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San Francisco Bay Area Rapid Transit District (BART) Climate Change Adaptation Assessment Pilot

DECEMBER 2013

FTA Report No. 0074
Federal Transit Administration

PREPARED BY
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Parsons Brinckerhoff, Inc.

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Metric Conversion Table

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
LENGTH				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
VOLUME				
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liter	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: volumes greater than 1000 L shall be shown in m^3				
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
TEMPERATURE (exact degrees)				
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C

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13. ABSTRACT

The objective of this pilot study was to evaluate the impacts of climate change on the San Francisco Bay Area Rapid Transit District (BART) infrastructure and to develop and implement adaptation strategies against those impacts. Climate change hazards considered are sea-level rise, downpours, and flooding. The study focuses on four specific types of assets: station and maintenance facilities, track and aerial structures, train control, and traction power. It evaluates the current and future impacts of the hazards and uses this information to assess the risk of four specific assets. Adaptation strategies are developed and linked to various departments within the organization.

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ABSTRACT

The objective of this pilot study was to evaluate the impacts of climate change on the San Francisco Bay Area Rapid Transit District (BART) infrastructure and to develop and implement adaptation strategies against those impacts. Climate change hazards considered are sea-level rise, downpours, and flooding. The study focuses on four specific types of assets: station and maintenance facilities, track and aerial structures, train control, and traction power. It evaluates the current and future impacts of the hazards and uses this information to assess the risk of four specific assets. Adaptation strategies are developed and linked to various departments within the organization.

Introduction

The San Francisco Bay Area Rapid Transit District (BART) is taking proactive steps to understand and address climate change impacts on BART assets. This project is one of seven pilots funded by the Federal Transit Administration (FTA).

Element 1—Climate Hazard Scenarios in the Bay Area

For BART, sea-level rise and changes in precipitation trends (including downpour and flooding) have the potential to severely disrupt operations and damage critical infrastructure in the Bay Area. For this study, three major climate hazards were selected for evaluation—sea-level rise, downpour, and flooding.

The Independent Science Board (ISB) recommended adopting an estimated rise in sea level of 16 in. by 2050 and a sea-level rise estimate of 55 in. by 2100 (Mount et al. 2007). SLR data maps were developed using NOAA coastal service center mapping methods. The SLR maps developed included different scenarios with 1) either 16 in. or 55 in. SLR and combined with 2) one of three different conditions: the daily high tide, a 100-year storm, and a 100-year storm plus wind waves.

For downpours, the seasonal precipitation trends in the Bay Area are expected to generally remain unchanged (Cal-Adapt 2013). There is a modest tendency predicted for an increase in frequency and magnitude of intense storm events (Cayan et al. 2008).

Flooding patterns in the East Bay are not anticipated to change drastically under climate change; however, increases in precipitation intensity may lead to longer durations of flooding and higher peak flows in rivers and storm drain systems. For 2100 conditions, this study considers areas within the 100- and 500-year FEMA floodplains and areas within ½ mile of either floodplain type as potentially vulnerable to flood events.

Element 2—Vulnerability and Risk Assessment

A risk assessment was done on each of the four BART assets and was generally based on guidance from *ISO 31000: 2009 Risk Management—Principles and Guidelines*. The risk assessment approach considers the likelihood and the consequence. Consequences consider the physical damage to the asset as well as the downtime of the asset or system. The baseline risk assessment also considers 1) the existing risk control measures that may decrease the likelihood of impact and 2) the adaptive capacity that may also reduce vulnerability.

The risk assessment ratings reflect the baseline future condition. The vulnerability is intended to be reevaluated again for future conditions after adaptation strategies have been implemented. The future baseline risk assessed for the four assets and climate hazards ranged from low to very high.

Element 3—Adaptation Strategies

Potential adaptations strategies are identified. The strategies are aimed at increasing the resiliency of the assets and realign BART's business practices to better respond to the climate change impacts. These adaptation strategies fall into one of four categories: Land Use and Planning, Design and Construction, Operations, and Maintenance. A complete list of potential strategies is included in Appendix B-1.

Asset-specific adaptation strategies are identified for each asset investigated. These strategies have a cost-benefit score of 4 or greater as defined in Element 3, are recommended for implementation in the near to medium term, and have low to moderate costs.

Element 4—Link Strategies to BART Organizational Structures and Activities

BART's approach to incorporating adaptation strategies into BART's organization is through mainstreaming climate change strategies through four primary areas of activity: land use and planning, design and construction, operations, and maintenance. The following subsections go into detail on the four areas of activity. Each section was developed to discuss 1) the current business practices or programs, 2) the impact climate change adaptation will have on the organization and business practices, and 3) the new responsibilities that will be assumed by the organization.

Element 5 – Asset Management and Life-Cycle Cost Analysis

Element 5 advances the study by addressing climate adaptation needs through a transit asset management approach and providing a framework for comparatively evaluating the costs to implement adaptive strategies on a life-cycle basis. Integrating asset management and a life-cycle cost analysis into the decision-making process for climate adaptation actions will enable BART to better understand if a climate adaptation measure makes financial sense for the agency, what the least-cost solution might be, and how to integrate the solution into its budgeting process. The approach, using a case study example, can be applied on a programmatic level to inform prioritization and budgetary decision-making processes.

In comparing the two scenarios for a pitched roof adaptation at the Fruitvale train control room, the adaptive scenario was found to be more favorable in direct costs than the business-as-usual scenario on a life-cycle basis. If indirect costs (costs to the user) were to be included, however, there would be a greater cost differential between the two scenarios.

In the future, the pilot expects that the life-cycle analysis will skew further in favor of the adaptive scenario. As the Bay Area experiences more extreme weather events in the future, climate-related incidents are more likely to occur.

Conclusion

This pilot accomplishes BART in taking the first steps towards climate change adaptation by developing and testing a functional framework for climate change adaptation. As chief element of BART's sustainability policy and initiatives, these adaptation strategies are critical to BART's role in combating climate change and enhancing regional sustainability by providing reliable and low-carbon transportation services to the Bay Area.

As a next step BART needs to devise a funding plan so that a comprehensive, system-wide, vulnerability and risk review of BART operating systems and assets can be performed. It is a value-added approach by leveraging the findings from several regional and federal climate change adaptation projects, by applying the methodologies developed through this pilot, and by continuing the broad teamwork that came together during this pilot.

SECTION
1

Introduction

Climate change in the Bay Area is a serious issue. Current and future impacts of climate change, including rising sea level, heavier downpours, heat waves, droughts, and wildfires, pose a threat to transit systems and the communities they serve. The San Francisco Bay Area Rapid Transit District (BART) is taking proactive steps to understand and address these threats as it affects its system.

This project is a pilot was funded via a cooperative agreement with the Federal Transit Administration (FTA). This pilot was conducted in parallel with six other pilots throughout the nation under FTA's Transit Climate Change Adaptation Assessment Pilots.

About BART

BART is a high-speed inter-city and metropolitan rail transit system consisting of 44 stations and over 100 miles of trackway in 4 counties. It provides transit service to patrons in the Bay Area region, which includes more than 100 municipalities. BART is the backbone of the regional and local public transportation network. BART was established in the late 1960s under the notion of "if the Bay Area is to be preserved as a fine place to live and work, a regional rapid transit system is essential to prevent total dependence to automobiles and freeways."

BART is an electrified rail transit system equipped with a state-of-the-art train control system that provides automatic train operations by regulating speeds, station stops, and routing through interlockings. The system also includes a network of communications, computer, and control systems to supervise train operations, control and monitor field equipment, provide patron assistance and information in stations, and other activities related to providing a safe and reliable rail transit system.

Building on Prior Studies

This study builds upon the vulnerability assessment, "Adapting to Rising Tides (ART): Vulnerability to Sea-Level Rise in Selected Communities in the San Francisco Bay Region," funded by the Federal Highway Administration (FHWA) and implemented by the Metropolitan Transportation Commission (MTC), the San Francisco Bay Conservation and Development Commission (BCDC), and California Department of Transportation (Caltrans). The rising sea-level data and respective flooding model developed from the Adapting to Rising Tides (ART) study uses data from the National Oceanic and Atmospheric Administration (NOAA) and serves as a foundation for this study.

Project Study Area

The project study area focuses on the East Bay coastline of the San Francisco Bay Area. The project study area spans from West Oakland to Hayward. The study area was selected to leverage the existing findings from the ART study.

Methodology

The study's framework is organized in the following manner:

- **Element 1**: Identify current and future climate hazards relevant to BART assets and operations. Sea-level rise, downpour, and flooding were selected for this study as the climate hazards of concern. Other climate hazards are important but are not part of the study's scope.
- **Element 2**: Assess and characterize the risk on BART infrastructure and operation. Assess risk on the four selected assets with respect to each hazard. While there are many potentially vulnerable assets, four were chosen to serve as a representative sample of the many assets of the BART infrastructure.
- **Element 3**: Develop adaptation strategies for land use and planning, design and construction, operations, and maintenance. Prioritize the strategies based on the relative cost and benefit.
- **Element 4**: Link the strategies to the organizational structure and activities. Identify current business practices throughout the BART organization to incorporate the strategies in a manner that mainstreams the solution.
- **Element 5:** Connect climate change adaptation with transit asset management approach and provide a framework for comparatively evaluating the costs to implement adaptive strategies on a life-cycle basis.

Objectives

The objective of this study was to develop an evaluation process to assess on the asset level, the vulnerability and risk of BART infrastructure against climate change impacts and to identify a set of applicable strategies that will increase the resiliency against those impacts.

Because of the limited scope of the study and available data, a full comprehensive systemwide study approach was not feasible. Rather, the study approach was a focused study grounded on real scenarios. The study intended for the methodology to be repeatable to other study areas and for the findings to be extrapolated to other BART assets.

The study also aimed to be a valuable example for other transit agencies in its approach to evaluating and addressing climate change. The findings will enable BART to share lessons learned with other rail transit agencies.

Regional Importance

BART cannot afford to let climate change impacts disrupt services or degrade its assets. As one of the premier transit systems providing vital transportation services in Bay Area, BART delivers more than 350,000 daily riders and has become an essential part of the region's economy and quality of life. In an analysis conducted in 2001, BART found that 33 of its then 39 stations were in neighborhoods of concern, as described by MTC through its Lifeline program. The lifeline transportation program supports projects that address mobility and accessibility needs in low-income communities in the region. In addition, in emergency situations, transit services such as BART are even more vital to the community it serves.

Climate Change Mitigation

BART is taking a holistic approach to climate change. In addition to climate change adaptations outlined in this study, BART has efforts focused on climate change mitigation to lessen future impacts by taking steps to reduce greenhouse gas (GHG) emissions. Together, mitigation and adaptation build a comprehensive climate strategy. BART's mitigation efforts are reducing the carbon footprint by "taking cars off the road," reducing energy demand per BART vehicle mile, and pursuing cost effective energy supplies that emit less GHGs.

Assets Included in this Project

Asset Types

This pilot selects the four most vital systems of an automated rapid rail transit system for developing adaptation strategies specific to sea-level rise, downpour, and flooding:

- **Stations and maintenance facilities**: There are currently 44 stations in the existing system and 3 basic types of station construction—aerial, at-grade, and subway. The stations are further classified as center platforms (located between tracks) and external platforms (located on the outside of the two tracks). BART has a total of four rolling stock and shop yards and one yard for other maintenance.
- **Track and alignment structures**: BART's track gage is non-standard at 66 in. (5ft.-6in.). Three basic types of trackway construction are used: at-grade, aerial, and subway. At-grade tracks are typically ballasted track using concrete ties. Aerial and subway tracks are typically constructed using concrete slab track with direct fixation fasteners. Continuous walkways are provided adjacent to all tracks to provide for emergency evacuation and maintenance access.
- **Electric power**: Electrical power in the BART system can be classified into two types: traction power and auxiliary power. Traction power is used

for vehicle propulsion, and auxiliary power is used in passenger stations, train control rooms, and other wayside facilities for lighting, power, control circuits, and other miscellaneous electrical loads. The electric system includes switching stations and traction power substations throughout the system.

- **Train control**: BART's train control system is fully automatic, wherein speed commands are transmitted to trains based on their distance to trains ahead. The speed level transmitted to a train is that which would allow a train separation equivalent to the safe braking distance corresponding to the speed being transmitted. The current system uses the fixed-block technology, wherein train detection is achieved using track circuits or blocks installed in the running rails.

Asset Selection

The four assets assessed as part of this study are the following:

- Station—Lake Merritt Station entrance
- Track—Oakland West track portal
- Power—Oakland Coliseum traction power substation
- Control—Fruitvale train control room

All assets chosen for the study are in Oakland, California, which is included in the ART study area.

BART selected specific assets that are vital to the asset type and are a typical element throughout the system. Another requirement of the selected asset was that there was existing knowledge on the asset's risk and consequence. The specific assets also underwent a screening process targeted to obtain a variety of pathways to vulnerability, a range in severity of climate impacts, and a spectrum in overall impact to the BART system.

There are a number of other facilities in this study location and others within the BART system that may be highly vulnerable to climate change, but they were not addressed in this study. This framework is intended to be repeatable and can be used across the BART system and other transportation systems in future studies.

