	**Extreme Tide (Storm Surge)** ***Temporary Flooding***						
	+SLR	**1-yr**	**2-yr**	**5-yr**	**10-yr**	**25-yr**	**50-yr**	**100-yr**
	Water Level above MHHW (in)							
Existing Conditions	0	14	19	23	27	32	36	41
MHHW + 6 inch	6	20	25	29	33	38	42	47
MHHW +12 inch	12	26	31	35	39	44	48	53
MHHW +18 inch	18	32	37	41	45	50	54	59
MHHW +24 inch	24	38	43	47	51	56	60	65
MHHW +30 inch	30	44	49	53	57	62	66	71
MHHW +36 inch	36	50	55	59	63	68	72	77
MHHW +42 inch	42	56	61	65	69	74	78	83
MHHW +48 inch	48	62	67	71	75	80	84	89
MHHW +54 inch	54	68	73	77	81	86	90	95
MHHW +60 inch	60	74	79	83	87	92	96	101
HYDRODYNAMIC ZONE 2								

Table 1. Sea Level Rise and Extreme Tide Matrix[v]

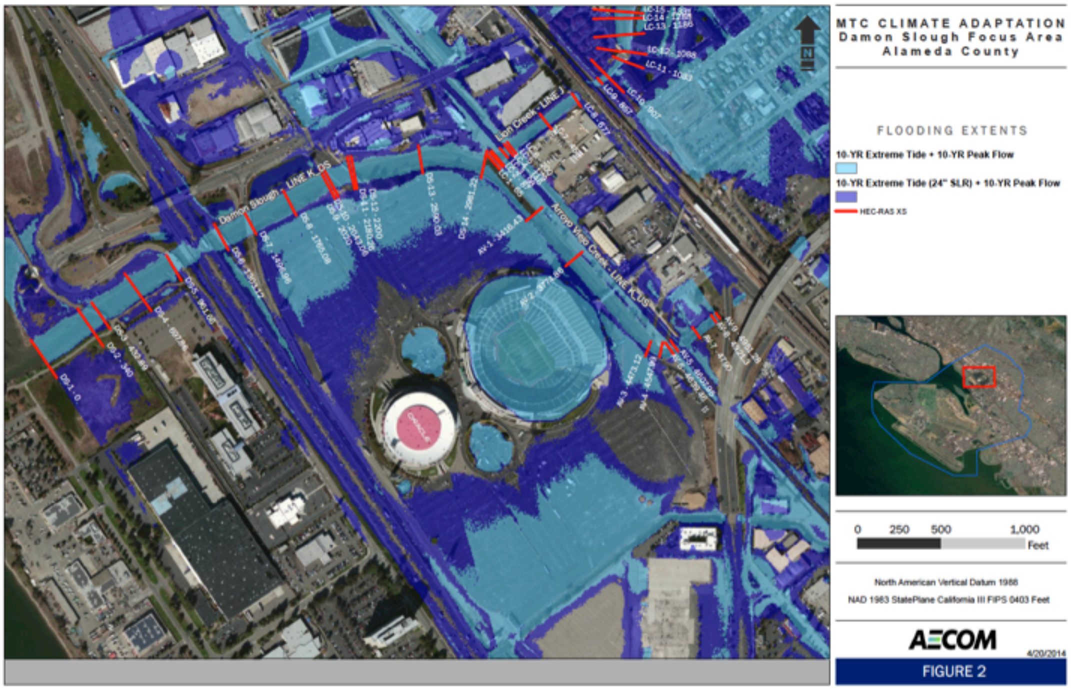


Figure 5 Flooding with a 10-year tide and a 10-year riverine flow

Exposure findings in this study differ from other ART Program projects in two ways:

1. Near the Oakland Coliseum, riverine flooding and coastal flooding interact and create much more severe storm event flood risk for the present day and the future. As part of the ART Transportation study, this relationship between riverine and coastal flooding was modeled in Damon Slough. Figure 5 shows flooding in the Coliseum area with a 10-year tide and a 10-year riverine flow. Modeling the joint probability of riverine and coastal flood events helps asset managers understand the kinds of events they may be vulnerable to and makes it possible to better identify what should be included as an adaptation response for the area. In Damon Slough, most current flood risk is driven by rain events in the large watersheds that drain through the Coliseum Area and the surrounding neighborhoods. This means some of the flood risk adaptation measures may need to be implemented in the upper watershed as well and that solutions that only include on-site or coastal strategies will likely not successfully address the issue.
2. This area has extensive seismic risk areas and this resilience study analyzed both flood and earthquake hazard zones. Evaluating flood and seismic risk together is especially important in Bay fill areas, which tend to be both low-lying and at risk of liquefaction due to their construction methods. Figure 6 shows the significant portions of Bay Farm Island and the Oakland Coliseum area constructed on fill over Bay mud and at high risk of liquefaction.

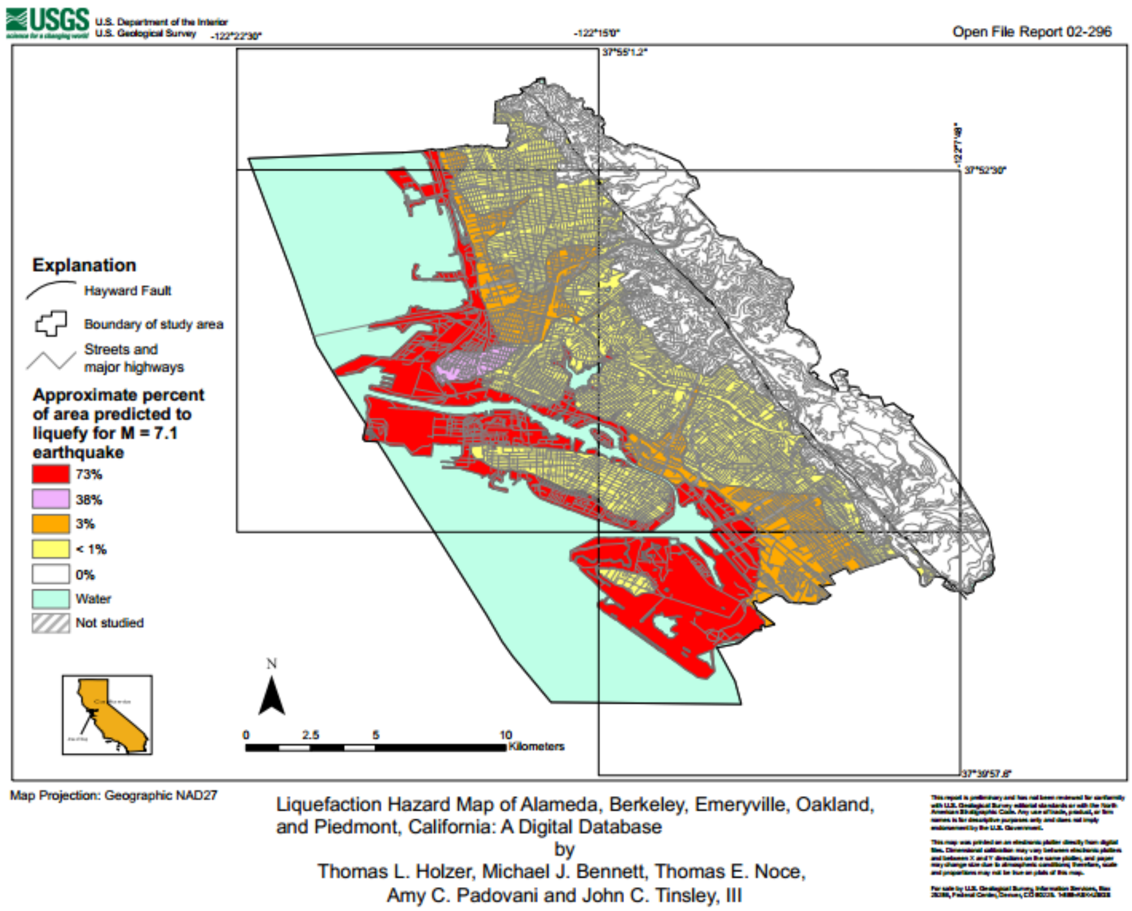


Figure 6. Liquefaction Hazard Map of Alameda, Berkeley, Emeryville, Oakland, and Piedmont, California

Potential Earthquake Impacts

There are three impacts associated with earthquakes that were considered in this study:

- **Ground shaking**

  Ground shaking occurs in all earthquakes. In large magnitude earthquakes a larger area of ground shakes, it also shakes harder longer than in small magnitude earthquakes. Earthquakes are typically measured by two metrics: moment magnitude (MW) and Modified Mercalli Intensity (MMI)[vi]. MW is a measure of the energy released. It is a function of the ruptured fault area and the geologic conditions of the fault. MMI measures earthquakes by the effects experienced at a specific site. The intensity changes based on the magnitude of the earthquake, the distance from the fault to the site, the directivity of the fault rupture, and the type of geologic material underlying the fault (e.g., softer soils amplify ground shaking and can cause greater damage).

  Ground shaking of the level expected across the focus area may cause wood-frame buildings to shift off of their foundations if not bolted. Shaking may damage older, non-retrofitted buildings, including air control and terminal facilities at the airport, and will likely break underground pipes and damage overhead power lines. Ground cracks may appear, causing damage to airport runways, roads, or buried utilities.

- **Liquefaction**
  Saturated soils that are loose or sandy will exhibit the characteristics of a liquid when shaken long and hard enough. Liquefaction may result in ground sinking or pulling apart, ground displacement, or ground failure such as lateral spreads and sand boils, or sand "volcanoes." Much of the focus area is vulnerable to liquefaction. Liquefaction is a significant threat for underground pipelines, airport runways, and road or highway surfaces, as it causes buckling of these features due to ground shifting. Liquefaction may also cause building damage due to foundation movement or cracking when the underlying soils shift, or when there is a loss of bearing capacity for foundation elements. Liquefaction can cause levee damage and failure, increasing the risk of flooding in low-lying areas.
- **Tsunamis**
  Tsunami waves are the result of large underwater displacements from offshore earthquake fault rupture or landslides. Tsunamis can be caused by offshore earthquakes within the Bay Area or even distant events. The focus area falls within the maximum tsunami run-up inundation line; however, tsunamis are considered rare events in the Bay Area, so the probability of inundation due to a tsunami is low.

Earthquake Scenarios

Earthquake scenarios are often developed by agencies such as ABAG and USGS to describe the most likely maximum probable earthquake from a given fault within that fault's return period. Using earthquake scenarios is useful for planning and design purposes as it can provide a likely picture of discrete events. This is helpful when studying impacts at a community level. Although there are over 15 faults within the Bay Area likely to produce a damaging earthquake, there are two major earthquake scenarios that would be most likely to heavily affect the Oakland/Alameda Resilience Study area. A major earthquake (MW 6.9) on the Hayward Fault or a major earthquake (MW 7.8) on the San Andreas Fault (a repeat of the 1906 earthquake) would both cause violent (MMI IX[vii]) ground shaking in the study area.[viii]

An earthquake along the Hayward Fault is the most probable scenario, as there is a 31% probability of a 6.7 or greater earthquake before 2036, while the San Andreas Fault has a 21% probability of an earthquake of the same magnitude in this timeframe.[ix] The likelihood of an earthquake on the Hayward Fault is greater, and the study area is in closer proximity to the Hayward Fault implying that there would be greater levels of ground shaking from this scenario. However, an earthquake on the San Andreas Fault could have equally or more devastating consequences. This is because a greater length of the San Andreas Fault is expected to rupture than along the Hayward Fault so that an earthquake along the San Andreas Fault could result in a larger magnitude event (harder and longer ground shaking). Because the San Andreas Fault is a greater distance from the study area, attenuation would cause the level of ground shaking to be similar in both scenarios; however the longer period of ground shaking in a San Andreas event could increase the potential for building damage and soil liquefaction.

The geologic conditions are such that shaking amplification from a major earthquake on either fault will be extremely high. Because of the study area's relatively close proximity to both major faults, and the likely epicenter of an earthquake on either of these faults, it will experience amplified and prolonged ground shaking as compared to other locations.

A major earthquake is also highly likely to produce liquefaction in the study area. USGS has developed maps that predict the percentage of certain areas that are likely to liquefy in a M=7.1 earthquake (see Figure 6).[x] Historic Bay Farm Island is composed of dense Merritt Sand, which forms a zone that has a very low liquefaction risk (<1% of the original island is predicted to liquefy in a M 7.1 earthquake). However, the rest of the Study Area is composed of soils that have a much higher liquefaction potential. These maps show that the majority of the study area aside from historic Bay Farm Island is in the highest liquefaction hazard zone (approximately 73% of the area is predicted to liquefy in a M=7.1 earthquake). The airport itself is built entirely on fill over estuarine deposits, including a formal tidal marsh, tidal flat, and shallow bay environments. The northeastern portion of the airport is located on formal tidal marsh with deltaic and stream channel deposits and marsh deposits, and the southwestern portion is built on fill over tidal flats and shallow bay. These geologic conditions contribute greatly to the airport's liquefaction susceptibility.