Asset and Bay Elevations

Table 1-1 shows the asset elevation and elevation difference with respect to the San Francisco Bay current mean sea level (MSL). The MSL refers to the arithmetic mean of hourly heights observed over the National Tidal Datum Epoch. The table is developed using asset elevations in North American Vertical Datum 1988 (shown as +ftAD) with the MSL of +4.0ftAD (Knowles 2010). The process used in evaluating the actual areas expected to be impacted by sea-level rise is explained in Element 1, Sea-Level Rise. Table 1-1 includes expected elevation difference as a result of 16-in. and 55-in. SLR in years 2050 and 2100, respectively, as discussed in Element 1 of this report.

Table 1-1 *Current and Projected Elevation Difference of Assets to Average Yearly High Water Level*

Location	Elevation in +ftAD	Current Elevation Difference	Year 2050 Elevation Difference	Year 2100 Elevation Difference
Lake Merritt Station entrance	+31ftAD to +34ftAD	+27 ft to +30 ft	+26.7 ft to +28.7 ft	+22.4 ft to +25.4 ft
Oakland West track portal (street level)	+13ftAD	+9 ft	+7.7 ft	+4.4 ft
Oakland Coliseum traction power substation	+12ftAD to +14ftAD	+8 ft to + 10 ft	+6.7 ft to +8.7 ft	+3.4 ft to +5.4 ft
Fruitvale train control room	+34ftAD to +36ftAD	+30 ft to +32 ft	+28.7 ft to +30.7 ft	+25.4 ft to +27.4 ft

Station: Lake Merritt Station Entrance

Lake Merritt station is located in downtown Oakland, about a half mile east of Broadway, near I-880, I-24, and Lake Merritt. The neighboring area includes residences, offices, and Laney College. The Immediate surrounding area is gently sloped, and the site slopes from about +27ft at the entrances on the east side of Oak Street to about +30ft above MSL at the entrances on the west side.

The station has two entrances located on ground level of a plaza that includes station mechanical equipment housing and structures. The plaza previously included a multi-story building that was torn down in recent years. The plaza also includes a fountain on the first below-ground level with large opening at ground level.

Figure 1-1

Atrium to Street Level at Lake Merritt Station

The four public stair entrances are enclosed in glass and lead down to the first level below ground, where the ticketing area is located. Stairs, escalators, and an elevator lead down to the tracks.

Figure 1- 2

Lake Merritt Station Entrance

The Lake Merritt station also includes the BART police headquarters.

The main areas of focus for this study are the ground level area and the first below-ground level of the station entrances. General impacts to the tracks and the BART police headquarters are discussed, but the major asset of focus will be the immediate areas of the station entrance.

Figure 1-3

Lake Merritt Station Entrance 1st Below-Ground Level

Track: Oakland West Track Portal

The track portal near the Oakland West station is the East Bay entrance to the Transbay tube, a crucial connector for the BART system. The track portal is located about one mile west of the station, between 7th Street and the San Francisco Bay Trail, among port staging yards. The topography of the area is generally flat, but the area to the south of the portal is slightly higher and slopes toward the portal entrance, which at ground level is about presently +9ft above the MSL.

The tracks that enter the portal transition from elevated to below-ground between the crossover at Maritime Street and the portal. The at-grade portion of the tracks is fenced off, and the fence is anchored on a concrete wall. The concrete wall varies in height from about 2–3 feet above the road on the north (road) side and is roughly the same height above ground on the south side.

Figure 1-4

Oakland West Track Portal

A gate to the portal is located at street level along 7th Street on the north side.

Figure 1-5

Oakland West Portal Gate

Credit: Google maps

Power: Oakland Coliseum Traction Power Substation

The Oakland Coliseum station is located in East Oakland, across San Leandro Street and the Arroyo Viejo from the Oakland Coliseum. The traction power substation is adjacent to the station, and both the station and substation are located underneath the aerial tracks. The area is relatively flat, and the station and traction power substation elevations range from about +8ft to +10ft above MSL and slope down from the southeast to the northwest.

The parking lot on the northeast side of the station connects to the station via a pedestrian underpass that crosses the adjacent Union Pacific rail tracks. The parking lot ranges in elevation from about +5ft to +9ft above MSL.

The Oakland Coliseum Substation receives 34.5kv AC from the Watson Ave Switching Station and transforms it to 1000V DC to electrify the third rail.

Figure 1-6

Oakland Coliseum Traction Power Substation (Northwest Edge)

Figure 1-7

Oakland Coliseum Traction Power Substation (View from San Leandro Street)

The traction power substation is due to be replaced. Construction is estimated to start in late 2013 for a duration of 10 months. The replacement work is being done under the Traction Power Renovation Program.

Control: Fruitvale Train Control Room

The Fruitvale station is located in the Fruitvale district of Oakland. It sits within a transit village consisting of shops, offices, apartments, and the Oakland Public Library. The train control room is located adjacent to the Fruitvale station, underneath the aerial tracks.

The train control room and station area ranges in elevation from approximately +304ft to +32ft above MSL; the adjacent transit village area ranges in elevation from approximately +32ft to +36ft above MSL.

Equipment maintained in the train control room include those for train control (MUX, operation alarms, interlocking system), communications (emergency and maintenance telephone, remote monitoring, elevator intercom, station communications), and power (backup battery, distribution).

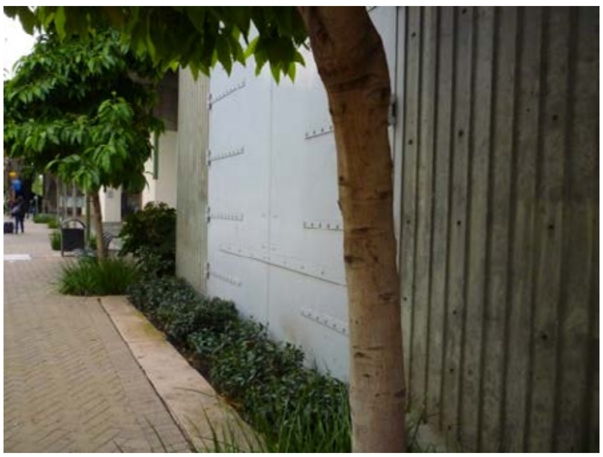


Figure 1-8

Outside of Fruitvale Train Control Room

Figure 1-9

Fruitvale Train Control Room Roof

Figure 1-10

Inside Fruitvale Train Control Room

SECTION

2

Element 1—Climate Hazard Scenarios in the Bay Area

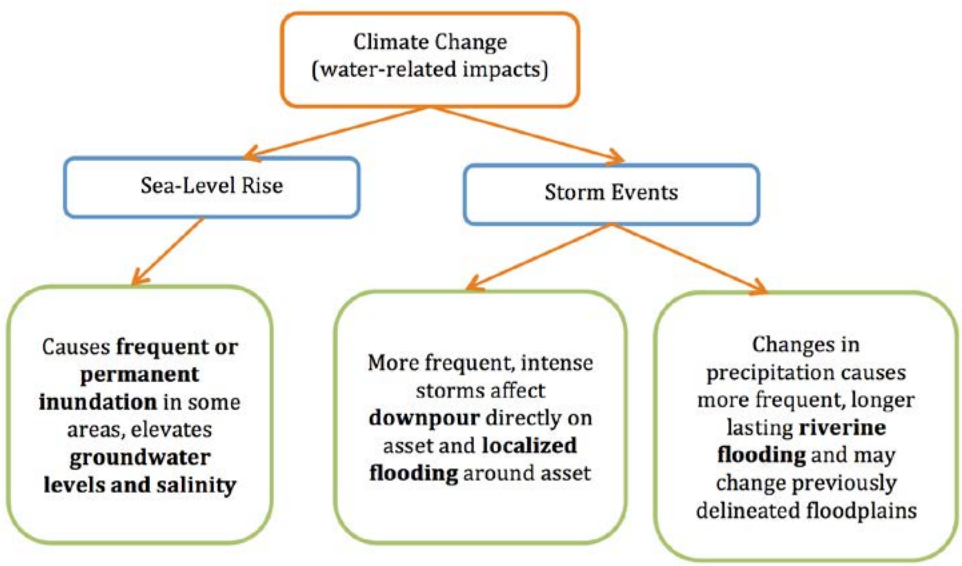
Climate change is expected to have very significant impacts in California and is predicted to impact temperature, precipitation, wildfire, sea-level rise, and coastal marine upwelling and currents (PIER 2012). For BART, sea-level rise and changes in precipitation trends (including downpour and flooding) have the potential to severely disrupt operations and damage critical infrastructure in the Bay Area. For this study, three major climate hazards were selected for evaluation—sea-level rise, downpour, and flooding.

Sea-level rise is expected to cause permanent inundation in some areas, and cause more frequent inundation in others when combined with storm effects such as precipitation, storm surge, and wind waves.

Changes to precipitation will impact rainfall experienced locally at asset sites—in the form of direct rainfall on the assets, and localized flooding in the area—and will impact regional riverine flooding. The relationship between climate change, sea-level rise, and changes to precipitation is shown in Figure 2-1.

Figure 2-1

Climate Impacts



The first hazard of the study, sea-level rise, is evaluated at the periods researched in NOAA's ART study timeline, year 2050 and 2100. The final two hazards, downpour and flooding, are evaluated at the present and in the year 2100.

Sea-Level Rise

Sea-level rise is the rise in mean sea level due to melting ice caps and warming ocean water. Sea-level rise predictions for 2050 and 2100 are the focus of this study, and the San Francisco BCDC and ART sea-level rise predictions were used to determine which areas may be affected by sea-level rise.

The ART study predictions for inundation, 1-in-100-year storm events, and 1-in-100-year storm events with wind waves were evaluated in the study area.

Impacts on groundwater in the area are also discussed for 2050 and 2100.

The ART Project Management Team selected 16 in. as the predicted mid-century sea-level rise (ART 2012). The Independent Science Board (ISB) established by California Governor Schwarzenegger recommended adopting an estimated rise in sea level of 16 in. by 2050 and a sea-level rise estimate of 55 in. by 2100 (Mount et al. 2007). Other sea-level rise predictions, including the USGS Cascades project data, was evaluated and found to have similar predictions for the four project asset locations (Knowles 2009).

Background on ART Sea-Level Rise Data

The GIS data sea-level rise data used in the ART were created in 2011 by AECOM using the NOAA Coastal Services Center mapping methods and should be used for planning, education, and awareness purposes. It is not intended for site-specific analysis. The study area is analyzed for the various sea level change scenarios.

The data labels used in this study are listed in Table 2-1.

Table 2-1 *Sea-Level Rise (SLR) Data*

Color	Label	Definitions
		Year 2050 SLR Scenarios
	16-in. SLR + MHHW*	16 in. of sea-level rise at daily high tide
	16-in. SLR + MHHW, low-lying	16 in. of sea-level rise at daily high tide in areas not hydrologically connected***
	16-in. SLR + 100-yr SWEL	16 in. of sea-level rise + 100 yr storm (100-yr stillwater level)
	16-in. SLR + 100-yr SWEL, low-lying	16 in. of sea-level + a 100-yr storm (100-yr stillwater level) in areas not hydrologically-connected
	16-in. SLR + 100-yr SWEL + wind waves	16 in. of sea-level rise + 100-yr storm with wind waves
		Year 2100 SLR Scenarios
	55-in. SLR + MHHW	55 in. of sea-level rise at daily high tide
	55-in. SLR + MHHW, low-lying	55 in. of sea-level rise at daily high tide in areas not hydrologically-connected***
	55-in. SLR + 100-yr SWEL	55 in. of sea-level rise + 100 yr storm (100-yr stillwater level)
	55-in. SLR + 100-yr SWEL, low-lying	55 in. of sea-level + a 100-yr storm (100-yr\ stillwater level) in areas not hydrologically-connected
	55-in. SLR + 100-yr SWEL + wind waves	55 in. of sea-level rise + 100-yr storm with wind waves

*MHHW = Mean high higher water
**SWEL = Stillwater elevation
***Hydrologically-connected refers to areas whose elevation is predicted to be below the inundation level and where overland flow paths are apparent. Not hydrologically-connected refers to those areas where overland flow paths are not apparent.

Sea-Level Rise in 2050

Inundation

Refer to Figures 2-2 to 2-4 for areas of potential inundation resulting from sea-level rise in 2050. The areas of 16 in. of inundation are limited in the study area. There are a couple areas near the Oakland Coliseum and Lake Merritt that fall into the not hydrologically-connected areas. A more in-depth study would need to be conducted to determine if there is a real connectivity in those areas.

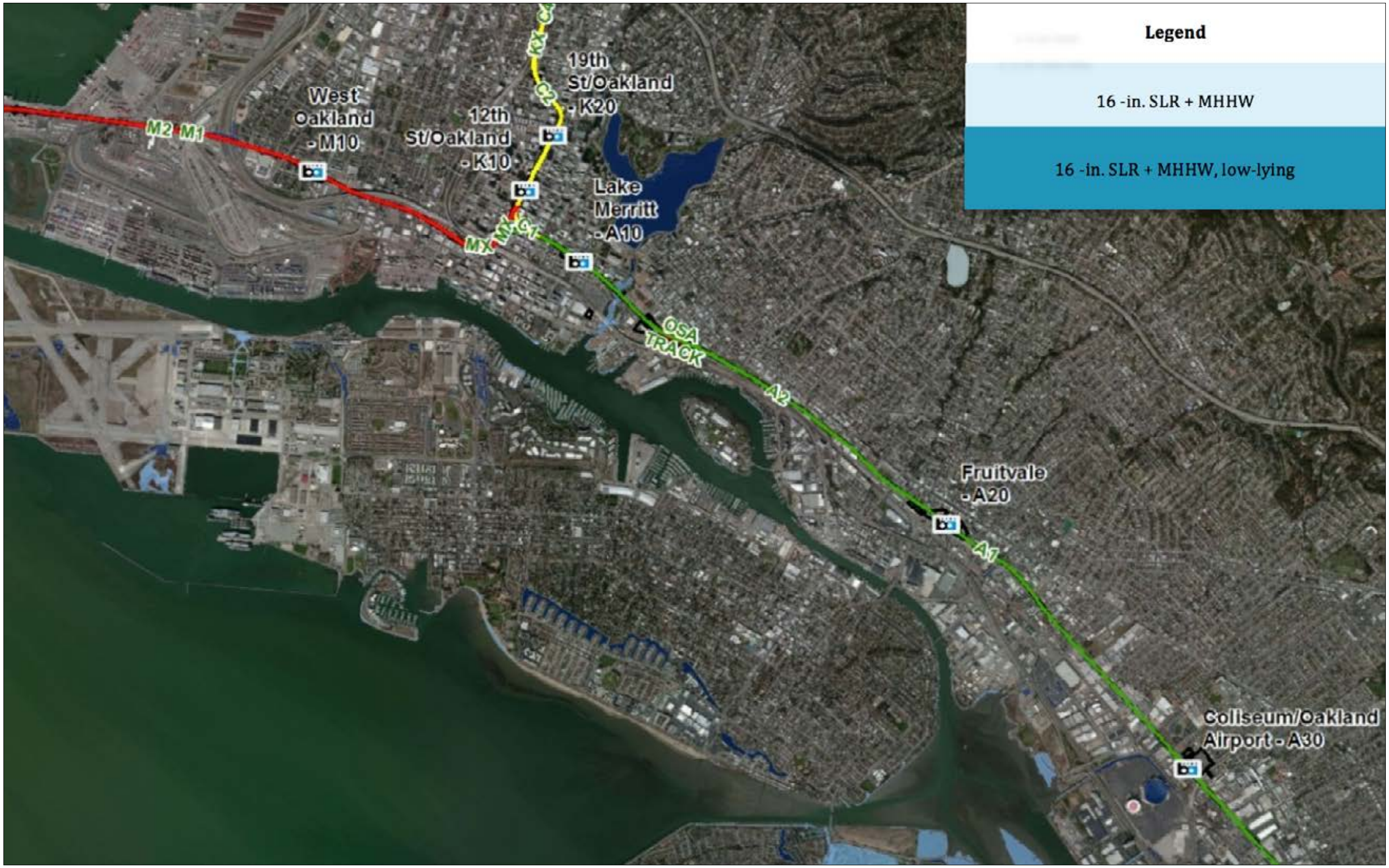


Figure 2-2 *16 in. of Sea-Level Rise*

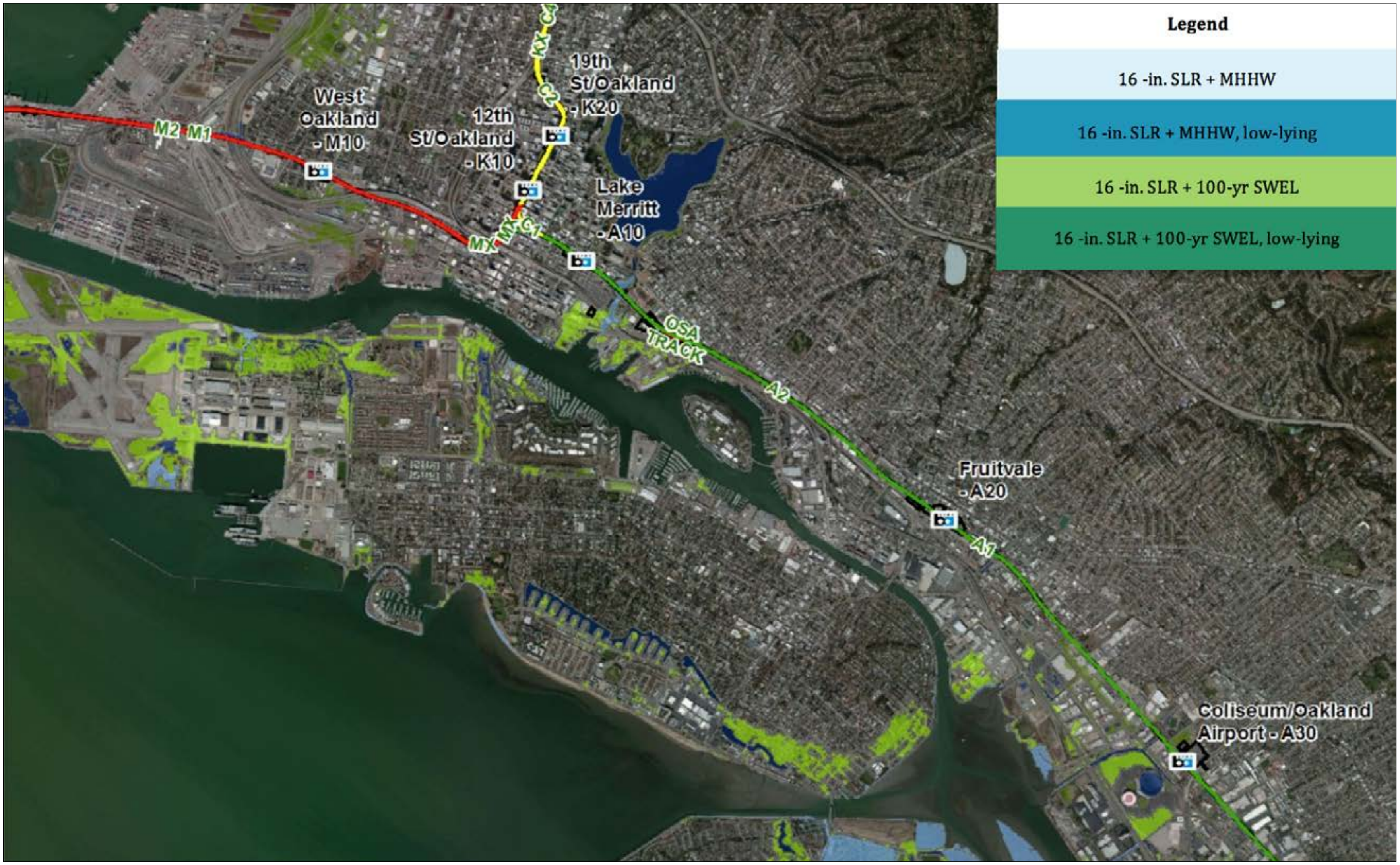


Figure 2-3 *16 in. of Sea-Level Rise and 100-Year Storm Event*

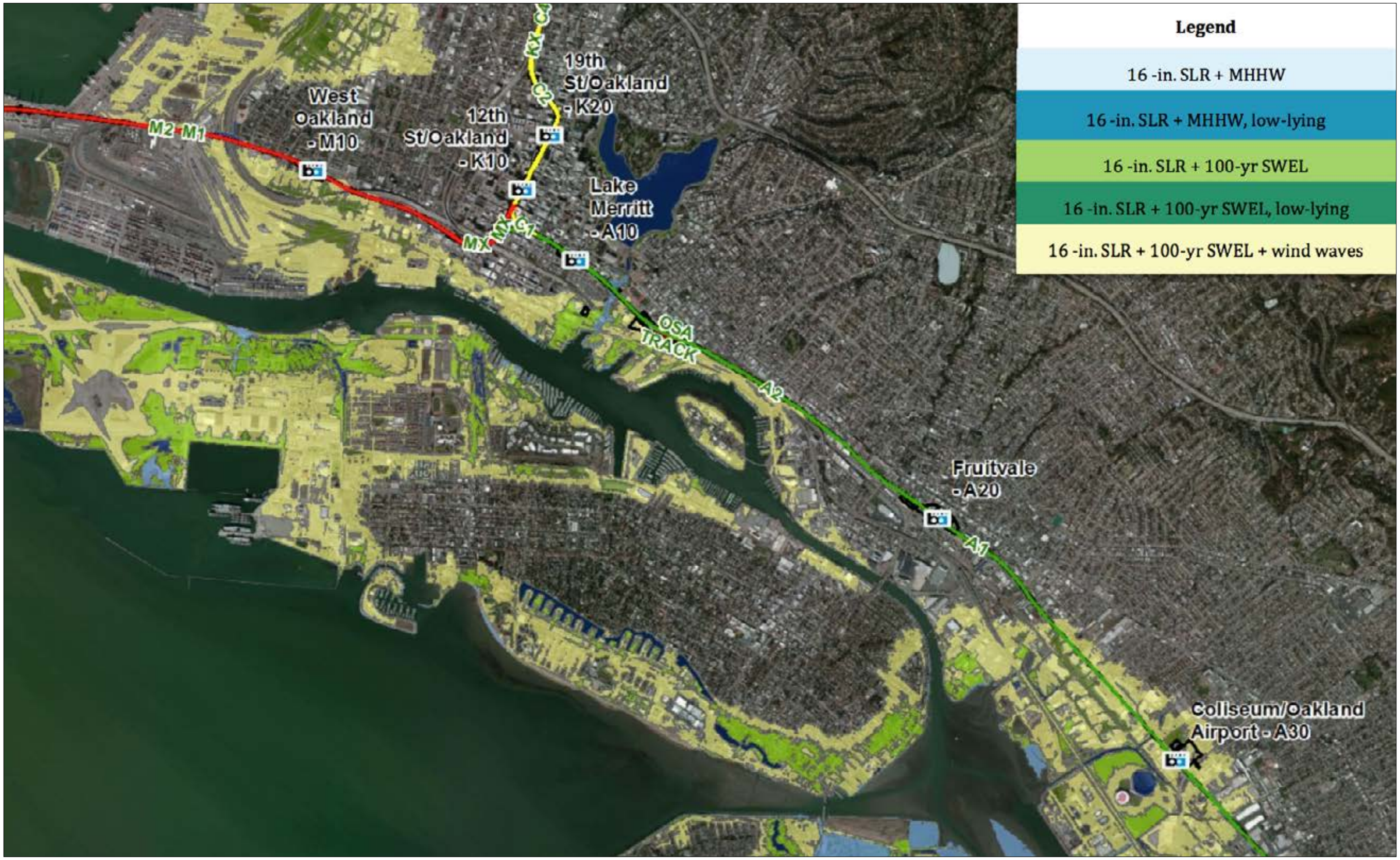


Figure 2-4 *16 in. of Sea-Level Rise and 100-year Storm Event with Wind Waves*

Impacts to Groundwater

Data related to the impact of sea-level rise on groundwater are limited; however, it is generally assumed that a rise in sea level could lead to a rise in groundwater levels and salinity levels of groundwater (ART 2012).

Sea-Level Rise in 2100

The ART Project Management Team selected 55 in. as the predicted end-of-century sea-level rise.

Inundation

Refer to Figures 2-5 to 2-7 for areas of potential inundation resulting from sea-level rise in 2100.