Sea Level Rise and Flooding Impacts and Scenarios

Coastal flooding between 12 and 36 inches above MHHW is flooding that could occur now with storm event extreme tides. Within the study area, the Bay Farm Island area in particular is vulnerable to coastal overtopping with just 36 inches of water over MHHW. This water level could occur with a 50-year water event (2 percent annual chance) or with projected 2100 sea level rise. The water overtops in four low spots, A, C, D, and E, shown in Figure 7. Flooding from these isolated low points would affect Doolittle Drive, North Field at the Oakland International Airport, and recreation, habitat and native species in Martin Luther King Jr. Regional Shoreline, shown in Figure 8. Even as water levels increase to MHHW+72", flooding on Bay Farm Island is primarily caused by low spots on the northeast shoreline. In Figure 9, the red and pink segments, show high overtopping potential. Overtopping of shoreline protection on Bay Farm Island causes widespread and deep flooding because of the island's low and flat topography. New vulnerabilities emerge as water levels rise due to storm events and sea level rise. For the complete exposure analysis and inundation mapping, see Appendix B.

Figure 7. Doolittle Drive low spots

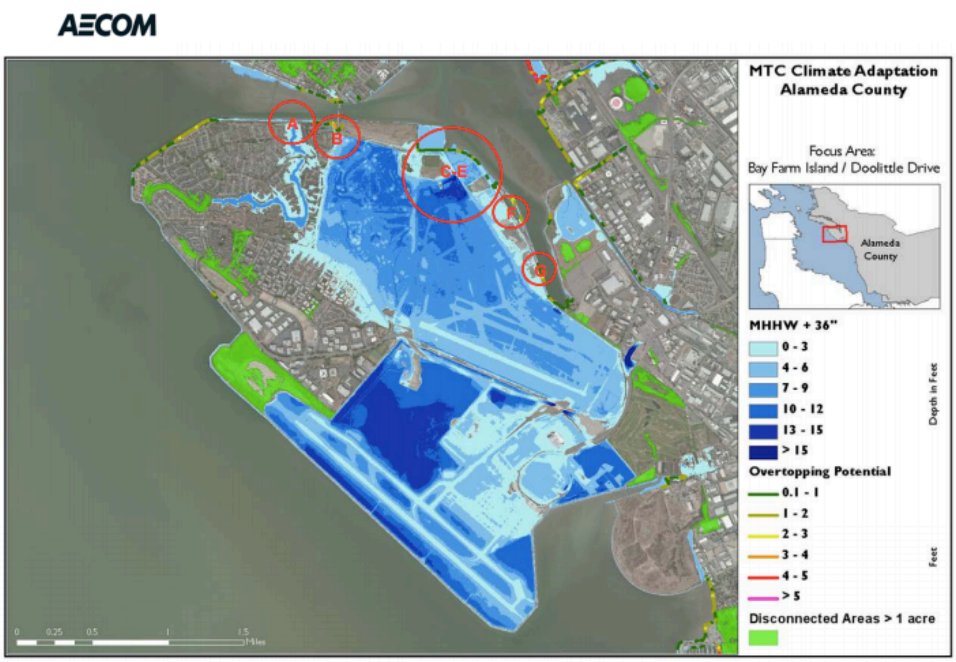


Figure 8. Updated Inundation and Flooding Analysis Using the Modified DEM.

Note: System-wide inundation of Bay Farm island is expected at 36inches of SLR. The tide gate wing-wall (Site A), the Harbor Bay Club shoreline (Site B), and sites along Doolittle Drive (Sites C-G) are the critical inundation pathways in this scenario.

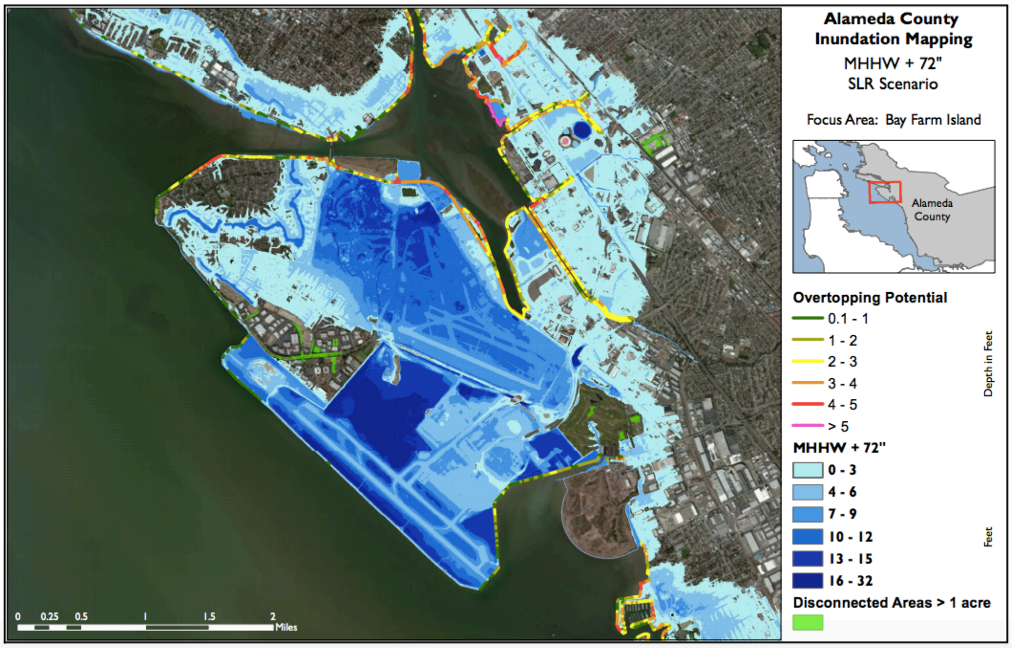
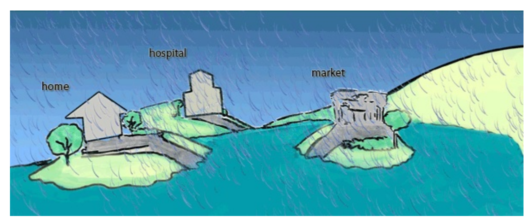


Figure 9. Alameda County Inundation Mapping

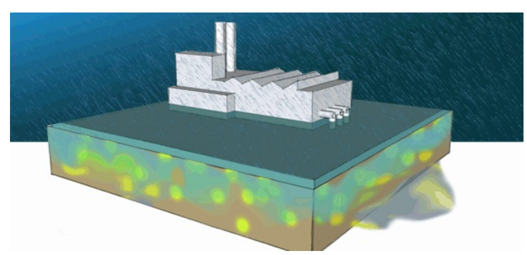
Once the refined exposure analysis was completed, the project team and the working group evaluated the assets that were exposed to one of the selected climate impacts and seismic impacts. The climate and hazard impact scenarios were presented to the working group and the following were used for the study:

1. More frequent floods



Extreme high Bay water levels will occur more often, leading to more frequent flooding in flood-prone areas that could disrupt access to power, goods and services, jobs, and emergency response and recovery resources.

2. More extensive, longer-duration flooding



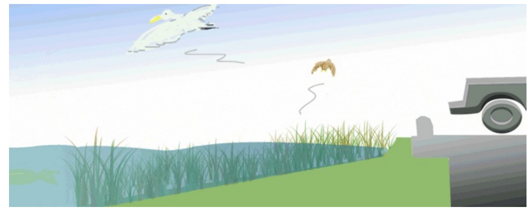
Higher Bay water levels especially during storm events will flood larger areas for longer periods of time. Along with many other potential impacts, this may result in the increased mobilization of pollutants if contaminated lands such as closed landfills are subjected to prolonged inundation.

Other potential consequences of flooding include:

- Increased cost to repair and maintain flood protection channels and storm drains that are overwhelmed during flood events
- Overwhelmed wastewater and stormwater treatment systems harming water quality, and environmental and public health
- Changes to sediment transport and deposition that affect the ability of tidal wetlands to keep up with sea level rise
- Lost wages and lower productivity during recovery, and disproportionate burden on individuals,

households and neighborhoods with certain characteristics (e.g., income, housing tenure, age, ethnicity).

3. Permanent inundation



Sea level rise will cause areas not currently exposed to the tide to be inundated, resulting in the loss of trails, beaches, vistas, and other shoreline recreation areas, and the need to either protect or move people and infrastructure.

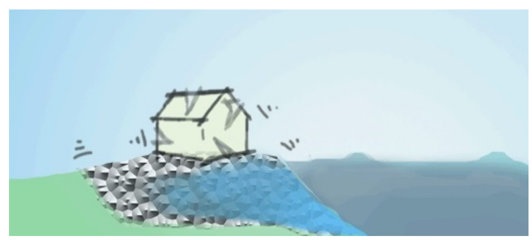
4. Shoreline erosion and overtopping

Higher water levels will cause changes in tidal and wave energy, leading to increased shoreline erosion and the potential for shoreline protection, such as levees, berms and revetments to be damaged or fail. There is also the potential that shoreline protection will be overtopped during storm events when there are extreme tides levels and wind-driven waves, flooding inland areas that are currently protected.

Other potential consequences of inundation, shoreline erosion and overtopping include:

- Damage to shoreline protection structures creating the need for more frequent replacement, repair and/or maintenance
- Disproportionate burdens on community members with certain characteristics (e.g., low income renters and homeowners) caused by repair, retrofits or relocation, and higher insurance, goods, and services costs
- Loss of tidal wetlands that cannot keep up or migrate inland and reduced ecosystem service benefits (water quality, habitat, flood risk reduction)

5. Elevated groundwater and increased salinity intrusion



As the sea level rises, groundwater levels and salinity intrusion will increase, affecting water supplies along the shoreline, damaging below or at-grade infrastructure, requiring additional pumping and costly maintenance and repairs of stormwater and flood control facilities, and increasing the risk of earthquake-induced liquefaction.

Other potential consequences of elevated groundwater and increased salinity intrusion include:

- Damage to below grade living spaces, finished basements, and below-grade electrical or mechanical equipment
- Mobilization of contaminants at contaminated sites, including those that have already been remediated or closed.

Assessment of Vulnerability and Consequence

After scoping the study, convening the working group and conducting the exposure analysis described above, ART Program staff began the vulnerability and risk assessment for 27 assets and five sectors in the study area. This assessment included the flood and seismic exposure mapping described above, the climate

Types of Vulnerability: Interstate 880 Example

Interstate 880 has governance, physical, and functional vulnerabilities in the study area. For governance, Caltrans does not own or maintain Damon Slough, but I-880 may be flooded at its crossing due to limited capacity within the flood channel. Physically, the roadway in this area is at-grade and exposed to current and future flooding. Functionally, I-880 is the primary goods movement corridor on the Alameda shoreline and there is insufficient capacity elsewhere in the transportation network to reroute commuter and goods movement in the event of damage or disruption. Assessing the different components of vulnerability and risk helped ART Program staff and working group members understand how assets and sectors are vulnerable as well as what types of actions could mitigate their risks. For the Interstate 880 example, Caltrans may not be able to address its physical and functional vulnerabilities without improving the governance issues around flood control channels in this area. Three fire stations, eight Oakland airport facilities, seven roads, four transit assets, one wastewater facility, and four natural areas and recreation facilities were assessed at the asset-scale with site-specific information. Senior care facilities, medical facilities, schools, and housing and community members were assessed at the sector scale because the large number of assets in each sector made asset-specific assessment impractical and their vulnerabilities are similar across different sites and asset managers. See Table 2 for a complete list of assets and sectors considered in this study.

and hazard impacts, as well as assessment questions about specific assets and sectors within the project area. Refining these assessment findings included review of the findings by asset managers, owners, operators and topic area experts and working group meetings to discuss preliminary results.

The selection of assessment scale was determined by several factors, including the availability of data and information, the level of participation from asset managers and representatives, the similarity of the vulnerabilities and responses and/or the level of risk faced by the assets. The five sectors assessed at sector scale were schools, childcare facilities, senior care facilities, utilities and communities. The asset scale assessments were conducted for the Coliseum BART Station, specific fire stations and tank farms, specific segments of roadway and interstate, bridges, parks, the Bay Trail and specific airport assets. See Table 2 for a full list of Sectors and Assets. Once the sectors and assets were evaluated, the relationships between and among the assets were considered to determine the critical issues and vulnerabilities facing the study area.

Drawing on methods and materials from the ART Program[xi], the ABAG Resilience Program and information and data available about the specific assets and sectors in the study area and information from similar studies, project staff and the working group developed profile sheets for each asset and sector, which include asset descriptions, key issue statements, and classified vulnerabilities. These profile sheets identify governance, information, physical and functional vulnerabilities for each asset or sector.

In order to ensure that each asset was evaluated consistently and through the lens of the four sustainability frames, ART Program staff and working group members answered assessment questions for assets and sectors in the study area. These questions covered existing conditions and stressors, site-specific qualities that could make an asset or sector more vulnerable to flooding and seismic impacts, and dependencies between the asset and other services. Asset managers, owners, operators and other topic area experts were given the opportunity to review and revise the assessment responses. Working group members were instrumental in providing feedback at the assessment question and vulnerability development stage.

The next sections provide a summary of assessment findings by sector, as well as summaries of some of the bigger assets in the study area. The full suite of asset and sector profile sheets can be found in Appendix A.