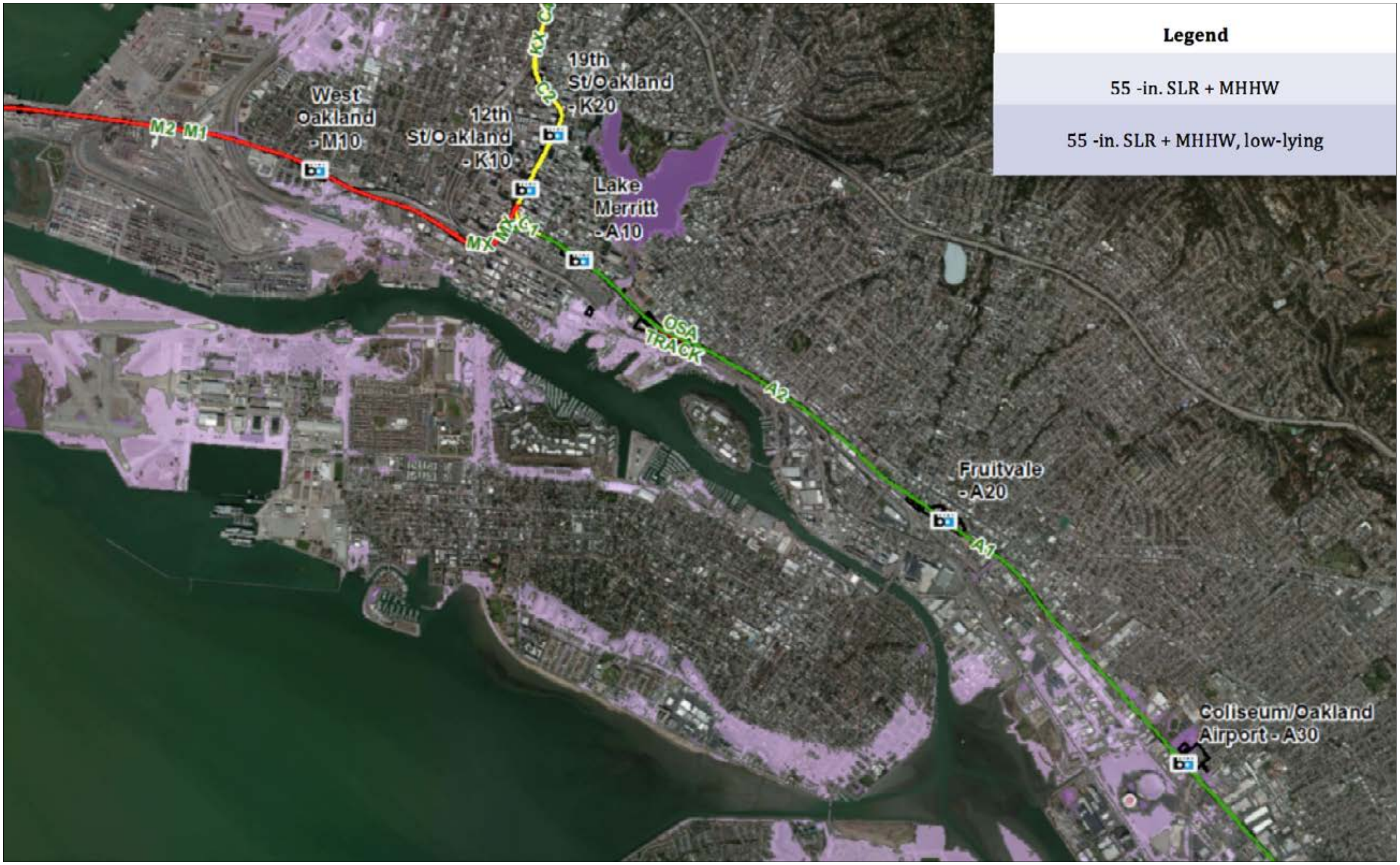


Figure 2-5 *55 in. of Sea-Level Rise*

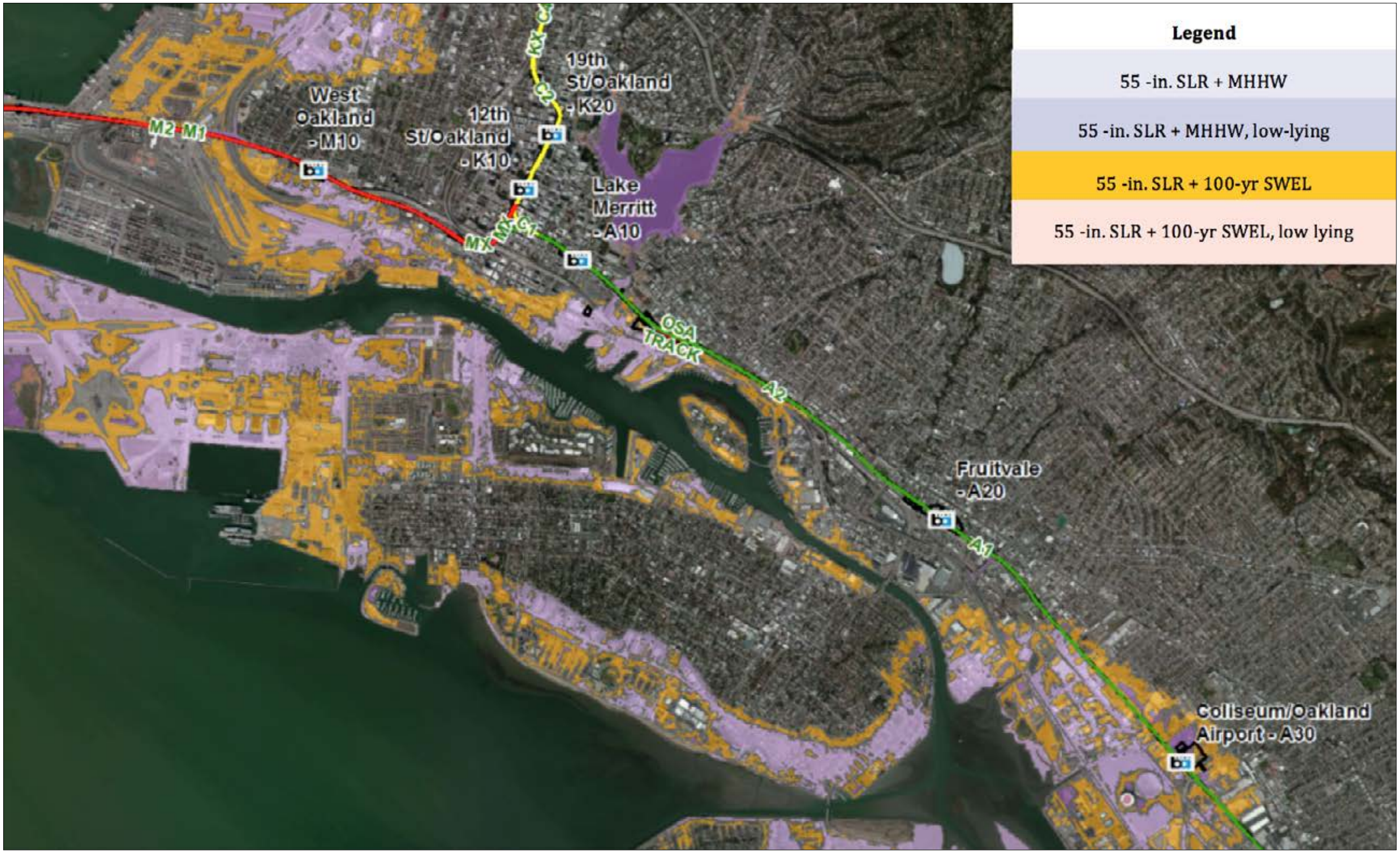


Figure 2-6 *55 in. of Sea-Level Rise and 100-Year Storm Event*

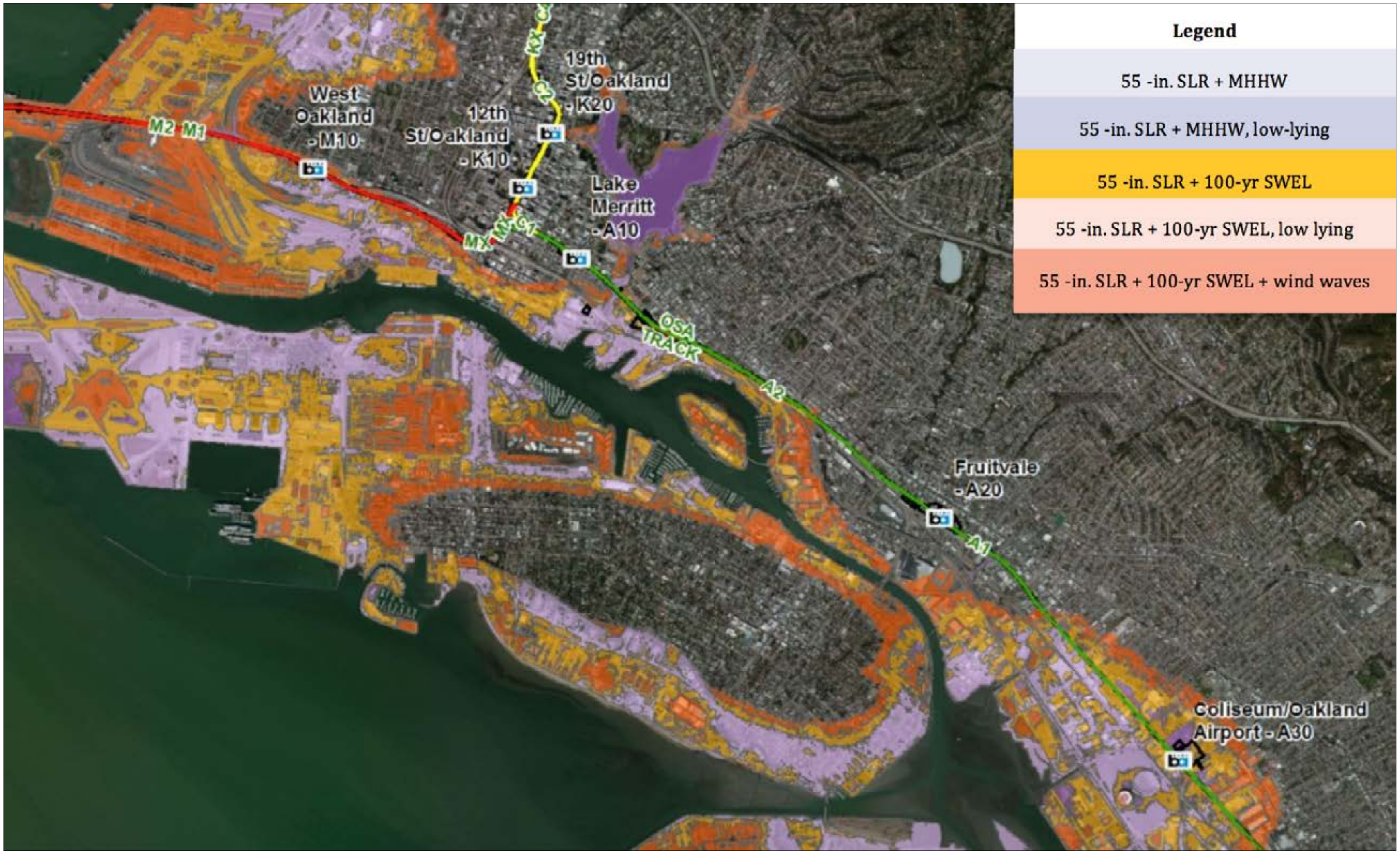


Figure 2-7 *55 in. of Sea-Level Rise and 100-Year Storm Event with Wind Waves*

Impacts to Groundwater

Data related to the impact of sea-level rise on groundwater are limited; however, it is generally assumed that a rise in sea level could lead to a rise in groundwater levels and salinity levels of groundwater.

Downpour

For the purposes of this study, downpour is considered rain that falls onto the project assets, such as building roofs and tracks, and that has the potential to cause localized flooding in the immediate asset area. Precipitation intensity and storm duration are considered in the current and future conditions.

Current Conditions

California experiences a Mediterranean seasonal precipitation regime—dry and warm summers, with mild and damp winters. The rainy season in the Bay Area generally lasts from October 15–April 15, and the mean annual precipitation of the study area ranges from 19–22 in. The 1-in-100-year, 1-hour storm intensity in the study area ranges from 1.0–1.5 inch/hr (USDC 1961).

Historical rainfall data close to the study assets is shown in Figure 2-8 and Figure 2-9.[1] The data used are freely available online and went through a cursory data scrub to remove outliers with data flags. The figures serve to illustrate the typical range in precipitation intensity observed in the Bay Area.

[1] NOAA-supported weather stations in proximity of the study area were found in Berkeley and San Leandro. However, no data were available beyond 1991 and 1990 for the Berkeley and San Leandro stations, respectively.

Figure 2-8

Berkeley Hourly Precipitation Data, 1948–1991

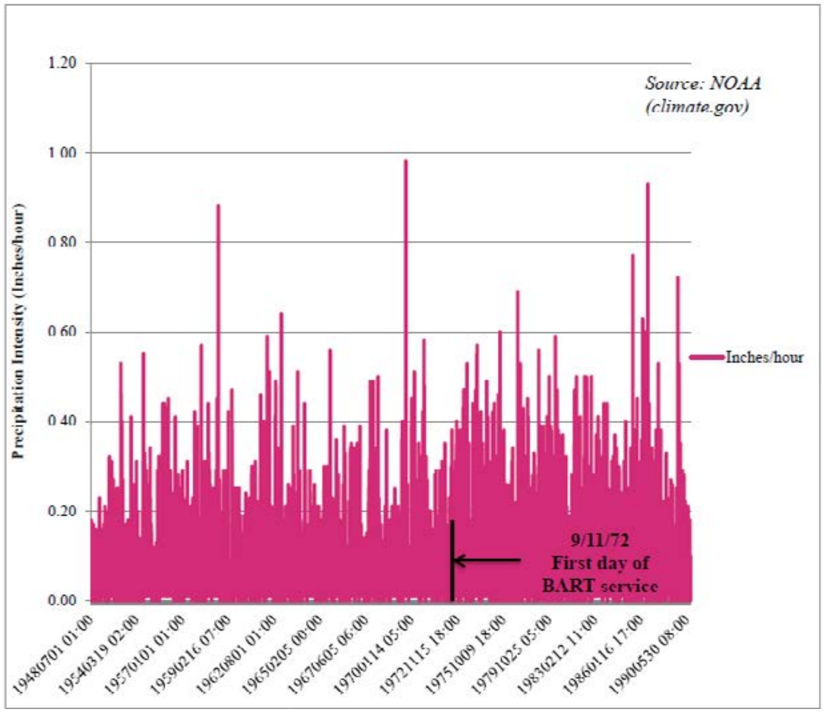
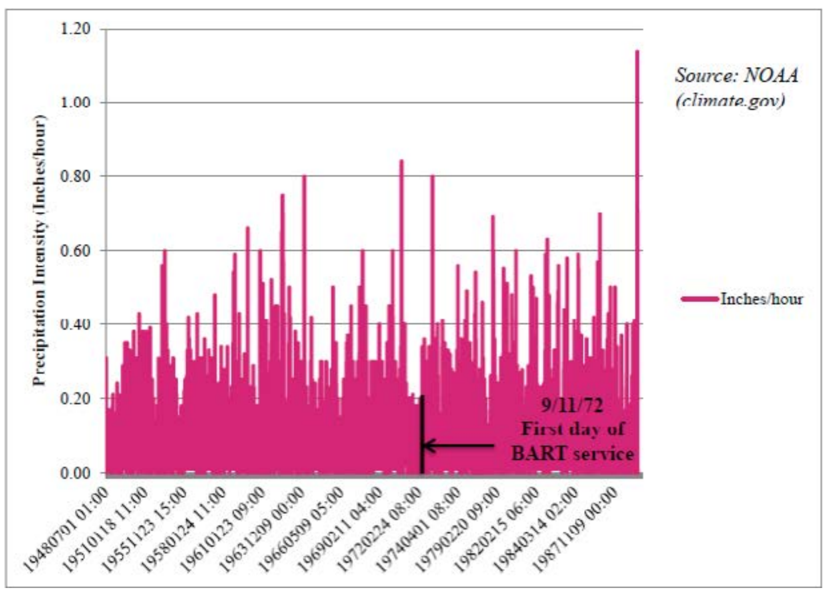


Figure 2-9

San Leandro Hourly Precipitation Data, 1948–1990



Future Conditions

The seasonal precipitation trends in the Bay Area are expected to generally remain unchanged (Cal-Adapt 2013). There is a modest tendency predicted for an increase in frequency and magnitude of intense storm events (Cayan et al. 2008). Thus, while the amount of precipitation may stay roughly the same, the Bay Area may see a slight increase in frequency of intense storms.

In other areas of the globe, governments have recommended increasing the storm design requirements used for designing new developments. In the UK's "Planning Policy Statement 25," sensitivity ranges have been published for future time periods.

Using a similar approach, a 30 percent increase in precipitation intensity for a given storm event in 2100 is recommended. For example, for the 1-in-100-year, 1-hour storm intensity in the study area, which ranges from 1.0–1.5 in., anticipating an increase to 1.3–2.0 in. is recommended.

Table 2-2

Precipitation Design Criteria

Present (2013) 1 in 100 Year 1 Hour Storm Intensity (East Bay)	Recommended Anticipated Increase	Future (2100) 1 in 100 Year 1 Hour Storm Intensity (East Bay)
1.0–1.5 (in./hr)	+30%	1.3–2.0 (in./hr)

The 1-in-100-year storm intensity criterion comes from the BART Facilities Standards (BFS) for critical drainage structures.

Flooding

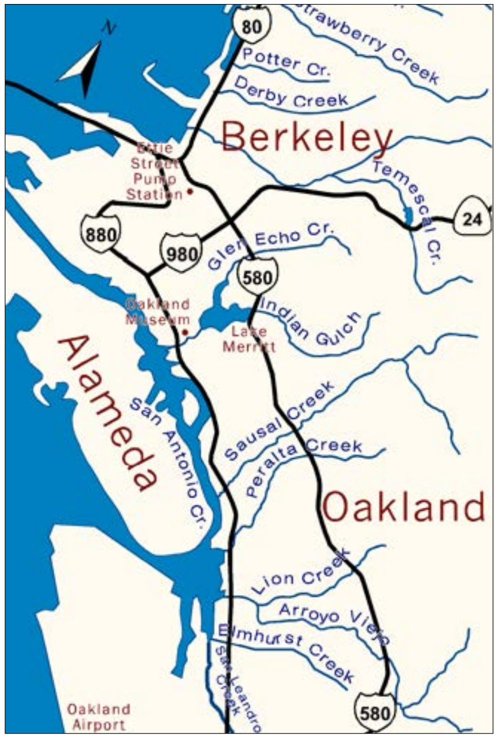
For the purposes of this study, flooding is riverine flooding defined as the inundation of an area that is typically dry, caused by increased flow in nearby water bodies such as rivers, creeks, and canals. This does not refer to coastal flooding which is covered in the sea-level rise discussion.

Current Conditions

Riverine flooding in general in the East Bay is impacted by rainfall and operations of rivers, including any reservoirs or pumping schemes. In the study area are a few creeks and canals and one lake. The main water bodies relevant to the study are Lake Merritt, Sausal Creek, Peralta Creek, Lion Creek, and Arroyo Viejo.

Figure 2-10

East Bay Water Bodies



Source: Oakland Museum of California Creek Guide

Riverine Flooding at Lake Merritt Station Entrance

Located approximately 0.25 miles away, Lake Merritt and the draining stream were identified as the closest water bodies to the Lake Merritt Station Entrance. The flooding in the Lake Merritt area is mitigated by the Lake Merritt Flood Control Project in all but the most extreme storm events. A flood control structure was constructed in response to the 1962 flood and includes tide gates that can be closed to prevent an influx of sea water in the case of a predicted storm event (Lake Merritt Institute 2013).

A by-pass around the flood control barrier, completed in 2013, will allow small watercraft and wildlife to pass between the lake and the Bay. It is not anticipated to adversely affect the flood control capabilities of the lake. Figure 2-11 shows the 100- and 500-year FEMA floodplains in the Lake Merritt area.

Figure 2-11 *Lake Merritt 100- and 500-Year FEMA Floodplains*

Riverine Flooding at the Oakland West Track Portal

No rivers were identified in the proximity of the Oakland West Track Portal.

Riverine Flooding at the Fruitvale Train Control Room

Rivers located in the proximity of the Fruitvale Train Control Room include Sausal Creek and Peralta Creek. Sausal Creek and Peralta Creek are partially day-lit and partially contained within storm drains. Both run through dense residential areas. Refer to Figure 2-12 for the 100- and 500-year FEMA floodplains for Sausal and Peralta Creek.

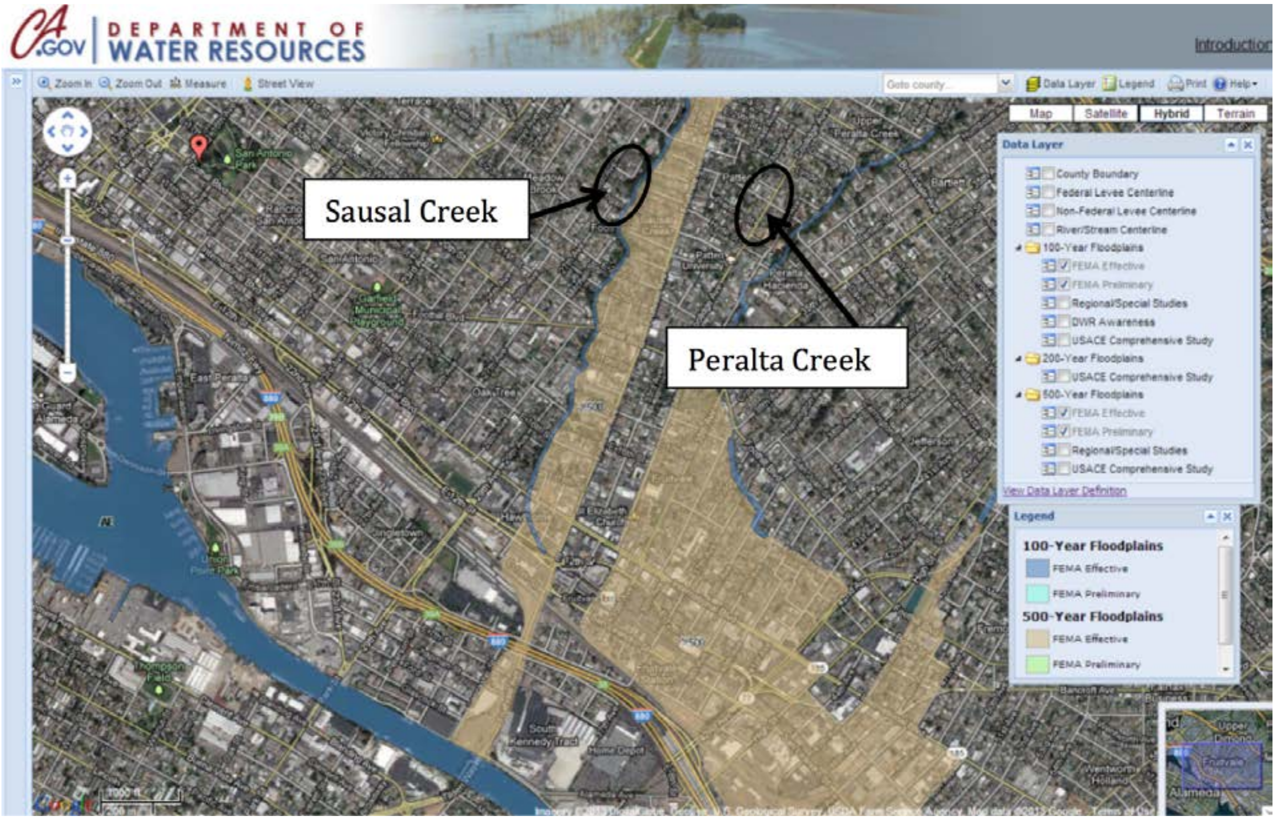


Figure 2-12 *Sausal and Peralta Creek 100- and 500-Year FEMA Floodplains*

Riverine Flooding at the Coliseum Traction Power Substation

Rivers located in the proximity of the Coliseum Traction Power Substation include Arroyo Viejo and Lion Creek. Arroyo Viejo and Lion Creek are both partially day-lit and partially contained in storm drains and run through dense residential and commercial areas. Around the Oakland Coliseum, Lion Creek discharges into Arroyo Viejo. Refer to Figure 2-13 for the 100- and 500-year FEMA floodplains for Arroyo Viejo and Lion Creek.

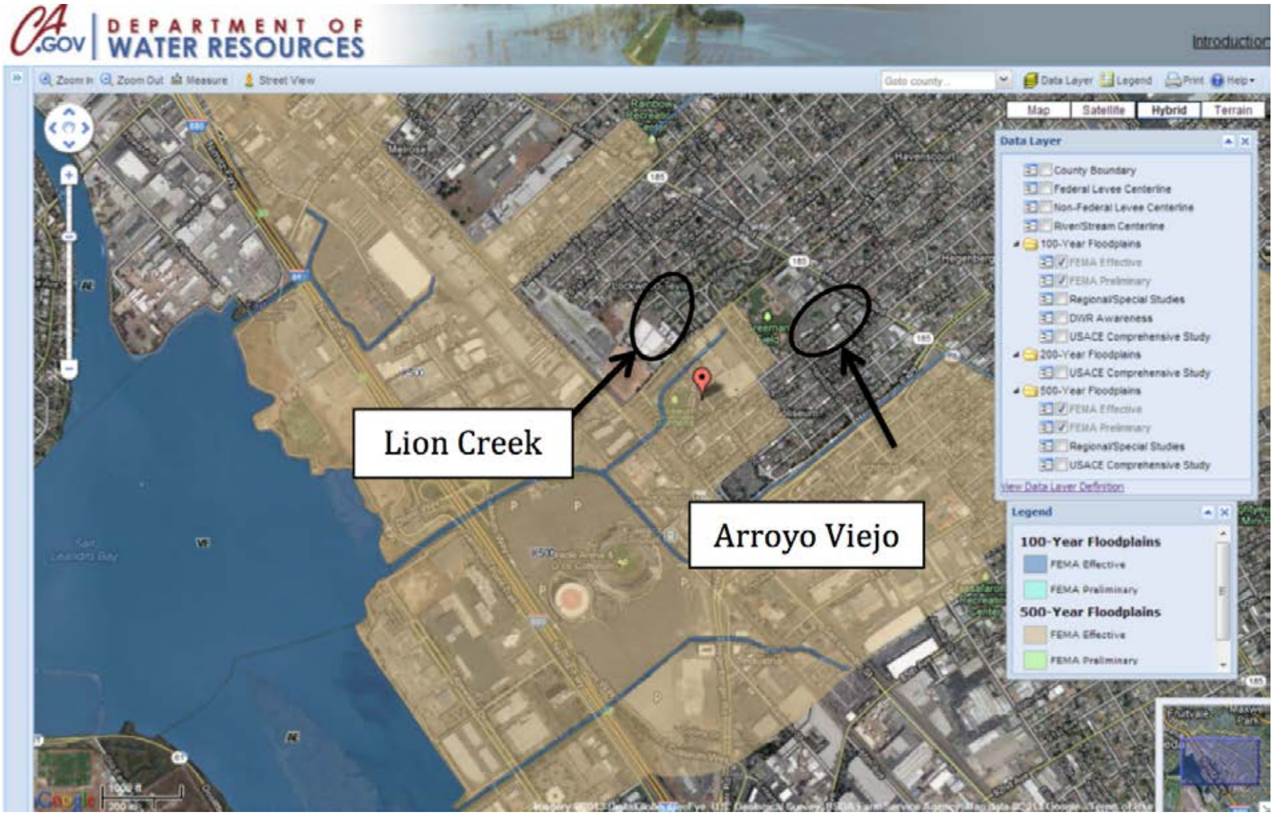


Figure 2-13 *Arroyo Viejo and Lion Creek 100- and 500-Year FEMA Floodplains*

Future Conditions

Flooding patterns in the East Bay are not anticipated to change drastically under climate change; however, increases in precipitation intensity may lead to longer durations of flooding and higher peak flows in rivers and storm drain systems.