Scale of assessment	Asset or Sector Name	Asset Owner
Sector	Schools	Alameda, Oakland, Private
	Childcare Facilities	Private
	Senior Care Facilities	Private
	Communities	Alameda, Oakland
Asset	Control Tower	Port of Oakland
	Fire Station #22	Port of Oakland
	Terminal 1	Port of Oakland
	Terminal 2	Port of Oakland
	Tank Farm	Port of Oakland
	North Field	Port of Oakland
	South Field	Port of Oakland
	Perimeter Dike	Port of Oakland
	98th Avenue	City of Oakland
	Airport Drive	City of Oakland
	Hegenberger Drive	City of Oakland
	San Leandro Street	City of Oakland
	Harbor Bay Parkway	City of Alameda
	Doolittle Drive	Caltrans
	Bay Farm Island Bridge	Caltrans
	Bay Farm Island Bike/Ped Bridge	Caltrans
	Coliseum Amtrak Station	Amtrak
	Coliseum BART Station	BART
	Oakland Airport Connector	BART
	Harbor Bay Ferry Terminal	WETA
	Otis Bridge	City of Alameda
	Fire Station #27	City of Oakland
	Fire Station #29	City of Oakland
	Pump Station G	EBMUD
	Bay Trail	EBRPD
	MLK Jr. Regional Shoreline	EBRPD
	Bay Farm Island Lagoon	City of Alameda/Bay Farm Island Homeowner's Association

Table 2. Oakland/Alameda Resilience Study Sectors and Assets

OAKLAND INTERNATIONAL AIRPORT

Oakland International Airport, a public airport located on Bay Farm Island, serves passenger airlines, cargo services, and general aviation. More than 10 million passengers travelled through the airport in 2014. North Field is used for general aviation. Facilities include two terminals, leased commercial facilities, fueling tanks, a control tower, Oakland Fire Station #22 and a perimeter dike. Oakland International Airport is owned and operated by the Port of Oakland with many commercial tenants including airlines and shipping companies.

Port of Oakland staff from the environmental and airport operations divisions participated in the working group and commented on assessment findings.

The airport is vulnerable to current and future flooding as well as liquefaction. Although the Port of Oakland has planned a seismic and flood risk reduction project for its Perimeter Dike, the airport is vulnerable to flooding through shoreline protection the Port neither owns nor maintains. Addressing this near term flood risk will require coordination with the City of Alameda, Caltrans and East Bay Regional Park District to improve the shoreline along Doolittle Drive. The airport is also subject to Federal Aviation Administration laws and policies, which can complicate adaptation efforts. The Oakland International Airport provides goods movement, commuter movement, and emergency response functions to the region and any damage or disruption at the airport would have widespread consequences.

GROUND TRANSPORTATION

Ground transportation in the study area includes Interstate 880, City of Oakland surface streets, and transit service provided by BART, Capitol Corridor JPA/Amtrak, AC Transit, the Oakland Airport Connector, and San Francisco Bay Ferry. Representatives from Caltrans, the City of Oakland, City of Alameda, BART, and Capitol Corridor JPA participated in the working group and contributed to the transportation assessment findings.

Transportation assets in the study area are exposed to both flooding and seismic risk. Roads and transit stations can be damaged and disrupted by temporary flood events and in many cases they rely on flood protection owned and managed by other agencies. In addition, any disruption in the transportation network affects other assets in the study area, which rely on access. Neighborhoods, community facilities and commercial facilities cannot function without safe ground transportation access.

Rail lines within and beyond the study area are vulnerable to sea level rise and storm events. In general, rail is highly sensitive to even small amounts of water on the tracks, and if a portion of track is damaged it often results in the closure of many miles of connected track. The region's capacity to withstand impacts to rail infrastructure is further hampered by the lack of redundant or alternative rail lines in the region. The Union Pacific Railroad in the project area carries both cargo and Amtrak passenger service, including the Capitol Corridor line serving Bay Area commuters. Disruption of the rail system would lead to an increase in the number of trucks needed to transport cargo and passenger vehicles needed for commuter movement, having negative and widespread effects on road congestion, air quality, and community noise and quality of life.

Roads in this area provide access to major local employment centers including the Port of Oakland Seaport and Oakland International Airport, and a connection for commuters between the East Bay and San Francisco Peninsula, and along the East Bay shoreline. Ground transportation disruption could have significant impact on worker access to local and regional jobs as well as regional, intra-state and inter-state goods movements.

NEIGHBORHOODS, COMMUNITY FACILITIES AND SERVICES

The Oakland/Alameda Resilience Study area includes neighborhoods within the City of Alameda and the City of Oakland and Alameda County With 36" of sea level rise, much of the eastern portion of Bay Farm Island may be flooded and there are inland areas of Oakland that may be flooded at 48", especially along I-880 near the Coliseum. However, there is minimal housing within the current 100-year floodplain. Because the profile area is less than 1.5 miles from the Hayward fault, the entire area is within a liquefaction hazard zone, meaning that the soil types are susceptible to liquefaction and the area is likely to be shaken long and hard enough to trigger liquefaction. Nearly all of the residential structures within the study area are less than 10 stories and unlikely to have foundations that are able to withstand liquefaction. In general, those that live in East Oakland are very low income, housing and transportation cost burdened, and transit dependent. There are also significant numbers of non-English speaking households. This combination of characteristics suggests that the established community in the profile area has limited ability or resources to invest in improving the housing they live in, and will either need to shelter in place or rely or public transportation to evacuate. These characteristics also mean that residents are more likely to be displaced if their homes are damaged, and may struggle to find affordable housing elsewhere. Conversely, the project's regional screening analysis did not identify a significant presence of community indicators for the residents living on Bay Farm Island, except that much of Bay Farm Island's community is housing cost burdened. Though its community members may not be transit dependent, only a few transportation assets serve the island, which may complicate evacuation and recovery. Representatives from the City of Oakland, the City of Alameda, and the Bay Farm Island Homeowner's Association participated in the working group and contributed to the assessment findings.

The study area contains 16 schools, 19 childcare facilities, and six senior care facilities. The schools are owned and managed by the Oakland Unified School District and the Alameda School District. The childcare and senior care facilities are privately owned and managed. These facilities were analyzed at the sector scale because of their similarities and large numbers. These facilities are vulnerable to flood and seismic risk because of their location, construction, and most of all, function. Schools and other community facilities often have at-grade entrances and are easily damaged by flooding. Even a short-duration flood event could cause a significant disruption given the long recovery time for a flooded school or care facility. Schools, senior and childcare facilities serve populations that are more vulnerable and less mobile, putting them at greater risk in the event of an emergency. These facilities require special consideration in case of evacuation due to mobility, medical needs, and other concerns. These facilities also rely on outside services, including transportation, staff and visiting medical personnel, utilities, and supplies, which can be compromised in a disaster. Although representatives from these facilities did not participate in the working group, emergency preparedness and response staff from the City of Oakland, City of Alameda, and the ABAG contributed to the assessment findings.

EMERGENCY RESPONSE

The study area contains three fire stations owned and operated by the City of Oakland. Fire Station #22 serves the airport and has special equipment for aviation disasters. Stations #27 and #29 serve the communities. The fire stations are vulnerable to future flooding because the buildings are at grade and firefighters rely on vulnerable roads to perform their emergency response function. In addition, the Oakland Airport and the city emergency responders provide local and regional disaster preparedness and response support. Building resilience into emergency and disaster response will require adaptation within emergency response and coordination with transportation agencies to maintain road access. Staff from Oakland's Fire Department participated in the working group and contributed to the assessment finding.

POWER, STORMWATER AND WASTEWATER UTILITIES

The study area contains power transmission facilities owned by Pacific Gas and Electric Company (PGE), stormwater facilities owned by the City of Alameda and the City of Oakland and wastewater facilities owned by East Bay Municipal Utility District (EBMUD). These utilities are critical to the communities and commercial land uses in the study area. Without stormwater management, wastewater treatment and electricity, homes, businesses and schools cannot serve local residents or the region. Future flooding and higher Bay water levels will exacerbate existing capacity issues in stormwater and wastewater management systems.

Pacific Gas and Electric provides power to the homes, community facilities, businesses and Oakland International Airport in the study area. Although no power plants are located in the study area and the power grid can reroute due to its redundancy, flooding could affect power supply in the study area. Many transmission lines are located within at-risk roadways such as Interstate 880. Any adaptation strategies to protect or reroute the road will also need to consider the power lines. This will require coordination between PGE and other asset managers.

The Harbor Bay Isle Lagoon on Bay Farm Island provides stormwater storage for the Harbor Bay Isle neighborhood. The water level in the lagoon can be lowered in preparation for storm events, but future water levels may allow bay water into the lagoon and flood homes. The lagoon and its tide gates and pumps are owned and managed by the City of Alameda and the Homeowner's Association. Representatives from the City of Alameda and the Harbor Bay Isle Homeowner's Association participated in the working group and contributed to the assessment findings.

EBMUD's pump station G conveys Oakland International Airport's wastewater to the treatment facility. Pump Station G provides a critical wastewater function for OAK and has no redundancy. The pump station already uses its full capacity and has limited remaining service life. Improvements to the pump station and interceptor system will need to be coordinated with Caltrans, OAK, and the City of Oakland to minimize disruptions and costs for wastewater and transportation. Representatives from EBMUD's planning division participated in the working group and contributed to the assessment findings.

NATURAL AREAS AND SHORELINE RECREATION

The study area contains one regional shoreline park, shoreline bicycle and pedestrian access on the Bay Trail including two pedestrian bridges, and tidal marsh habitat. The park, Bay Trail, and marshes are primarily owned and managed by East Bay Regional Park District (EBRPD). Small sections of trail belong to the City of Oakland or Alameda County Flood Control and Water Conservation District. Representatives from the planning and park operations departments at EBRPD participated in the working group and contributed to the assessment findings.

Martin Luther King Jr. Regional Shoreline is a popular, 717-acre park located along the shoreline around San Leandro Bay from Tidewater Boating Center to Doolittle Pond. It provides a diversity of recreation opportunities, including 3.7 miles of Bay Trail with six bridges, the Tidewater Boating Center with facilities and launches for rowing and paddleboats, a boat launch ramp, the Shoreline Center (meeting facility), 16 acres of grass turf, nine staging areas providing parking, picnic tables and restrooms, a staff office, the Arrowhead Marsh Overlook ramp and boardwalk, interpretive signage, wildlife viewing opportunities, and three marshes – Arrowhead, New, and Damon – which provide habitat for endangered species.

Due to its shoreline location and narrow footprint, shoreline recreation in this area is vulnerable to future flooding and there are few upland alternatives for new trails or recreation facilities. Marshes will also downshift and drown as Bay water levels rise, as they cannot retreat without upland space. EBRPD will need to coordinate with Caltrans, the Port of Oakland, Oakland and Alameda in order to preserve and enhance shoreline recreation and habitat in this area. EBRPD is considering Bay Trail improvements on Bay Farm Island that may improve shoreline resilience depending on their construction methods.

CROSSCUTTING ASSESSMENT FINDINGS

Assessment findings in the study area underscored the need for collaborative vulnerability assessment and adaptation planning. Many assets and land uses are vulnerable to flooding from shoreline protection or flood control infrastructure that is owned and maintained by others. Other assets are vulnerable because they rely on roadways and utilities that may be disrupted by flooding. Addressing the relationships and dependencies among assets requires a collaborative approach that reaches beyond property lines and current governance structures. The importance of these relationships make it critical that the assessment evaluate and develop adaptation responses that would work to address not only asset and sector specific vulnerabilities, but these interrelated vulnerabilities as well. This need was recognized during the ART Alameda Project and these types of vulnerabilities or issues were identified as "key planning issues".

Starting in early 2015, ART staff and the working group entered the define step of the planning process and developed key planning issues for the study area. These issues were verified and refined through field trips to Bay Farm Island and the Coliseum area as well as tabletop planning exercises with exposure maps. These key planning issues draw on the profile sheets and assessment findings to highlight vulnerabilities that cannot be addressed at the agency, asset or sector scale alone. The working group will develop collaborative adaptation responses for these key planning issues, evaluate the responses by determining how well they achieve the study's resilience goals, and select actions for early implementation. The six key planning issues are detailed below.

Key Planning Issues

1) ACCESS ON AND OFF BAY FARM ISLAND AND TO AND FROM OAKLAND INTERNATIONAL AIRPORT (OAK) IS ALREADY LIMITED DUE TO THE ISLAND'S GEOGRAPHY, IS VULNERABLE TO FUTURE FLOODING AND SEISMIC EVENTS, AND WILL AFFECT THE ECONOMY, PUBLIC HEALTH AND SAFETY, AND COMMUNITY FUNCTION IF DISRUPTED.

The economic and social values of the study area are heavily dependent on ground transportation options. Oakland International Airport, neighborhoods, and commercial businesses cannot function without reliable and safe access for goods, commuter and community movement. Even minor disruptions to the transportation network could have regional economic consequences given the large amount of cargo and commuter movement in the study area. Neighborhoods, schools, emergency facilities and other community land uses are even more sensitive to disruptions in access. If people cannot reach or leave their homes, cannot seek medical attention, or use community services like schools, childcare or senior facilities, they cannot lead healthy and safe lives in their community. Missing one day of work for some community members can mean the loss of a job or significant economic harm to them. Emergency responders need road access to serve their communities as well.

During a flood or seismic event, the nature of Bay Farm Island limits the access on and off of the island and could lead to serious public health and safety consequences if people cannot be evacuated or cared for in place. There are two main corridors for ground transportation access to and from Bay Farm Island: Bay Farm Island Bridge in the north, connecting to Doolittle Drive and Bay Farm Island Parkway, and the eastern approach to the island, including Hegenberger Road, 98th Avenue, and the Oakland Airport Connector and connecting Oakland International Airport to the Coliseum area and I-880. Doolittle Drive serves as shoreline protection along the northeast side of Bay Farm Island but is overtopped with water levels of MHHW+36". In the near future, culverts under Doolittle Drive will need to be improved to reduce flood risk on Port of Oakland property. As water levels rise, Doolittle Drive will need to be redesigned in coordination with the Port of Oakland, EBRPD, City of Alameda, and Caltrans.

Why Define Key Planning Issues?

The ART Program and other adaptation planning projects have developed adaptation actions to address a wide array of asset-specific vulnerabilities. These actions can be used to quickly identify how to address asset-specific issues. They should be included in the asset profile sheets to be shared, one-on-one, with the relevant asset managers and owners.

Unlike asset-specific issues, the vulnerabilities that underpin key planning issues cannot and should not be solved separately by individual asset managers or owners. These complex issues require collaborative problem solving by the working group and other stakeholders. Focusing on addressing key planning issues with the working group makes best use of time and resources to achieve the project resilience goals.

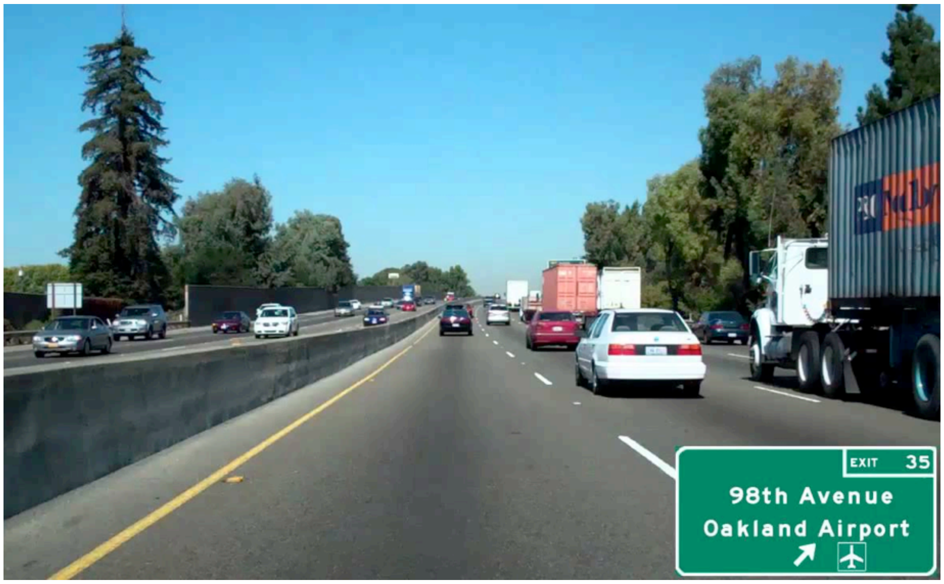


Figure 10. 98th Avenue Bay Farm Island/Oakland Airport

The eastern approach to the island is less vulnerable to direct shoreline overtopping. However, the roads are vulnerable due to inadequate shoreline protection and the fact that many of the roads are low or underpasses, and these roads provide major goods and commuter movement corridors between OAK and the Bay Region. The 98th avenue underpass could experience very deep flooding because of its below-sea level elevation. The Oakland Airport Connector is vulnerable because of its sensitive electrical, mechanical equipment in its at-grade components and in the locations where it goes below the ground. Despite its recent construction, sea level rise and future storm events were not included in the planning and design for the Connector.

2) HOUSING, COMMUNITY MEMBERS, AND COMMUNITY FACILITIES ARE VULNERABLE TO CURRENT AND FUTURE FLOODING AS WELL AS SEISMIC EVENTS.

Impacts to these facilities could result in major consequences for people where they live, work, and recreate. Flooding and seismic events, like other natural disasters, cause disproportionately severe consequences for populations with pre-existing vulnerable characteristics. Residents in the study area have these characteristics in varying frequency. For the study, the most prevalent and important vulnerability indicators include low income, transit-dependent, housing-cost burdened and medically dependent residents, as well as the very young and very old. These population characteristics make it more difficult for residents to prepare for, respond to, and recover from a seismic or flood event.

Indicator	Measure
Housing cost burden	% household monthly housing >50% of gross monthly income
Transportation cost burden	% household monthly transportation costs >5% of gross monthly income
Home ownership	% not owner occupied housing
Household income	% households with income less than <50% AMI
Education	% persons without a high school diploma > 18 years
Racial/Cultural Composition	% non-white
Transit dependence	% households without a vehicle
Non-English speakers	% households where no one ≥ 15 speaks English well
Age - Young children	% young children < 5 yrs
Age – Elderly	% elderly, > 75 years

Table 3. Indicators of Community Vulnerability[xii]

Hazard mitigation and emergency response planning does not always adequately address these population characteristic disparities, so already disadvantaged communities bear disproportionate risk and have fewer resources to recover from a flood or seismic event. This can delay and impair full recovery, leading to economic and social consequences. The Stronger Housing, Safer Communities project conducted in 2014 by ABAG and ART Program staff, found that even temporary population displacement after a disaster significantly slows recovery time, creating significant impacts on the economy. Keeping people in their homes keeps social networks intact, keeps local businesses open, keeps employees near workplaces and keeps the economy strong. Much of our housing stock is vulnerable to disasters, and many of our residents do not have the resources to stay and rebuild if their homes are significantly damaged, as rebuilding housing in the region can be costly and take years (See Figure 11). This issue is particularly severe in the Bay Area because of existing housing cost burden and the tight housing stock, leading to a lack of available short term or replacement housing. In addition to housing vulnerabilities, many community facilities such as child care facilities and senior housing are privately operated and may not be adequately protected by local or state ordinances. Protecting community members before, during and after a flood or seismic event requires an understanding of their current and future vulnerabilities and a special focus on their unique needs.

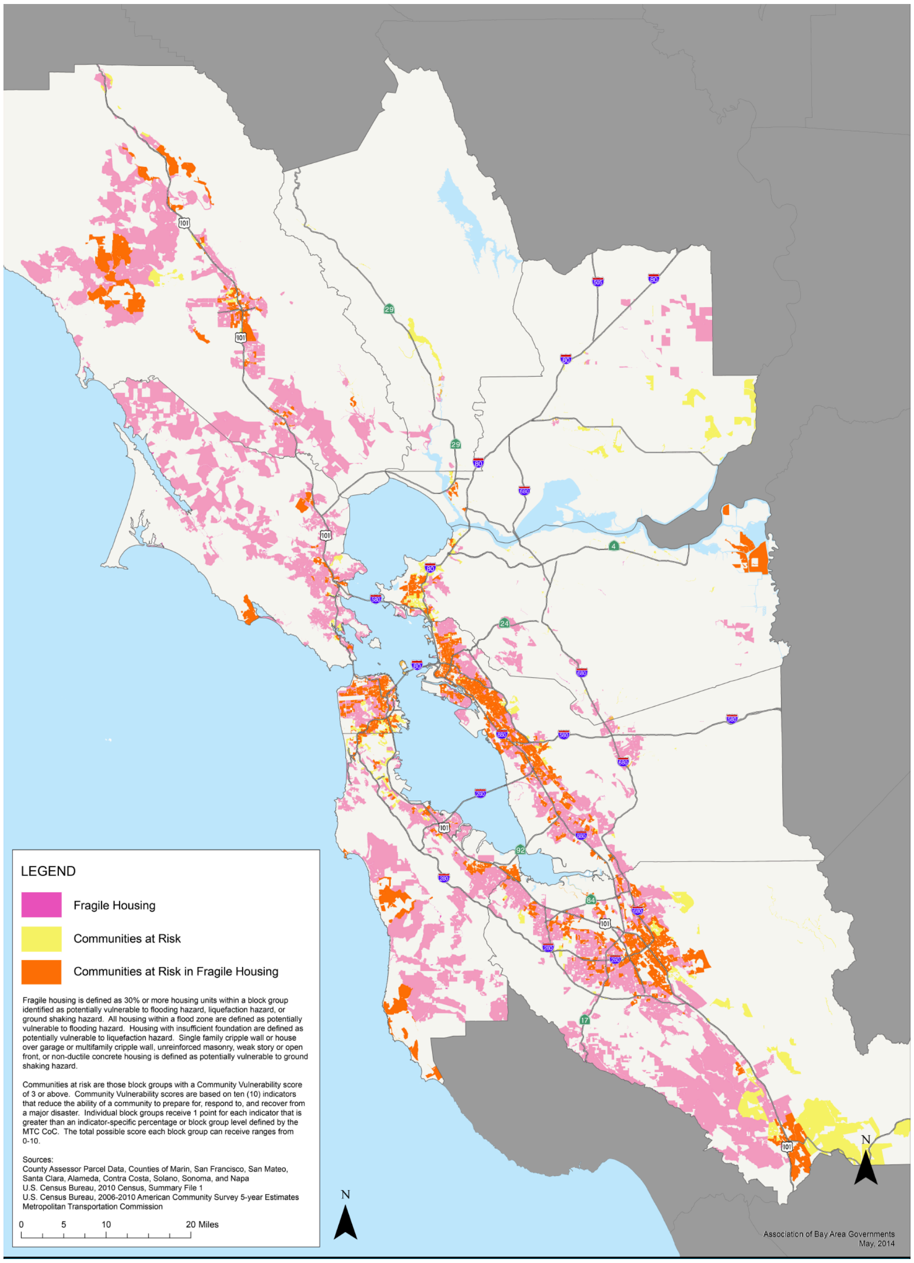


Figure 11. Housing and Community Vulnerabilities (From Stronger Housing, Safer Communities Report)

3) THE OAKLAND COLISEUM FACILITIES, TRANSPORTATION ASSETS, AND NEIGHBORHOOD ARE VULNERABLE TO BOTH CURRENT AND FUTURE FLOODING DUE TO AT-CAPACITY FLOOD CONTROL CHANNELS AND RISING BAY WATER LEVELS.

The Coliseum area and surrounding neighborhood in Oakland is vulnerable to flooding caused by the interaction between riverine and coastal flood events. As shown in Figure 12, four flood control channels flow through the area, Damon Slough, which drains Lion Creek and Arroyo Viejo, Elmhurst Creek, and San Leandro Creek. These channels drain large watersheds that extend to the Oakland hills, so mitigating flood risk in this area may require low-impact development and storage in the upper watershed as well as on site flood management and coastal protection measures. Modeling of joint coastal and riverine flood events demonstrates the near term flood risk in this area. Tables 4 and 5 demonstrate the first flooding scenario for different waterways in this area, most of which have current flood risk with less than 100-year water levels.

AECOM

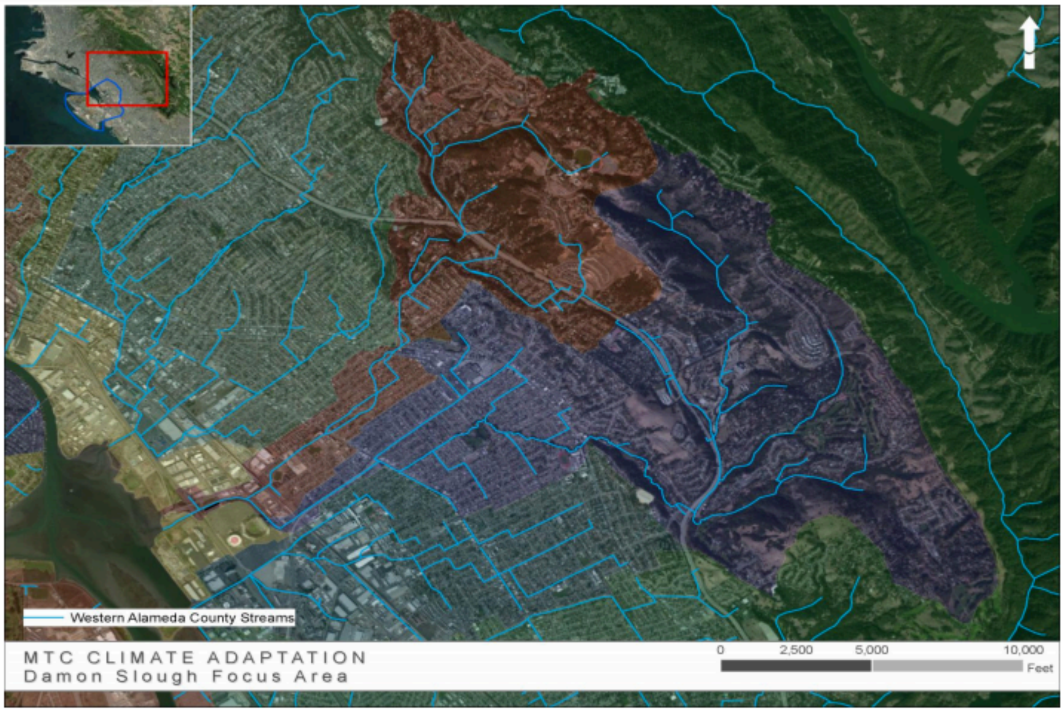


Figure 12. Watershed Map for Oakland Coliseum Focus Area

The Oakland Coliseum Complex and transportation assets in the area provide economic value to the City of Oakland and the region through sports and entertainment events year round. Figure 13 shows the plans to enhance the function and resilience of this area. Stormwater and wastewater drainage are insufficient and have caused disruptions to Coliseum facilities in the past. BART, Capitol Corridor and AC Transit service in the area is vulnerable to future flooding and serves the transit-dependent Coliseum community and the region at-large. Interstate 880 is vulnerable to flooding at its stream crossings in this area and is critical to goods movement and the regional economy. Table 5 shows current and future flood risk for transportation assets in this area, most of which occurs during joint coastal and riverine events. As shown below, many assets are vulnerable to current flood events and all are vulnerable to flooding with 12" of sea level rise.