Changes in the operations of any creeks/canals connected to storm drains (e.g., replacement of pipes) could also impact the floodplains, although adverse effects may be mitigated by the governing flood control district.

In addition, extreme storm events along the California coast, dubbed "atmospheric rivers," may become more frequent and intense by the end of the century (Cayan et al. 2008). Scientists are evaluating the potential real-world consequences of these atmospheric rivers, also called megastorms. Megastorms have been arriving in California about every 200 years, with the last megastorm, in 1861, creating widespread flooding in the Sacramento area (Dettinger et al. 2012). USGS is conducting research into these storms; however, it could be years before research is settled enough to be incorporated into updated rainfall design criteria.

For the purposes of this study, considering areas within the 100- and 500-year FEMA floodplains and areas within ½ mile of either floodplain type as potentially vulnerable to flood events in 2100 is recommended. The ½ mile is a conservative estimate based on experience from similar climate change and risk assessment projects. The ½ mile estimate considers the topographic character of the study area which is relatively flat.

SECTION 3

Vulnerability and Risk Assessment

Approach

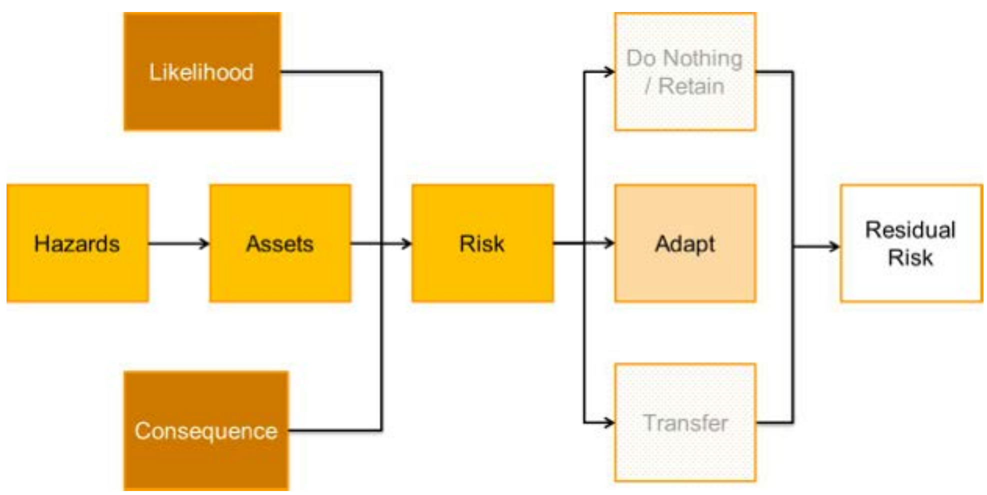
This section outlines the risk assessment approach used for the following four BART assets:

- Station—Lake Merritt Station entrance
- Track—Oakland west track portal
- Power—Oakland Coliseum traction power substation
- Control—Fruitvale train control room

The risk assessment involves a determination of the likelihood of each hazard scenario and the likely consequences should the hazard scenario occur.

The risk assessment used in this study is generally based on *ISO 31000: 2009 Risk Management—Principles and Guidelines*, which provides the definitions, principles, and generic guidelines for risk management and sets out the relationship between the principles and the framework in which it occurs. Figure 3-1 outlines the approach in this study.

Figure 3-1
Risk Approach



In Figure 3-1, the risk treatment strategies of Do Nothing/Retain and Transfer are not considered in this study. During the hazard selection and asset identification process, the combination of hazards and assets were considered in depth for their suitability in benefiting from adaptation strategies as the primary means of risk treatment. The residual risk is defined as the risk after implementation of the adaptation strategy.

Risk Assessment Approach

The risk matrix presented here defines the likelihood and consequence of the climate change scenarios that pose a threat to the BART assets in this study.

Tables 3-1, 3-2, and 3-3 describe the likelihood of the hazard scenarios and the consequence of the scenario. The rank scale is a number between 1 (low) and 5 (high) to indicate severity.

Likelihood

The likelihood is a qualitative description of the probability of the hazard affecting the site under the future conditions as influenced by climate change. The likelihood is assessed on the basis of a predefined hazard scenario (e.g., 1-in-100-year storm event—downpour), an understanding of the local topography/ features, climate change trends, and an analysis of site specific historic data (e.g., hydrologic data).

Table 3-1

Likelihood Scales: Downpour

	Probability	Downpour
1	Improbable	Unlikely during next 25 years
2	Remote	May arise about once in 10–25 years
3	Occasional	May arise once in 10 years
4	Probable	May arise about once per year
5	Frequent	Could occur several times per year

Table 3-2

Likelihood Scales: Flood

	Probability	Flood Plains
1	Improbable	Negligible chance of inundation in 100- and 500-year flood plains
2	Remote	Unlikely but not negligible chance of inundation in 100- and 500-year flood plains
3	Occasional	Less likely than not, but still appreciable chance of inundation in 100- and 500-year flood plains
4	Probable	As likely as not chance of inundation in 100- and 500-year flood plains
5	Frequent	More likely than not chance of inundation in 100- and 500-year flood plains

Table 3-3

Likelihood Scales: Sea-Level Rise (SLR)

Probability		SLR (Year 2050)	SLR (Year 2100)
1	Improbable	Not in any SLR designated area	Not in any SLR designated area
2	Remote	Within 16 in. sea-level rise + 100-year storm (100-year with wind waves)	Within 55 in. sea-level rise + 100-year storm (100-year with wind waves)
3	Occasional	Within 16 in. sea-level rise + 100-year storm (100-year at still water level)	Within 55 in. sea-level rise + 100-year storm (100-year at still water level)
4	Probable	Within 16 in. sea-level rise + daily high tide (MHHW*)—hydrologically-unconnected areas	Within 55 in. sea-level rise + daily high tide (MHHW)—hydrologically-unconnected areas
5	Frequent	Within 16 in. sea-level rise + daily high tide (MHHW)	Within 55 in. sea-level rise + daily high tide (MHHW)

*MHHW - mean high higher water

Consequences

Assuming that the hazard scenario has occurred at the site, the consequences to the assets are assessed. These consequences are determined by understanding the magnitude of the hazard (e.g., 2 in. per hour), mechanisms for water impacting the assets (e.g., rainwater breaching the control room roof panels), and value and function of the assets to the overall BART system.

The consequences are defined in terms of (1) repair cost to the physical damage on the asset and (2) revenue service downtime to the system due to the hazard scenario occurrence. Conservatively, the consequence level is chosen on the more severe of the two criteria.

Table 3-4

Consequence Scales

Consequence		Repair Cost to Physical Damage		Revenue Service Downtime
1	None	Minor cleanup, less than $10K	OR	No impact
2	Minor	Repairable; less than $100k for repair works		Less than 10 minutes; site-level impact only
3	Moderate	Repairable; greater than $100k, less than $2M		10–30 minutes; site-level impact only
4	Major	Repairs and replacement; greater than $2M, less than $20M		31 mins–1 hour; site-level impact only
5	Catastrophic	Repairs and replacement; greater than $20M		More than 1 hour; systemwide impact

For each of the hazards, the consequence of the hazard is assessed for the baseline condition (i.e., the future condition without adaptation) and for the future condition after implementing adaptation strategies.

Risk Appetite

Finally, the likelihood and consequence of the hazard scenarios are combined in Table 3-5 to determine a risk value which is rated from low to very high.

Table 3-5
Risk Matrix

Likelihood	Risk Matrix				
5 – Frequent	Medium	Medium	High	Very High	Very High
4 – Probable	Low	Medium	High	High	Very High
3 – Occasional	Low	Medium	Medium	High	High
2 – Remote	Low	Low	Medium	Medium	Medium
1 – Improbable	Low	Low	Low	Low	Medium
	1 – Negligible	2 – Minor	3 – Moderate	4 – Major	5 – Catastrophic
	Con sequences				

The risk matrix reflects BART's risk tolerance and is established after consensus by internal BART stakeholders. The risk is evaluated for the baseline future condition.

Adaptive Capacity

One key dimension of an asset's vulnerability and risk to climate change impacts is how well it can "accommodate or adjust to an impact to maintain its primary functions," known as adaptive capacity (ART 2012). There are many potential dimensions to adaptive capacity, including ability to maintain key functionality, asset redundancy, ability to maintain an operational system, and time and costs to restore service. An asset's adaptive capacity was considered in assessing the ability of a particular adaptation strategy to reduce the consequence rating of a given climate change impact. This consideration is expressed in determining the benefit-cost score for a given strategy and asset.

Lake Merritt Station Entrance

Physical Assets

The Lake Merritt station entrance has the following structural, mechanical, and electrical physical assets:

- Ticketing machines
- Station agent booth
- Fare gates
- Escalators
- Elevators
- Lights
- Communications (phones, intercoms, etc.)
- Restrooms
- Storm drainage
- Security systems

- Stair enclosure
- Stairs
- Concession area
- Custodial equipment

Lake Merritt station (including the headhouses) was constructed in 1969. Some station roof slab repair work was done in 1996.

Existing Risk Control Measures

The primary protection measures in place to prevent water hazards from entering and damaging the station entrance are roofing, glass enclosures, a storm drain system, and pump systems.

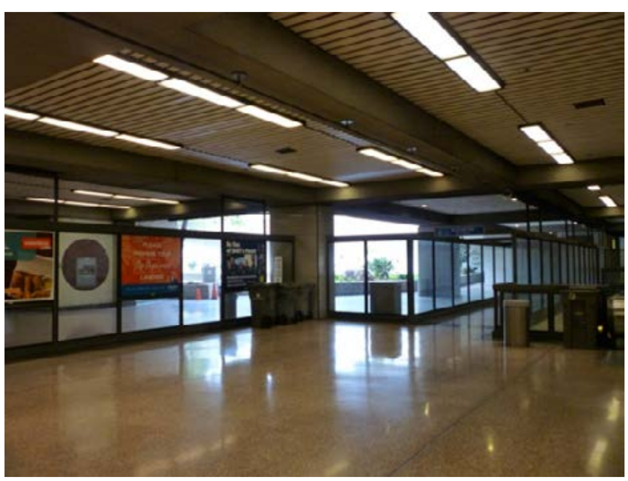
Two types of roof exist at the station. The station stair and elevator entrances have slab roofs, and in the below-ground areas, the street-level plaza area functions as the roof (Figures 3-2 and 3-3).

Figure 3-2

Station Stair and Elevator Entrance

Figure 3-3

Station Below Street Level



Glass and concrete enclose the street-level stair and elevator entrances, providing a modest level of protection from water entering the stair entrances. The doors do not appear to be weather-proofed (Figure 3-4). Glass also encloses the first below-ground station level.

The storm drain system inlets in the plaza and adjacent streets provide protection against runoff from entering the station entrance.

Figure 3-4

Inlet near Fountain

All drains in the mezzanine and platform levels drain to the sump pump system at the track level. The sump pump system connects to the drains to the municipal storm sewer. All drains in the street level drain directly to the municipal storm sewer system.

Adaptive Capacity

The Lake Merritt station entrances are located on a site with a large plaza, allowing a great deal of flexibility as to how the entrances may be adapted to deal with climate change impacts—primarily those related to water ingress into the underground station. However, as an underground facility, the station itself cannot be moved easily, nor can it be abandoned without disabling a significant portion of the BART system. Overall, it has a moderate adaptive capacity.

Vulnerability to Hazard

Sea-Level Rise

The Lake Merritt station is not expected to be affected by sea-level rise impacts such as inundation, increased storm surge levels, or wind waves during storm events. Therefore, the asset of interest, the Lake Merritt Station entrance, is not expected to be impacted. However, the potential exists for changes to groundwater levels or salinity. The station platform is two floors below the street level. Historically, the station platform has been dry but shifts in the water table may affect those circumstances.