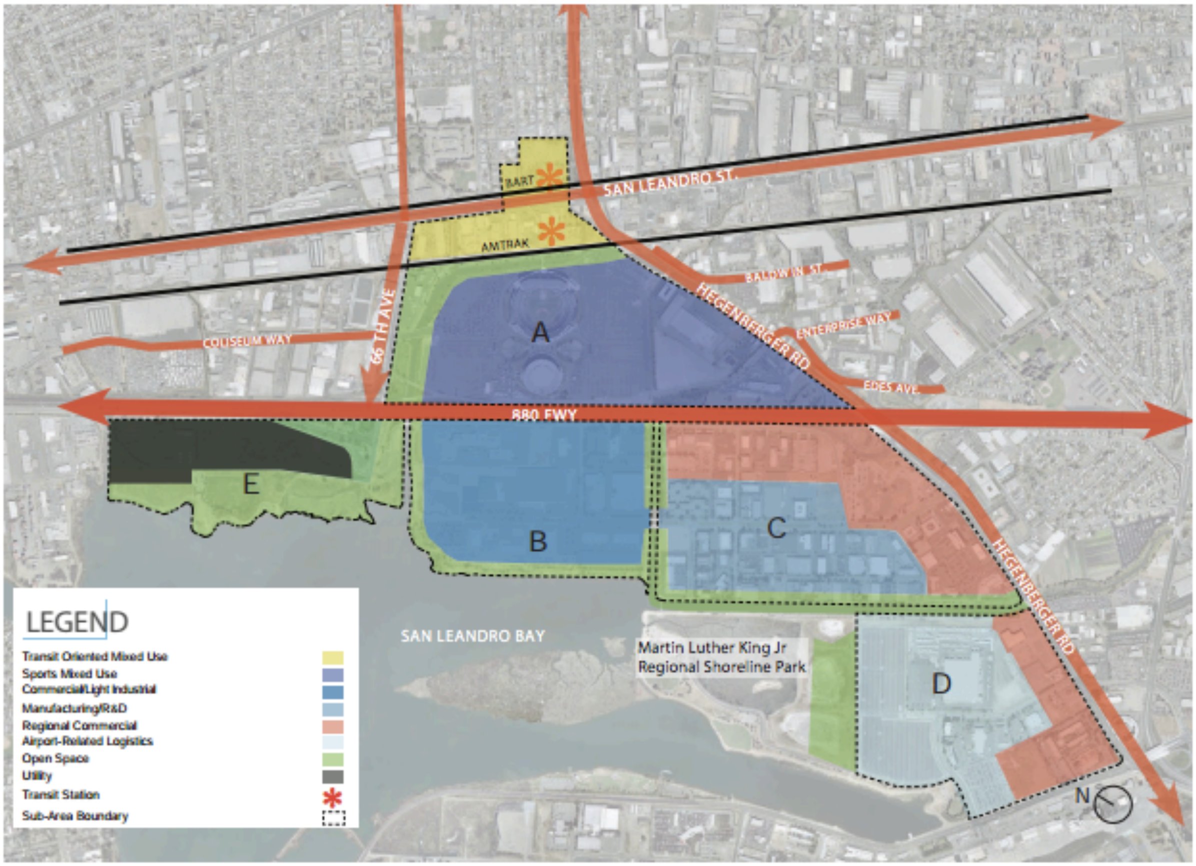


Figure 13: Oakland Coliseum Specific Area Conceptual Land Use Plan

Asset	Scenario	Timing of Flooding			
		From Riverine		From Coastal and Riverine	
		Extreme Tide	Peak Flow	Extreme Tide	Peak Flow
Damon Slough	Existing	-	-	100-Year	10-Year*
	12-inch SLR	-	-	10-Year	10-Year*
	24-inch SLR	-	-	10-Year	10-Year*
Arroyo Viejo Creek	Existing	MHHW	50-Year	10-Year	25-Year
	12-inch SLR	MHHW	50-Year	10-Year	10-Year
	24-inch SLR	MHHW	25-Year	10-Year	10-Year
Lion Creek	Existing	MHHW	50-Year	10-Year	25-Year*
	12-inch SLR	MHHW	25-Year*	10-Year	10-Year*
	24-inch SLR	MHHW	25-Year*	10-Year	10-Year*

*Flooding occurs at isolated transects, but is not yet extensive.

Table 4. Timing of Flooding at Stream Channels in study area

Asset	Scenario	Timing of Flooding			
		From Riverine		From Coastal and Riverine	
		Extreme Tide	Peak Flow	Extreme Tide	Peak Flow
I-880 Crossing[1]	Existing	-	-	-	-
	12-inch	-	-	100-Year	10-Year
	24-inch	MHHW	100-Year	10-Year	10-Year
Coliseum Complex	Existing	MHHW	50-Year	10-Year	10-Year
	12-inch	MHHW	50-Year	10-Year	10-Year
	24-inch	MHHW	25-Year	10-Year	10-Year
Coliseum Amtrak Station / Rail Corridor	Existing	MHHW	50-Year	10-Year	25-Year
	12-inch	MHHW	50-Year	10-Year	25-Year
	24-inch	MHHW	25-Year	10-Year	10-Year
Coliseum BART Station	Existing	MHHW	100-Year	10-Year	100-Year
	12-inch	MHHW	100-Year	10-Year	10-Year
	24-inch	MHHW	100-Year	10-Year	10-Year
OAK Airport Connector	Existing	MHHW	50-Year*	10-Year	25-Year*
	12-inch	MHHW	50-Year*	10-Year	25-Year*
	24-inch	MHHW	50-Year*	10-Year	10-Year*

*Flooding occurs at isolated transects, but is not yet extensive.

[1] Flooding of roadway adjacent to Damon Slough occurs when water levels reach 10.5' NAVD (approx.).

Table 5. Timing of Flooding at Key Assets in Study Area

This area was part of a specific plan process led by the City of Oakland aimed at economic development with no explicit flood risk reduction benefits. The current specific plan, adopted in 2015, calls for thousands of new housing units as well as commercial development and new stadiums. These land uses are long-term investments that will need to be protected from both current and future flood risk. Special coordination between the City of Oakland and other public and private partners will be necessary to plan for future water levels while meeting other local needs for housing and economic investment.

4) OAKLAND INTERNATIONAL AIRPORT (OAK) IS VULNERABLE TO FUTURE FLOODING AND SEISMIC EVENTS BOTH WITHIN ITS FACILITIES AND THROUGH ITS DEPENDENCE ON OTHER ASSETS.

The Oakland International Airport provides regionally significant goods movement, commuter movement, air passenger travel for business and personal purposes, and emergency response functions. The airport is protected by shoreline protection it owns (the perimeter dike) and by shoreline protection it does not own (Doolittle Drive). Federal Emergency Management Agency (FEMA) preliminary flood risk mapping in 2015, shown in Figure 13, highlights possible current flood risk with a 100-year coastal water level. This flood risk is due to low-lying areas along Doolittle Drive, not along the airport's Perimeter Dike.

Figure 14: 2015 FEMA Preliminary Flood Insurance Rate Map (FIRM) Adapted from: http://fema.maps.arcgis.com/

Significant airport facilities are at risk, including major runways, critical structures like the terminals and air traffic control tower, and smaller but very important assets like the tank farm for fuel supply and Fire Station #22. Most airport facilities are not resilient to flood impacts and the airport cannot function if its runways, terminals, control tower, and other assets are disrupted. In order to maintain operations at OAK, the Port of Oakland will need to coordinate with utilities, tenant businesses, neighboring landowners, and transportation agencies in the area as well as relevant regulatory agencies.

5) THE OAKLAND/ALAMEDA STUDY AREA CONTAINS SHORELINE HABITAT, INCLUDING HABITAT FOR THE ENDANGERED CALIFORNIA RIDGEWAY'S RAIL. HOWEVER, MUCH OF THIS HABITAT EXISTS IN THE FORM OF FRINGING MARSHES, WHICH ARE NOT PREDICTED TO PERSIST GIVEN SEA LEVEL RISE, SEDIMENT PROJECTIONS AND SURROUNDING LAND USES.

Martin Luther King Jr. Regional Shoreline contains multiple marsh complexes. Arrowhead marsh, the largest within the park, contains habitat mounds constructed as intermediate adaptation space for endangered Ridgeway Rails, but cannot survive future water levels. Due to adjacent land uses and the narrow footprint of the park, EBRPD does not have adequate space to restore upland transition zone for marshes on its property. In order to protect habitat and recreation access, EBRPD will need to coordinate with the Port of Oakland, Alameda County Flood Control and Water Conservation District, and neighboring landowners.

Figure 15: Martin Luther King Jr. Regional Shoreline Park, Arrowhead Marsh Habitat Mounds

In the Coliseum Area Specific Plan[xiii], the City of Oakland aims to "Create enhanced open space, Bay access, and natural habitat opportunities that will restore natural habitat, and create public educational and Bay accessibility opportunities for Oakland and Bay Area residents. As part of this plan, new development in this area should include improved recreation and bicycle/pedestrian corridors as shown in Figure 13. Making these recreation assets resilient to sea level rise will be challenging, given their shoreline location and narrow alignments. The City of Oakland, EBRPD, and the community all have a role to play in greening this area for environmental and societal benefits.

6) OVERARCHING: PERMITTING AND REGULATORY ISSUES ALONG SHORELINE AND WITH MULTIPLE OWNERS AND JURISDICTIONS MAY DELAY OR IMPEDE ADAPTATION.

Most agencies were designed to address the conditions and issues that existed when they were created, with some amendments and updates along the way that allow them to address current issues with static solutions. Sea level rise and future flooding will require asset managers to plan and implement more iterative projects and ask regulatory agencies to acknowledge shifting baselines for habitat and other resources.

In addition to these challenges, the Oakland/Alameda study area has special Federal Aviation Administration requirements and funding arrangements for improvement in and around Oakland International Airport. Securing funding for adaptation will also require new collaboration between recreation, restoration, and infrastructure funding sources to implement multi-objective projects, e.g., Port of Oakland cannot fix Doolittle Drive without cooperation from Caltrans and EBRPD but the final project could benefit the airport, recreation, and ground transportation. These governance issues affect all sectors and landowners in the study area and limited progress can be made on the first five key planning issues without improving governance. The ART Program, along with its regional partners at ABAG, the Coastal Conservancy, Metropolitan Transportation Commission and the Bay Area Regional Collaborative, are working to clarify these governance challenges and develop strategies for both individual agencies and the region to carry forward. This study, as well as the Stronger Housing, Safer Communities and Regional Hazard Mitigation and Adaptation Planning efforts by ABAG and the ART Program, are attempts to demonstrate and streamline adaptation at the regional and local level. Moving adaptation from planning to implementation will require efforts at the local, regional, state and federal scale. This study cannot develop solutions for all of these problems, but its findings can support regional efforts and build capacity within local agencies to improve resilience.

Phase II: Adaptation Responses and Implementation Options

The work conducted in Phase I of the study included the first three steps of the ART planning process: Scope and Organize, Assess, and Define. Phase II of the study, included the Plan and Implement steps of the ART planning process (see Figure 3). This phase of the study focused on developing adaptation responses and implementation options based on the outcomes of the assessment and the six key planning issues.

After refining the vulnerability and risk findings, including asset profile sheets and the key planning issues, the working group transitioned towards developing actions to reduce vulnerability and risk. To begin, ART Program staff and working group members developed and refined adaptation responses at the asset and sector level. These adaptation responses include identified vulnerabilities, proposed actions, and implementation information including possible leads, partners, processes, and funding sources. Many of these responses include preliminary actions that build towards broader adaptation strategies.