Figure 3-5 *Sea-Level Rise Scenarios in 2050 near Lake Merritt Station Entrance*

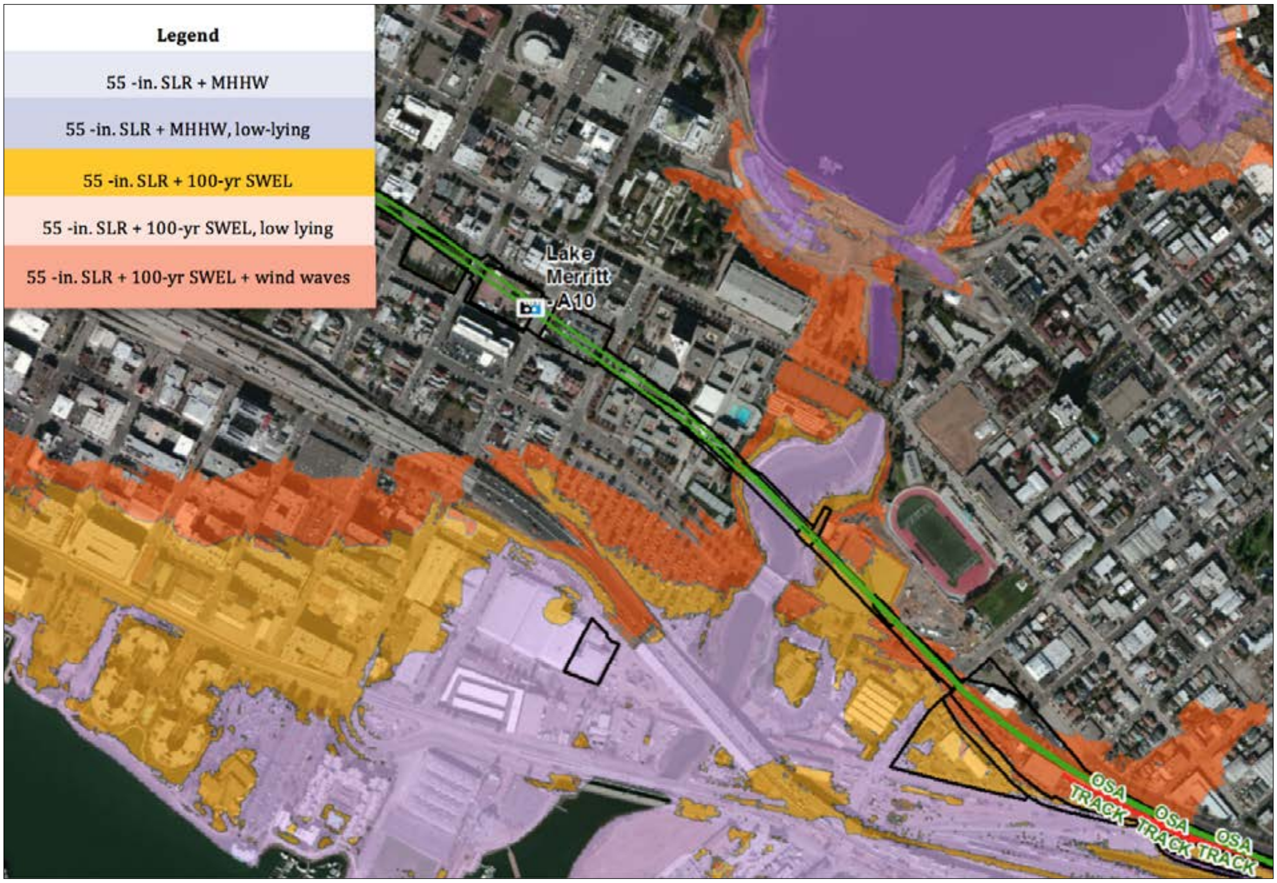


Figure 3-6 *Sea-Level Rise Scenarios in 2100 near Lake Merritt Station Entrance*

Downpour

There are many potential routes for rainfall to affect the station entrance:

- Direct storm water into the atrium may spill into station entrance
- Inlet blockages of the storm drains in the plaza, street, or fountain area may increase runoff to station entrance
- Water breaches entrance doors or elevator shaft
- Failures in the storm drain system (or connectivity to it) lead to water backups in station

Flooding

The station is not currently vulnerable to flooding because it is not located in or close to the 100- or 500-year floodplains. The operation of the Lake Merritt flood control structure will continue to influence the nearest floodplain. See the Introduction, "Flooding—Current Conditions," for further description of the Lake Merritt flood control structure.

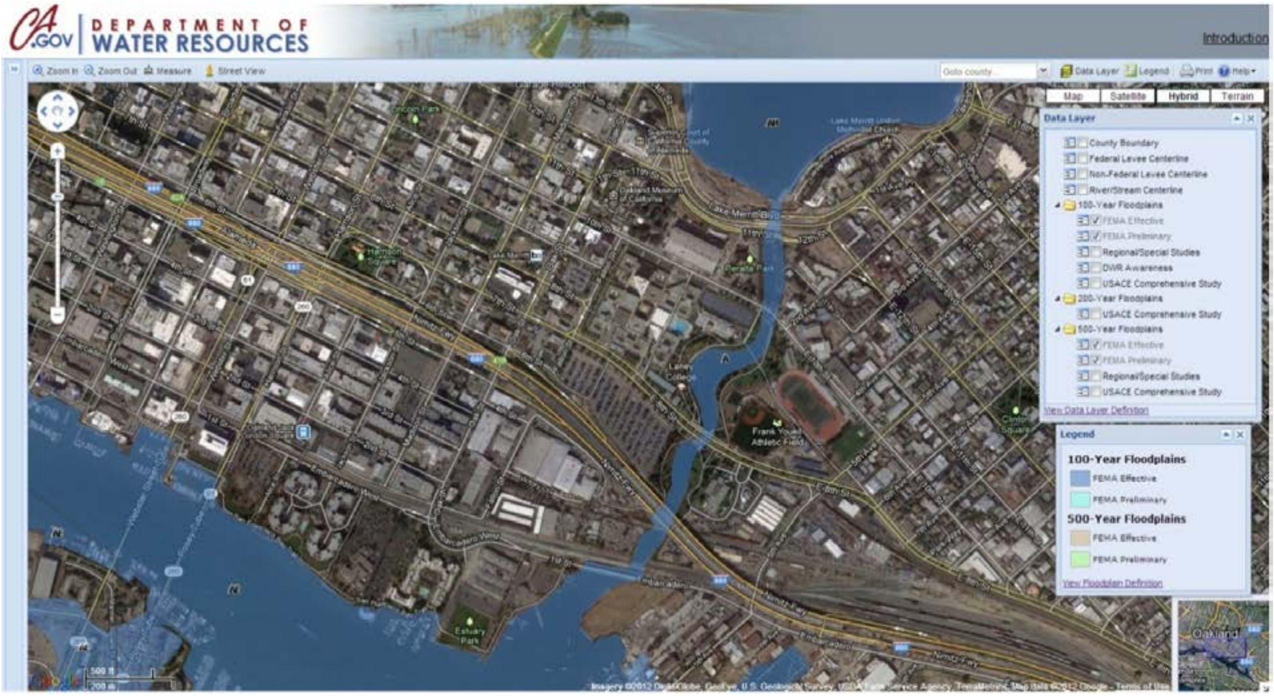


Figure 3-7 *Lake Merritt Station Area 100- and 500-Year FEMA Floodplains*

Baseline Risk Assessment

Future Hazard Scenario

Table 3-6 shows the baseline risk estimate under the worst-case scenarios.

Table 3-6

Future Baseline Risk Metric for Lake Merritt Station Entrance

Lake Merritt: Station Entrance			
Hazard Scenario	*Likelihood*	*Consequence*	*Risk*
16 in. SLR	1	3	Low
55 in. SLR	1	4	Low
Downpour/localized flooding	3	2	Medium
Riverine flooding	3	3	Medium

Present Hazard Scenario

At present, sea-level rise is not a threat to the Lake Merritt station entrance because it is well above sea level. Downpour is slightly less of a threat but still potentially damaging due to the station entrance's multiple pathways of vulnerability. Riverine flooding has a low chance of occurring in the area due to the operation of the Lake Merritt Flood control structure.

Oakland West Track Portal

Physical Assets

The Oakland West track portal has the following structural, mechanical, and electrical physical assets:

- Tracks
- Concrete walls
- Fencing
- Electrical conduits
- Storm drainage
- Sump pumps
- Gate
- Security systems

Existing Risk Control Measures

The existing risk control (protection) measures at the track portal include a storm drain system, sump pumps, and concrete walls. Per the Oakland West Portal track chart, a sump pump exists beyond the mouth of the tunnel portal.

A low concrete wall runs along the edge of the track portal (see Figure 3-8). It is about 2 feet in height above the road on the north (road) side and roughly the same height aboveground on the south (rail) side.

The access gate was originally designed to limit water flow into the trackway. However, the gate was replaced and currently does not offer good protection against inflows of water.

Figure 3-8

Storm Drain Inlet in Street near Oakland West Portal

Adaptive Capacity

The Oakland West track portal has very low adaptive capacity, as it is an immovable, critical part of the regional transportation system, linking the East Bay to San Francisco via the Transbay Tube. Targeted strategies can improve the portal's resilience against water ingress. However, the fundamental geometry and location of the portal cannot be changed, and there are no alternative facilities that could serve the same purpose.

Vulnerability to Hazard

Sea-Level Rise—16 in. in 2050

The area near the portal is not predicted to be inundated in 16 in. of sea-level rise, nor is it currently predicted to be inundated in the 100-year flood under 16 in. of sea-level rise. Wind waves during large storm events do have the potential to affect the area. The impact would likely limit access to the portal via the surrounding roads, as the majority of the port area could be affected. Wave inundation could likely affect the portal in a manner similar to current localized flooding issues, but potentially with a much greater volume of water and with saltwater instead of fresh.

Groundwater is currently affecting the portal as evidenced by moist vegetation growing in large cracks in the wall and sea-level rise has the potential to exacerbate the issue. As witnessed during a site visit, large cracks in the concrete wall exist near the entrance to the portal. As sea-level rises, the groundwater levels and salinity in the areas may increase, which could damage underground systems. The current groundwater levels and impacts need to be better understood at the current stage.

Figure 3-9

Water Damage at Oakland West Portal

Additionally, sea-level rise may affect the hydraulic grade lines (HGLs) in the nearby separated storm drain system because of the portal's proximity to the sea. This could affect drainage during frequent storm events, making localized flooding more of an issue. More information about the location of storm drain outfalls and capacity of the storm drain system in the area is needed.

Figure 3-10 *Sea-Level Rise Scenarios in 2050 near Oakland West Portal*

Sea-Level Rise—55 in. in 2100

The portal area is anticipated to be inundated in the 100-year storm event under 55 in. of sea-level rise. Wind waves during large storm events also have the potential to affect the area. The portal is not predicted to be inundated in 55 in. of sea-level rise alone. The impact during storm events would likely be access limitations to the portal via the surrounding roads, as the majority of the port area could be affected. Wave inundation could affect the portal in a manner similar to current localized flooding issues, but potentially with a much greater volume of water and with saltwater instead of fresh.

The impacts to groundwater levels will be of a similar nature as but potentially more severe than 16 in. of sea-level rise. Groundwater tables may become higher in level and salinity by 2100.

Additionally, 55 in. of sea-level rise may severely affect the HGLs in the nearby separated storm drain system because of the portal's proximity to the sea. Documentation of the location of storm drain outfalls and capacity of storm drain system in the area is needed, and regular contact with the City of Oakland regarding the state of the storm drain system is recommended.

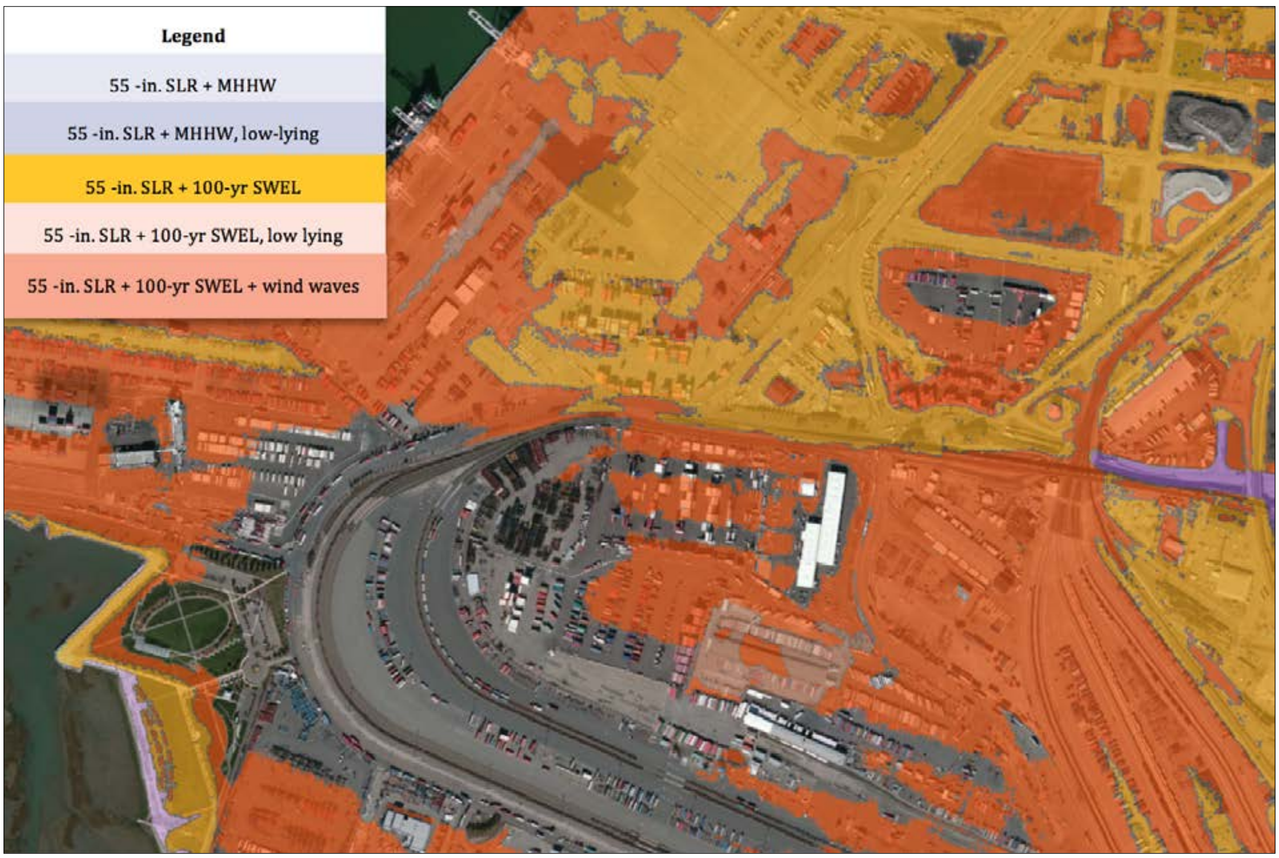


Figure 3-11 *Sea-Level Rise Scenarios in 2100 near Oakland West Portal*

Downpour

The portal area is currently quite sensitive to downpour—localized flooding is noticed during storm events. During a workshop on February 5, 2013, it was reported that many of the storm drain inlets in the area become blocked with trash during storm events, which leads to localized flooding.