In order to fully understand the key planning issues as they fit onto the landscape and to develop appropriate multi-sector, multi-objective adaptation responses, ART Program staff divided the study area into two geographies. The first area, the Coliseum area of Oakland, unites riverine and coastal flooding issues, regional transportation assets, community facilities and recreation and major planned redevelopment. Although there are many different land uses and vulnerabilities in this area, they share near term flood risk due to the flood control channels in the area. The second area, Bay Farm Island, is exposed to coastal flood risk caused by inadequate shoreline protection along Doolittle Drive. The flooding is less severe and the potential adaptation responses less technically complex in this area, but the governance arrangements between the airport, two cities, Caltrans and EBRPD make implementing adaptation actions very difficult. For both of these areas, ART Program staff organized field trips and tabletop planning exercises to help the working group wrestle with interrelated vulnerabilities and strategies in these geographies.

Adaptation Responses

Each adaptation response includes three important building blocks:

- A vulnerability or issue;
- One or more actions; and
- Implementation options.

This approach is valuable because it connects the actions developed in the second phase of the process directly to the assessment outcomes that were developed in the first phase and presents a number of possible stand-alone or sequenced actions that can be taken. The approach also provides a substantial level of detail about possible implementation partners and processes. As a package, the adaptation response provides not only the actions that can be taken, but makes a case for why those actions are necessary and who needs to be involved.

The completion of the last two steps of the ART planning process is not the end of adaptation planning in the study area; rather it is a jumping off point for taking local and regional action that will build resilience both within and beyond the study area. The ART Program will continue using advocacy, research, guidance and regional planning to support working group members and other agencies to build regional and local resilience in the study area. The following sections provide a detailed description of the process and outcomes of this work.

The Plan Step

The outcomes of the Plan and Implementation steps included comprehensive adaptation responses for identified vulnerabilities, evaluation of the adaptation responses against the study's resilience goals, and pathways towards implementation. The process used to achieve each of these outcomes is discussed briefly below, and then described in further detail in the remainder of the report.

As with all steps in the Oakland/Alameda Resilience Study, ART Program staff worked closely with the working group during the development and vetting of adaptation responses. This cooperation, both during formal working group meetings and one-on-one with working group members, ensured adaptation responses were feasible and appropriate for the local vulnerabilities identified. This engagement has also helped working group members understand their role in implementing the adaptation responses developed for the study area. Both of these outcomes built capacity within and beyond the working group to take up the challenge of adapting to sea level rise and flood impacts in the study area.

After the adaptation responses were developed the working group members evaluated them using criteria grounded in the study resilience goals. The evaluation helped the working group understand more deeply the adaptation responses and led to refining the responses to more broadly benefit all frames of sustainability. After evaluating the adaptation responses against the study's resilience goals the working group chose actions to begin implementing in the near-term. This selection was based on the timing of the issues identified, resources available, and the availability of information to support implementation. At the final working group meeting, members developed implementation pathways that identified the immediate next steps, the lead agency or agencies, and the advocacy needed to advance actions to address the key planning issues.

Approach to Developing Adaptation Responses

The process for developing adaptation responses included desktop research by staff, discussions and meetings with working group members, field work, review of actions and strategies from previous ART projects, review of local plans and efforts such as the Coliseum Specific Plan, and collecting working group and expert input on specific assets and actions. The result was draft adaptation responses for the individual asset, sectors and services assessed as well as the six key planning issues that had been identified by the working group. The study's Plan and Implement steps focused in on these key planning issues because of the timeliness, complexity, and critical nature of the underlying vulnerabilities, and the consequences that could accrue if the impacts did occur.

Draft adaptation responses for the 25 assets assessed were shared with the working group at a facilitated open house meeting where the group considered which actions and implementation options would be the most practical, feasible, and responsive to the underlying vulnerabilities. Table 6 presents an example asset adaptation response and Appendix A includes the full set of asset adaptation response tables.

Functional Vulnerability

Vulnerability T11: There is not sufficient commercial airport runway capacity in the San Francisco Bay Area to serve as a short- or long-term alternative to Oakland International Airport if it were damaged or disrupted due to sea level rise or storm events.

Action Number	Action	Action Type	Process	Possible Actors	Action Characterization
T11.1	Update the San Francisco Bay Area's Regional Airport Systems Planning Analysis (RASPA) to consider sea level rise, storm events, earthquakes, and other hazards	Evaluation	Long-range Planning	RAPC, ABAG, BCDC, MTC, Regional Airports, FAA	Unlocking, Regional
T11.2	Analyze sea level rise, storm events, earthquakes, and other hazards in updating the Master Plans of the region's airports	Evaluation	Long-range Planning	Regional Airports, FAA	Unlocking, Local, Regional
T11.3	Consider sea level rise and storm event impacts when developing passenger and cargo demand projections for the region's runway capacity	Program/operation	Long-range Planning	Regional Airports, FAA	Regional
T11.4	Develop a stakeholder group to identify sea level rise and storm event adaption options for the Oakland International Airport that considers airport assets, key infrastructure that the airport relies on (transportation, power, water, etc.), and opportunities to benefit adjacent, non-airport vulnerable assets	Coordination	New Initiative	Port, FAA, RAPC, ABAG, BCDC, MTC, Cities, Counties, CBOs, Private Sector	Local, Regional, High Priority

Table 6: Transportation Adaptation Response

Adaptation responses were also developed for the six key planning issues. These adaptation responses highlight how individual agencies or asset managers might work together to solve the crosscutting issues identified in the study, and integrate their action with other efforts at the local, regional, state and federal scales. Some of the actions to address the key planning issues could be implemented by agencies in the study area while others, such as new standards for buildings or emergency plans, would need to be enacted at the state scale but would have local effects. The actions presented are neither an exhaustive list of possibilities, nor a step-by-step guide to taking action in the study area. Rather, these actions are a starting point for further discussion and consideration of what priority actions should be advanced. More detail on the process for choosing priority actions and designing implementation pathways can be found later in this report.

In order to better understand the key planning issue vulnerabilities and their cross-sector adaptation responses, ART Program staff took the working group on two field trips, one around the Coliseum area in Oakland and one along Doolittle Drive on Bay Farm Island. These field trips helped working group members visualize how proposed adaptation responses may or may not integrate with the existing landscape. They were also an opportunity to discuss the potential benefits of action implementation as well as the consequences of not taking action. In some cases, new adaptation responses were developed, or actions were combined in a new way to better achieve economic, environmental, and social resilience. The field trips were paired with tabletop adaptation planning exercises so that working group members could identify and address implementation challenges, physical limitations of particular sites, and information gaps.

Oakland/Alameda Resilience Study

Oakland Coliseum Field Trip

The Field trip to the Coliseum area of Oakland in July 2015, focused on the four flood control channels that run through the study area and how rising sea level will reduce their capacity and exacerbate flood risk from riverine and coastal events. These flood control channel vulnerabilities affect nearly every land use in the Coliseum area, including housing and transit facilities far from the shoreline but along tidal channels. From the assessment, it was clear that mitigating flood risk in this area would require extensive work both along the channels and in the upper watershed, far outside the study area. The field trip helped ART Program staff and working group members familiarize themselves with the landscape, visualize how infrastructure in this area is often physically co-located, and better understand the limitations and opportunities to develop actions to reduce the risk in this area. After the field trip, the working group was given a menu of adaptation options including increasing flood storage in the channel, building storage in the upper watershed, creating floodable development at the Coliseum site, and retreating in a managed fashion from this area. In discussing these options, and various combinations thereof, the working group decided this area will require a further assessment and planning that includes the upper watershed as protecting the Coliseum area will require an “all of the above” response that includes improving the flood control channel, expanding watershed flood storage, pumping floodwaters, and building floodable development.

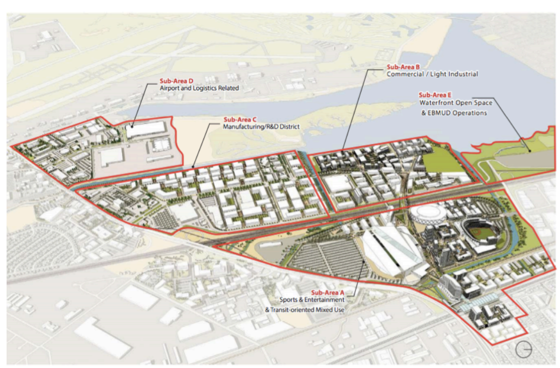
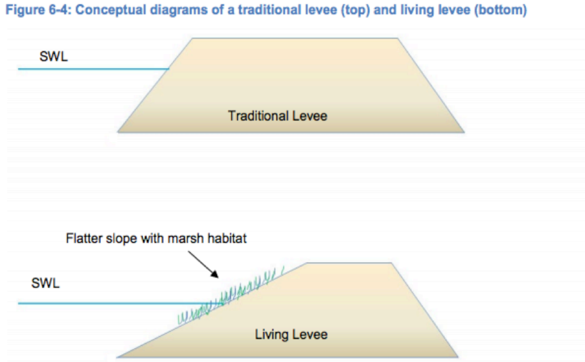


Figure 1.2: Coliseum Area Specific Plan Conceptual Buildout
Source: JRDV / City of Oakland

Figure 6-4: Conceptual diagrams of a traditional levee (top) and living levee (bottom)



Oakland/Alameda Resilience Study
Bay Farm Island Field Trip

The second field trip, held in August 2015, included the Bay Farm Island community, Doolittle Drive, the Bay Trail, Oakland International Airport and Martin Luther King Jr. Regional Shoreline Park. This portion of the study area is primarily at risk from coastal flooding along Doolittle Drive, which provides de facto shoreline protection for Oakland International Airport's North Field and the airport related businesses in the area, as well a leaseholds of the Port of Oakland. The roadway, owned by Caltrans, has several low points as seen in Figure 16. These low points could result in flooding of the roadway and airport facilities and disrupt access to and from the Bay Farm Island community. Addressing this flood risk is not difficult. The shoreline in this area is mostly riprap and the roadway could be raised or shoreline protection could be developed that would reduce the potential for flooding at lower water levels. The challenge is the current governance arrangements. Caltrans owns the roadway, the Port of Oakland owns and operates the airport facilities, the Bay Farm Island community is part of the City of Alameda, and East Bay Regional Park District (EBRPD) manages the adjacent park and is pursing an extension of the Bay Trail along this section of shoreline. There are, however, actions that could be taken to alleviate the existing governance challenges. For example, the City of Alameda transferred ownership of Webster Street (which is not in the study area) from Caltrans to the city in order to install bicycle and transit improvements. This type of action only works if there is a clear local lead that will take ownership and plan, fund, and implement proposed actions. After the field trip, the working group discussed the various options for improving the roadway and shoreline as well as the different implementation challenges that would need to be overcome given shared ownership and the lack of an agency that has the capacity or authority to take the lead in this area.

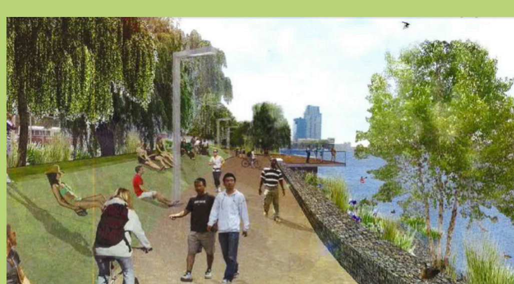


Figure 16: Sites In the DEM Contributing To Inundation in Low SLR Scenario

Adaptation Responses for Key Planning Issues

Below is a brief description of the six key planning issues that were identified in the study area and the actions that were proposed actions to address them.

Access to Bay Farm Island and Oakland International Airport

Access on and off Bay Farm Island and to and from Oakland International Airport (OAK) is already limited due to the island's geography, and is vulnerable to future flooding and seismic events. Loss of access to Bay Farm Island will affect the economy, public health and safety, and community function if disrupted. Three major roads serve OAK and the community on Bay Farm Island: 98th Avenue, Hegenberger Road, and Doolittle Drive (SR-61). 98th Avenue is vulnerable to sea level rise and storm event impacts from direct coastal inundation, especially in the vicinity of the underpass on Bay Farm Island. Addressing this vulnerability will be complicated because 98th Avenue is co-located with utilities, sewers and the BART Oakland Airport Connector, and it crosses San Leandro Creek. Hegenberger road provides goods and commuter movement between Bay Farm Island and the region. Hegenberger road is vulnerable because of its low elevation and because the City of Oakland owns and maintains the roadway but not its shoreline protection. Doolittle Drive is vulnerable to flooding, and culverts under the roadway may create near term flooding for Bay Farm Island, Port of Oakland property, Oakland International Airport and some areas within the City of Oakland. Improving the culverts and the resilience of Doolittle Drive will require extensive coordination between the Port of Oakland, Caltrans, EBRPD, and the cities of Alameda and Oakland. Addressing access issues will require new coordination efforts, improved maintenance, and possibly new structures. Possible adaption actions include:

- Conduct analyses of critical infrastructure to identify the potential for increased erosion, scour and wear due to increased tide and wave energy
- Conduct a "hot spot" analysis to identify key routes and nodes critical to traffic flow, assess their vulnerability and risk, and develop actions to improve their resilience to sea level rise and storm events
- Increase the capacity to accommodate re-routed traffic on alternative routes, or build new routes, in areas not at risk from sea level rise and storm events
- Develop design standards for new infrastructure and capital improvements investments that will protect critical elements from sea level and groundwater rise
- Install manual, remote control, or automatic temporary barriers or waterproof closures to protect at- or below-grade critical elements such as station entrances, tunnels, maintenance facilities, asset storage areas, and rail alignments

Housing, Communities, and Community Facilities

Housing, community members, and community facilities are vulnerable to current and future flooding as well as seismic events. Impacts to these facilities could result in major consequences for people where they live, work, and recreate. Community organizations, cities, counties and other agencies will need to work together to plan and prepare for climate and seismic impacts in the study area. Potential planning and capacity building actions include:

- Develop and maintain a centralized database of non-profit, community, and faith-based organizations, equipment and service providers, and others that can communicate with communities at risk
- Develop and maintain a voluntary database that includes specific needs within the Bay Farm Island and Oakland communities related to emergency response
- Develop community-led education and outreach campaigns designed for specific local populations on the risks of sea level rise and storm events
- Revise emergency response policies, procedures, and trainings, including strategies for managing community needs such as providing specialized equipment or evacuation procedures
- Develop and keep current hazard mitigation plans meeting established standards to ensure eligibility for state and federal emergency funds
- Develop contingency plans and procedures to address the need for short-term sheltering and long-term housing for displaced residents, with particular attention to certain populations and those with specific needs such as animal caretakers

Emergency response organizations will play a critical role in community services before, during, and after flood and seismic events. Communities can also help build their own disaster preparedness. Potential emergency preparedness and response actions to build community resilience in the study area include:

- Provide expanded Communities of Oakland Respond to Emergencies (CORE) trainings, Neighborhood and Community Emergency Response Team (NERT and CERT) refresher classes, and annual exercises that include flooding preparedness and response

- Increase inspection and maintenance of infrastructure that that is sensitive to water or salt in areas at risk from sea level rise, storm events, or elevated groundwater levels
- Provide incentives or require that fire stations be retrofitted using waterproof shutters, shields or doors and salt-resistant materials to reduce flood damage
- Waterproof and/or raise the elevation of at- or below-grade electrical and fuel components at the fire station to protect against flooding and allow for continued function during a flood event
- Develop policies or incentives to expand access to auxiliary water and power sources, e.g., on-site power generators with sufficient fuel for several days, portable generators, or pre-negotiated rental or leasing agreements for portable sources
- Develop policies or incentives to encourage/require emergency response plans and procedures to consider how power, water, and supplies necessary to maintain the function of fire stations during a flood emergency, will be delivered given that many access routes and transportation modes may also be disrupted

Individual community facilities like schools, day cares, senior care facilities and health care facilities will need to protect not only their facilities but their functions from sea level rise and seismic impacts if they want to continue to serve all members of their community, and especially the young, the elderly, and the medically-dependent. Actions to protect community facilities and functions include:

- Review and update community facility emergency preparedness and response plans to address sea level rise and storm event contingencies
- Provide technical assistance to community facilities to support the development and maintenance of emergency response plans, including storm evacuation procedures and shelter-in-place guidelines
- Review, update, and train staff on evacuation protocols that take into account flooding and storm events
- Develop policies or incentives to encourage/require emergency response plans and procedures to consider how power, water, and food necessary to maintain the function of community facilities during a flood emergency, will be delivered given that many access routes and transportation modes may also be disrupted
- Develop plans and procedures to obtain or distribute specialized supplies needed to either shelter-in-place or evacuate students, patients and clients
- Expand or form multi-agency and cross-jurisdictional partnerships (including community-based organizations) to improve the capacity to address the needs of community members and their caregivers during a disaster or emergency
- Develop contingency plans and procedures to address the need for short-term accommodation and long-term relocation for displaced students in other childcare centers
- Establish mutual aid agreements and initiate or strengthen joint protocols with adjoining communities for cooperative disaster response, as well as strengthening partnerships between public and private

community facilities

- Reduce dependency on community facilities that are vulnerable to sea level rise by building alternative facilities or by increasing the capacity of existing facilities in areas not at risk from sea level rise or by providing relocation assistance for private childcare facilities
- Conduct vulnerability and risk assessments of individual community facilities and develop site-specific strategies to reduce service disruptions or closures
- Develop policies or incentives to encourage/require at-risk community facilities to implement changes to facility structures or operations that would reduce potential for disruption or closure due to sea level rise or storm events

Flooding of the Oakland Coliseum Area

The Oakland Coliseum facilities, transportation assets, and neighborhood are vulnerable to both current and future flooding due to at-capacity flood control channels and rising Bay water levels. Addressing this current and worsening problem will require long term planning that includes improved plans and policies, education and outreach, repair and/or retrofit of existing infrastructure, including flood management facilities, and development of new infrastructure. Possible actions include:

- Develop community-led education and outreach campaigns designed for specific local populations on the risks of sea level rise and storm events
- Revise emergency response policies, procedures, and trainings, including strategies for managing community needs such as providing specialized equipment or evacuation procedures
- Include current and future flood risk in land use planning and project review in this area
- Participate in FEMA's Community Rating System to mitigate flood risk and lower flood insurance premiums
- Review existing transportation asset management plans to identify gaps in completeness, quality and accessibility of information most relevant to emergency response, adaptation planning, and federal funding
- Install manual, remote control, or automatic temporary barriers or waterproof closures to protect at- or below-grade critical elements such as station entrances, tunnels, maintenance facilities, asset storage areas, and rail alignments
- Construct permanent structures to protect at- or below-grade critical elements such as station entrances, tunnels, maintenance facilities, and asset storage areas
- Develop and maintain a centralized database of non-profit, community, and faith-based organizations, equipment and service providers, and others that can communicate with communities at risk
- Improve flood control channel capacity through dredging, widening, and/or installing living levees
- Improve upper watershed flood storage to reduce peak flows through the Coliseum area
- Improve institutional relationships between the City of Oakland and Alameda County Flood Control

and Water Conservation District so maintenance and improvement of stormwater and flood control infrastructure is better coordinated

Dependence of Oakland International Airport on other Assets

Oakland International Airport (OAK) is vulnerable to future flooding and seismic events from direct impacts on its facilities and because of its dependence on other assets. The Port of Oakland owns and manages most of the facilities at the airport, however action to maintain airport function through on-site improvements must be coordinated with Port tenants and the Federal Aviation Administration, and ensuring continuity of services provided by others will require coordination with utility providers as well as the Cities of Alameda and Oakland, and Caltrans. The Port of Oakland is in the process of improving its perimeter dike to reduce seismic and flood risk, and has submitted tentative plans to FEMA for a flood risk reduction project to protect the North Field area. Potential actions include exploring new funding methods, updating and improving existing infrastructure, and working with neighboring properties to manage future flooding and access issues. Other possible actions include:

- Increase inspection and maintenance of infrastructure that is sensitive to water or salt in areas at risk from sea level rise, storm events, or elevated groundwater levels.
- Monitor groundwater and salinity levels near vulnerable infrastructure by leveraging existing data or collecting site-specific data as necessary.
- Form or expand existing coordination with private partners to engage in collaborative, multi-objective planning and facilitate cost-sharing in making improvements to increase the resilience of the Tank Farm, Transfer Station and pipelines to sea level rise, storm and earthquake impacts.
- Require and install (if not already in place) shut-off, overflow, and re-routing and/or other mechanisms to function during an emergency to both prevent fuel release and restore fuel supply.
- Develop agreements with the City of San Leandro and Kinder Morgan with shared management objectives for the perimeter dike. Identify decision-making and funding responsibilities, as well as requirements (e.g., FAA regulations) related to maintenance, repair, or upgrade.
- Dedicate funding and resources (if not already done) to inspect, maintain, upgrade, and repair vulnerable, at-risk portions of the perimeter dike – particularly after seismic or storm events.
- In coordination with entities involved in operations and management at the terminal, assess vulnerabilities and plan for and facilitate cost-sharing in making on-site improvements to increase the resilience of the terminal to sea level rise, storm and earthquake impacts.
- Waterproof and/or raise the elevation of at-grade electrical equipment above anticipated flood levels.
- Review existing operations and maintenance plans, and emergency response plans to determine where preparation is inadequate for flooding impacts to airport facilities

Shoreline Habitat and Recreation

The Oakland/Alameda study area contains shoreline habitat, including habitat for the endangered California Ridgeway's Rail. Much of the habitat is fringing marshes, which is not predicted to persist given sea level rise, diminishing sediment supplies, and the proximity of adjacent development. Possible actions include:

- Develop a decision-making framework for selecting resilient, multi-objective shoreline adaptation responses given economic, environmental and social equity trade-offs
- Develop policies, guidance or incentives to encourage setbacks and buffers adjacent to tidal marshes that protect sensitive species and allow appropriate types of public access and recreation uses
- Improve or protect high tide refugia where it is already limited and vulnerable to increased inundation, e.g., install artificial refugia
- Protect existing, or create new, corridors that facilitate the movement of birds and wildlife to viable adjacent or nearby habitats
- Protect, enhance, or restore baylands outboard of structural shorelines to preserve wave attenuation benefits, thereby reducing wave erosion, the likelihood of overtopping, and maintenance needs of structures such as non-engineered berms and levees

Permitting and Regulatory Challenges

Permitting and regulatory challenges for improvements to the shoreline or for assets located in shoreline areas is an overarching issue that may delay or impede adaptation. This may be a particular challenge where there are multiple owners and jurisdictions that need to collaboratively develop and implement solutions.

- Develop and implement a regional permit authorization program to expedite the ongoing maintenance, minor repair, or upgrade of structural shorelines
- Develop policies or incentives to require or encourage the consideration of sea level rise and storm events in developing, planning, and funding capital investments
- Require the consideration of sea level rise in land use plans and project designs, e.g., General Plan Safety Elements
- Improve coordination among agencies to ensure consistent regulatory and planning approaches to sea level rise adaptation, and to reduce programmatic or legislative barriers to assessing and addressing future risks
- Explore new institutional arrangements such as Joint Powers Authorities or Memorandums of Understanding to solve cross-jurisdictional vulnerabilities
- Explore new funding strategies for adaptation including geological hazard abatement districts, enhanced infrastructure financing districts and others

Developing and Applying Evaluation Criteria

ART Program staff developed draft evaluation criteria based on the study's resilience goals and then engaged the working group in applying them to select key planning issue adaptation responses. The evaluation criteria were instrumental in helping the working group better understand the intended and unintended consequences of different actions. The criteria also helped identify potential refinements that were needed to improve the feasibility of each response; balance the environmental, social, economic and governance aspects; and influence the disaster life cycle. The criteria that were used are presented below.

Evaluation Criteria	
Feasibility	Possible with existing or expected funding sources
	Possible within existing administrative, technical, or legal practices
	Has high likelihood of political support
	Addresses current issues and/or provides current benefits
Economic benefits	Promotes or retains jobs
	Maintains goods and commuter movement
	Maintains airport services
	Protects infrastructure investments
Social benefits	Protects access to jobs or services
	Maintains shoreline access
	Maintains recreational or educational opportunities
	Increases public awareness
	Preserves community function
Environmental benefits	Promotes grey to green (nature based solutions)
	Creates or maintains appropriate habitat and biodiversity
	Maintains or improves water quality
Governance	Supports or creates collaborative decision making

	Encourages broad public or private sector partnerships
	Addresses adaptation information gaps
Builds Resilence in Disaster Lifecycle	Builds preparedness
	Mitigates risk
	Improves disaster response
	Encourages resilient recovery

Table 7: Evaluation Criteria

The working group used the criteria during the November 2015 meeting to evaluate a subset of the key planning issue adaptation responses. Working in small groups, example adaptation actions were scored as having a positive, negative, or neutral affect on each of the criteria. This process helped working group members identify persistent information gaps, such as not knowing the watershed storage capacity of Lion Creek in Oakland. The whole group then discussed the results, which served to highlight differences in the understanding of the feasibility and benefits of different actions. For example, EBRPD and State Coastal Conservancy staff had different viewpoints about the potential performance of green infrastructure along Doolittle Drive. Some of these disagreements were resolved in the meeting, others required further investigation, and some remain unanswered as the information to resolve them is not yet available. Using the evaluation criteria provided the working group and project team to identify the opportunities and limitations for solving some of the more complex challenges, which was an important step towards implementation.

Example Evaluated Adaptation Responses

The first set of adaptation responses evaluated by the working group addressed possible modifications to Interstate 880 where it crosses Damon Slough. The proposed strategies included:

- Elevate the at-grade portion of I-880 in its current alignment
- Reroute I-880 to a protected location
- Transfer traffic to other modes (rail, transit) and other roadways (I-580)
- Do nothing to existing roadway, temporarily reroute traffic during flood event disruptions

The working group evaluated these options with a particular focus on feasibility. Much of the group discussion focused on how in the near term, the do nothing option is most likely. Rerouting the interstate or seeking alternatives roads or modes to carry the existing goods and commuter traffic were seen as unlikely options due to capacity constraints and the difficulty in finding a new roadway alignment. The working group had many questions about how the roadway would be elevated, including what the final elevation would be, how long of a segment would need to be elevated, and how would Caltrans and Alameda County Flood Control coordinate to not only raise the roadway but also widen it where it crosses Damon Slough.

The working group also discussed the changes that could be made to Damon Slough to improve flood control channel capacity. These included actions within and outside the study area given that the slough is connected to the greater watershed, and these connections have implications on the level of flood protection provided by the channel. Proposed actions evaluated included:

- Raise Damon Slough levees to increase channel capacity
- Widen the channel and build living levee along Damon Slough to increase channel capacity (requires expansion into adjacent parking lots)
- Implement the adopted 2015 Oakland Coliseum Specific Plan
- Install watershed improvements to reduce flood volumes and offset peak flows (e.g., upstream storage, infiltration, retention)

The working group discussed the relative benefits and limitations of each of these actions in terms of how much flood storage they would provide and how much they would reduce peak flows through Damon Slough. The working group determined that any successful flood risk reduction strategy in this area would need to incorporate aspects of all four actions. It was also clear to the group that no one agency, whether at the city, county or state level, could implement these actions single-handedly.

The third set of adaptation responses evaluated included physical interventions and governance arrangements that could improve Doolittle Drive on Bay Farm Island. Proposed actions evaluated included:

- Install riprap and Bay Trail along Doolittle Drive with added elevation
- Install seawall and Bay Trail along Doolittle Drive with added elevation
- Install living levee and Bay Trail along Doolittle Drive with added elevation
- Caltrans transfers Doolittle Drive to local control under the City of Oakland or Alameda

In this area, it was necessary to consider the physical structure and governance arrangement in parallel because some of the new configurations would not meet Caltrans state highway standards and therefore would require a variance from the standards or a transfer or ownership to a new entity, such as the City of Oakland. By evaluating these options, the working group realized they wanted to investigate possible green infrastructure options for shoreline protection. There was strong consensus for pursuing a Bay Trail alignment that could also provide flood risk reduction benefits. Despite the widespread support for a multi-benefit recreation and flood control project in this area, there is no clear lead agency to plan, seek permits for, and implement such a project. While many of the vulnerabilities identified for individual assets could be addressed by a single agency provided that funding was available and regulatory issues were not significant, issues such as those found at the intersection of Damon Slough and Interstate 880 are much more difficult to address within current approaches to addressing flood risk.

Pathways to Implementation

The final working group meeting, held March 2016, focused on developing pathways to implementation, identifying next steps, and discussing how the study's findings would fit into ongoing projects and future adaptation efforts. ART Program staff used the input from the field trips and the evaluation criteria meeting in combination with the feedback received on the drafts of initial draft of the report to outline remaining questions and roadblocks to action. The working group then spent time thinking through the information, coordination, advocacy, funding, permits, and process approaches that would be needed for successful adaptation response implementation. Working group members identified future roles for their agencies, the ART Program, and other local, regional and state agencies in both near- and long-term implementation. See Figures 17 and 18 for examples of how the working group answered the issues of what information is needed, who the lead and partners would be, early actions and other components of the implementation pathways to addressing vulnerabilities at Interstate 880 and Doolittle Drive.

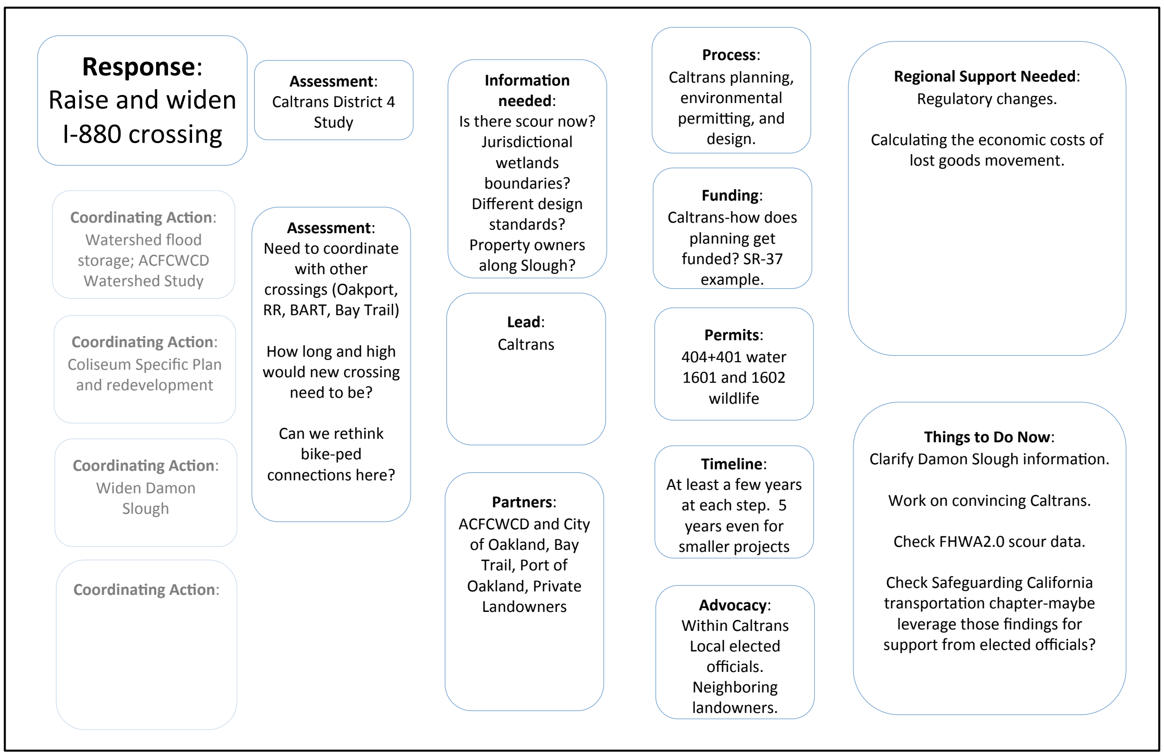


Figure 17. Implementation Pathway: I-880 Vulnerability and Possible Adaptation Responses

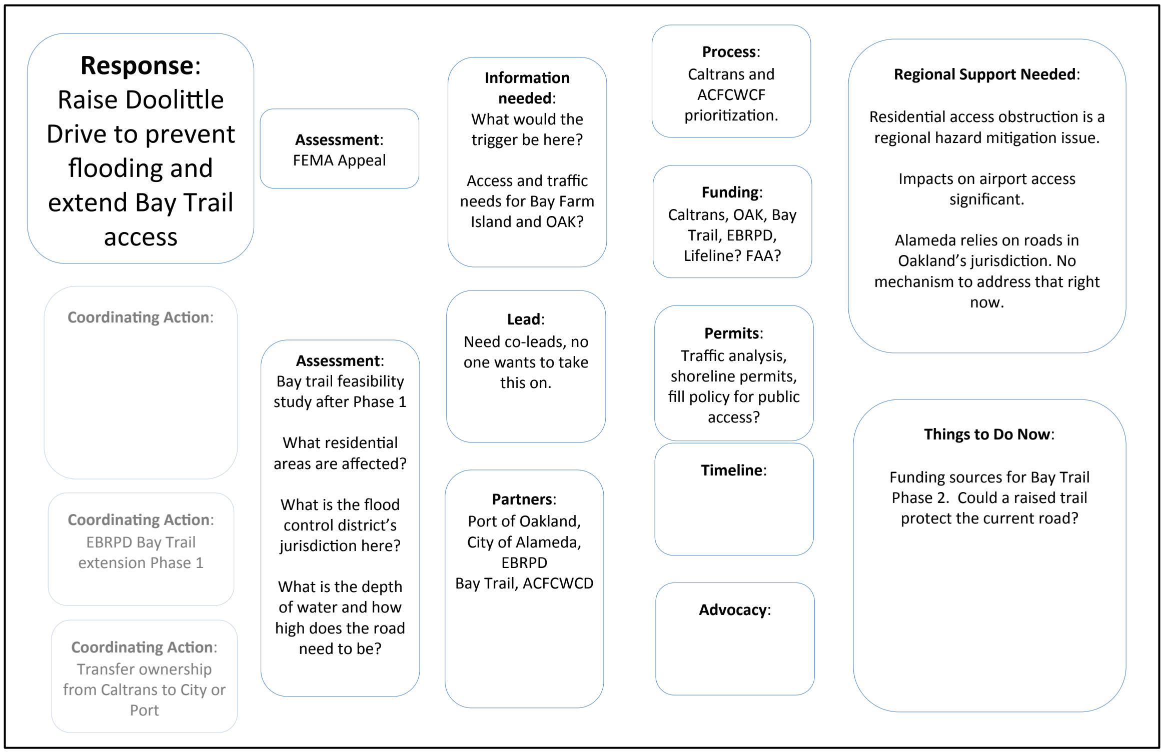


Figure 18. Implementation Pathway: Doolittle Drive Vulnerability and Possible Adaptation Responses

Conclusion and Recommendations

The ART Oakland/Alameda Resilience Study is an important example of a local-scale collaborative planning project. The study assessed vulnerabilities, determined planning priorities, and developed adaptation responses and implementation options. Findings in this study have both drawn on and feed into the planning, regulatory and project work being advanced by working group members. The outcomes of the study include:

- A vulnerability and risk assessment completed for the study area;
- Preliminary adaptation strategies for specific assets and geographic areas of the study area;
- Project findings and recommendations included in City of Oakland 2015 Oakland Coliseum Area Specific Plan;
- Integration of findings into the Resilient Oakland, a component of the 100 Resilient Cities Initiative;
- Support and assistance to the City of Oakland in developing a local hazard mitigation plan and recovery plan;
- Integration into the Oakland Sea Level Rise Roadmap and the development of findings and analysis to be included in the roadmap;
- Oakland International Airport proposal to reduce current and future flood risk to airport facilities;
- East Bay Regional Park District's Bay Trail expansion plans for Martin Luther King Shoreline Park; and

- A better understanding of the need for regional, state and federal support and action to make local adaptation possible.

These outcomes serve this specific study area and can support planning in other locations around the Bay.

The study area (Figure 2) represents a microcosm of the planning issues and vulnerabilities that exist throughout the Bay Area, where significant transportation, natural habitats, neighborhoods, and people share the shoreline. The study is also the first project for which the ART Program and ABAG Resilience Program evaluated and developed responses for both flooding and seismic hazards together, and analyzed the combination of coastal and riverine flooding.

ART Program staff and working group members continue efforts to implement recommendations developed in this study and to use the findings to inform resilience-building efforts in the study area and throughout the region. For example, the City of Oakland has incorporated findings and actions from this study into their 2016 Local Hazard Mitigation Plan Update, the Downtown Oakland Specific Plan, and the City of Oakland's Sea Level Rise Roadmap. The study can also inform other efforts including the City of Alameda's Hazard Mitigation Plan Update and the regional Resilient by Design Initiative.

The ART Program will continue to support these and other local adaptation efforts by sharing assessment findings, advocating at the regional, state and federal level for regulatory changes and funding, and developing adaptation actions and implementation options that will build the region's capacity to address the sea level rise and other natural hazards.

As an example, the agency that leads the ART Program's lead agency, has been conducting a fill policy review and commissioner workshop series to start the process of aligning regulatory and planning efforts to build climate resilience across the Bay area. The ART Program's partnerships with the State Coastal Conservancy, ABAG, Metropolitan Transportation Commission (MTC), Caltrans, and other state and regional agencies will continue to bring attention to critical adaptation issues, especially for critical regional assets such as shoreline natural habitats, transportation, and communities. In the immediate future, the ART Program is continuing assessments in Contra Costa County, beginning work on a regional assessment and adaptation plan in partnership with MTC and the Bay Area Regional Collaborative, and working at the regional planning scale on the updated Sustainable Communities Strategy with MTC and ABAG. The ART Program will continue to serve as a resource for Oakland/Alameda Resilience Study working group members and all local governments in the Bay Area as they begin implementing adaptation projects.

Acknowledgements

Throughout the study process, ART Program staff worked with participating agencies and regional partners to integrate findings of other efforts and find synergies between the study and other assessments and work products, and encourage the exchange of local and regional perspectives. The current planning, regulatory, and project work being advanced by working group member agencies is part of, and critical to, improving

resilience in the Oakland/Alameda study area, and the ART Program would like to acknowledge the hard work and dedication of the working group members and the agencies and organizations they represent.

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[i] http://files.mtc.ca.gov/pdf/MTC_ClmteChng_ExtrmWthr_Adtpn_Report_Final.pdf
[ii] http://resilience.abag.ca.gov/
[iii] http://www.adaptingtorisingtides.org/project/bay-area-transportation-climate-resilience-projects/
[iv] For full technical memo, see Appendix B; methods and results available at: http://www.adaptingtorisingtides.org/wp-content/uploads/2015/09/ALA-Report_FINAL_2015.05.26sm_REPORT.pdf
[v] Adapting to Rising Tides Alameda County Shoreline Vulnerability Assessment

[vi] Full descriptions available in: Richter, C.F., 1958. Elementary Seismology. W.H. Freeman and Company, San Francisco, pp. 135-149; 650-653.
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[ix] United States Geological Survey, Southern California Earthquake Center, and California Geological Survey (2008). Uniform California Earthquake Rupture Forecast (UCERF). Available at http://earthquake.usgs.gov/regional/nca/ucerf/
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