The portal area is also exposed to direct rainfall on the tracks. Blockage of inlets or failure of sump pumps could lead to excessive amounts of water on the tracks.

The BART Facilities Standards (BFS) calls for "suitable berms or other positive flow control means" to protect the portal from flooding. Some protection is gained by the low concrete walls, but there is still opportunity for flow below the gate. Further modeling of the runoff patterns in the area could determine if the concrete walls provide adequate protection during extreme storm events that cause localized flooding.

Flooding

Currently, the area is mildly sensitive to riverine flooding. It is about 1/3 mile from the 100-year FEMA floodplain, and no additional 500-year floodplains are shown. The portal is a low spot in the surrounding area, so if the floodplain changes, the portal could be especially susceptible to flooding.

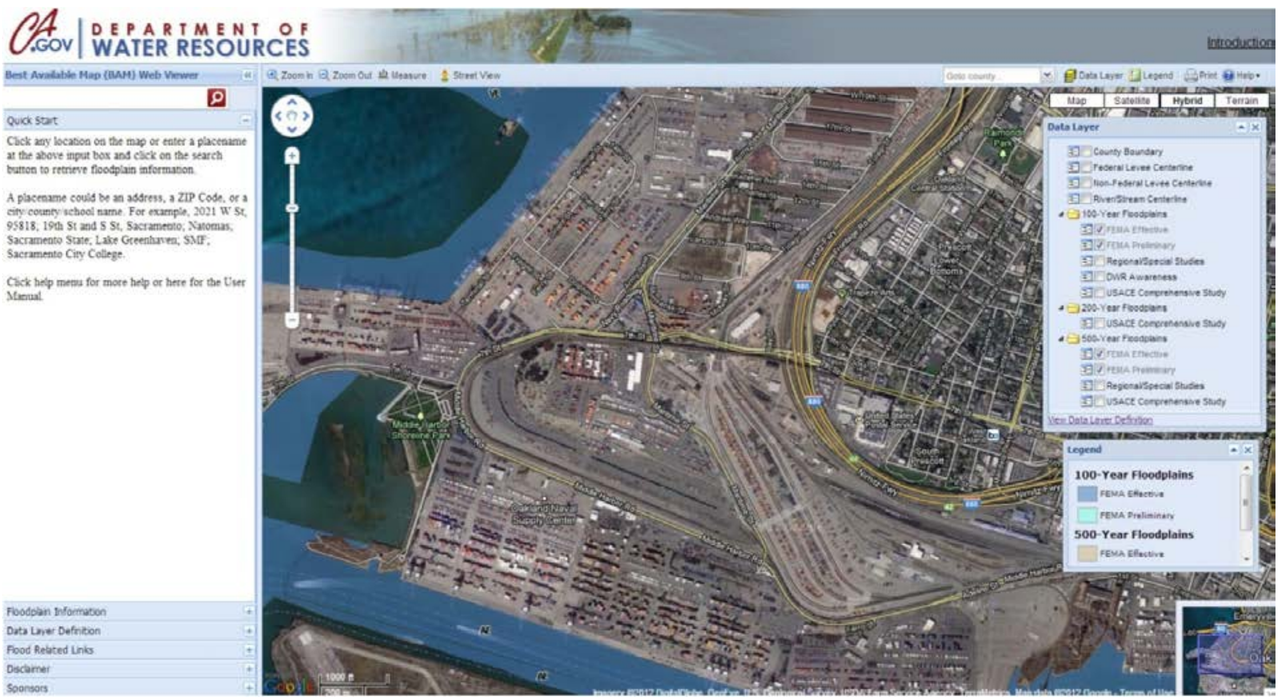


Figure 3-12 *Oakland West Portal Area 100- and 500-Year FEMA Floodplains*

Baseline Risk Assessment

Future Hazard Scenario

Table 3-7 shows the baseline risk estimate under the future hazard scenarios.

Table 3-7

Future Baseline Risk Metric for Oakland West Portal

Hazard Scenario	*Likelihood*	*Consequence*	*Risk*
16 in. SLR	2	5	Medium
55 in. SLR	3	5	High
Downpour/localized flooding	3	5	High
Riverine flooding	2	5	Medium

Present Hazard Scenario

At present, sea-level rise is not a threat to the Oakland West track portal. Downpour is slightly less of a threat now than anticipated to be in 2100, but still potentially damaging due to trash blockages of the storm drain inlets, lack of waterproof gate, and general topography of the area. Riverine flooding has a low chance of occurring in the area due to the lack of rivers, and topography of the area.

Oakland Coliseum Traction Power Substation

Physical Assets

The Oakland Coliseum traction power substation has the following structural, mechanical, and electrical physical assets:

- Transformers
- Switchgear
- Cable ducts
- Circuit breakers
- SCADA equipment
- Equipment housing
- Concrete walls
- Fencing
- Electrical conduits
- Storm drainage
- Security systems

Existing Risk Control Measures

The existing risk control (protection) measures at the traction power substation include equipment housing and a storm drain system.

The majority of the equipment in the substation is housed in metal cases. In the case of rain events typical to the area, the cases keep the equipment protected. Failure in the waterproofing under prolonged, intense rain could damage the equipment. Some of the equipment housings have drains to direct water away from the top of the case structures (Figure 3-13).

Figure 3-13

Oakland Coliseum Traction Power Substation Equipment Housing

The surrounding streets drain to storm drain inlets.

Figure 3-14

Storm Drain Inlet Outside Traction Power Substation

Credit: Google Maps

The aerial tracks drain to downspouts in the columns. The downspouts in some—potentially all—areas drain directly to the neighboring pavement.

Figure 3-15

Aerial Track Downspout

Adaptive Capacity

The Oakland Coliseum traction power facility has a moderate adaptive capacity. It is possible for the station to be dismantled and raised or relocated above future high-water levels, but likely at considerable expense. Other strategies, such as making a watertight perimeter wall, may be viable alternatives as well. In addition, while this facility is offline, BART trains will likely be able to continue operating, so long as adjacent traction power facilities along the track are online.

The adaptive capacity rating does not include potential regional planning efforts around climate change, which may become prominent for sea-level rise issues. The Oakland Coliseum and the Amtrak station are two other valuable pieces of infrastructure that will likely be impacted by sea-level rise and are close to the BART station and traction power substation. Changes to the operation of those facilities or future installation of regional protection measures, such as sea walls or levees, could result in alteration of the BART station and traction power substation, or reduction of the vulnerability.

Vulnerability to Hazard

Sea-Level Rise—16 in. in 2050

The station and substation are predicted to be affected by the 1-in-100-year storm event by 2050 with wind waves during storm events. These types of storm events have the potential to occasionally inundate the area with anywhere from a few inches to multiple feet of water. The area is not anticipated to be inundated by 16 in. of sea-level rise alone.

A concrete wall surrounds a portion of the substation, but water-permeable gaps in the wall exist in the form of metal fences. Overall the substation is vulnerable to storm events in 2050.

Figure 3-16 *Sea-Level Rise Scenarios in 2050 near Oakland Coliseum Traction Power Substation*

Sea-Level Rise—55 in. in 2100

The station and substation are anticipated to be in an area of permanent inundation in 2100, with higher levels experienced during storm events. Much of the surrounding area, especially those areas between the bay and the station, would be affected by the increase in sea level. These areas may become completely inaccessible via the adjacent roads.

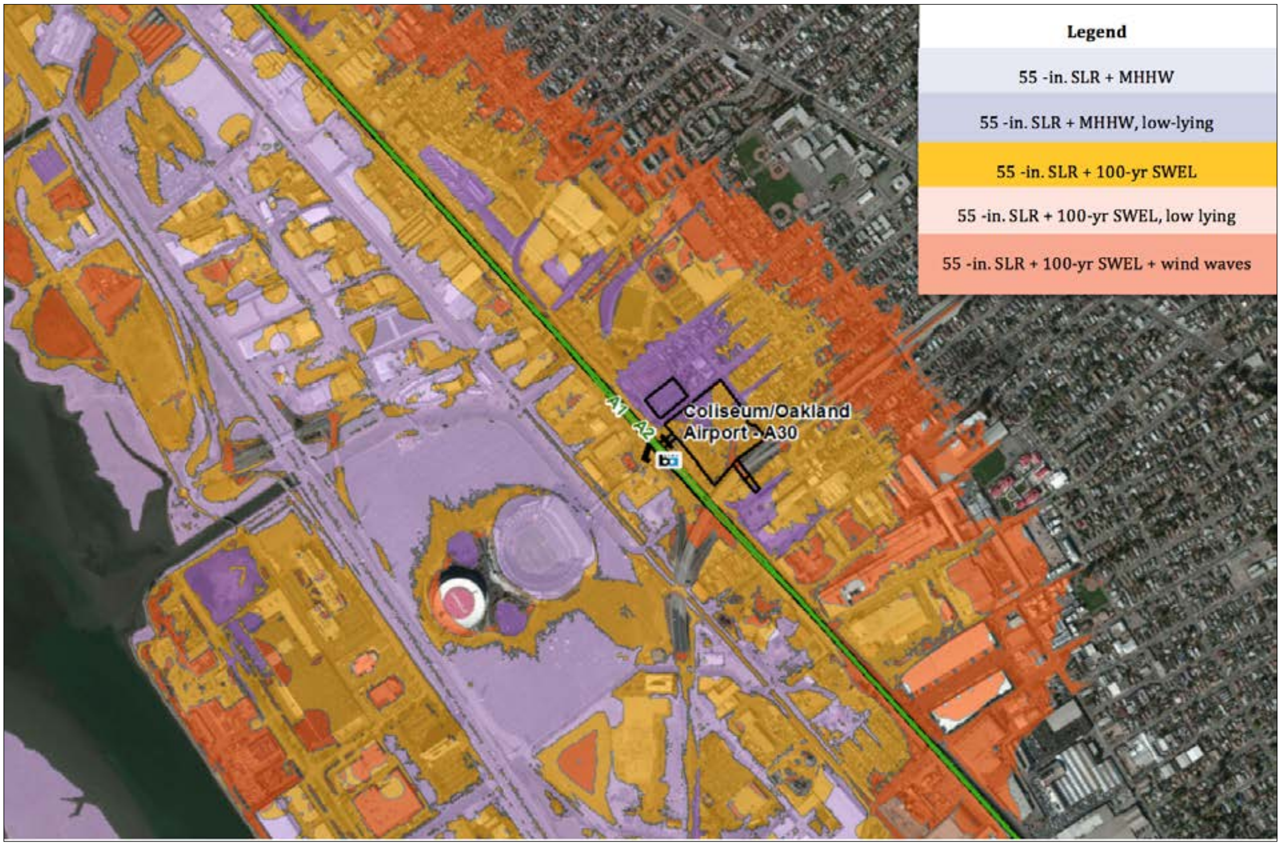


Figure 3-17 *Sea-Level Rise Scenarios in 2100 near Oakland Coliseum Traction Power Substation*

Downpour

The substation is moderately vulnerable to downpour since it is exposed to the elements. The condition of the equipment housing, the capacity of the nearby storm drain network, and the runoff pattern within the substation platform are all important factors in how vulnerable the area is to downpour.

Flooding

The station and substation are within a 1-in-500-year FEMA floodplain with a designation of X500, which do not have elevations of floodwater determined. The area could potentially see a few inches to multiple feet of water during a 1-in-500-year flood event. This could cause extensive damage to the substation.

The station and substation are close to 1-in-100-year FEMA floodplains in the Arroyo Viejo and Lion Creek. Both flood events of this magnitude appear to be contained within the banks of the waterways.

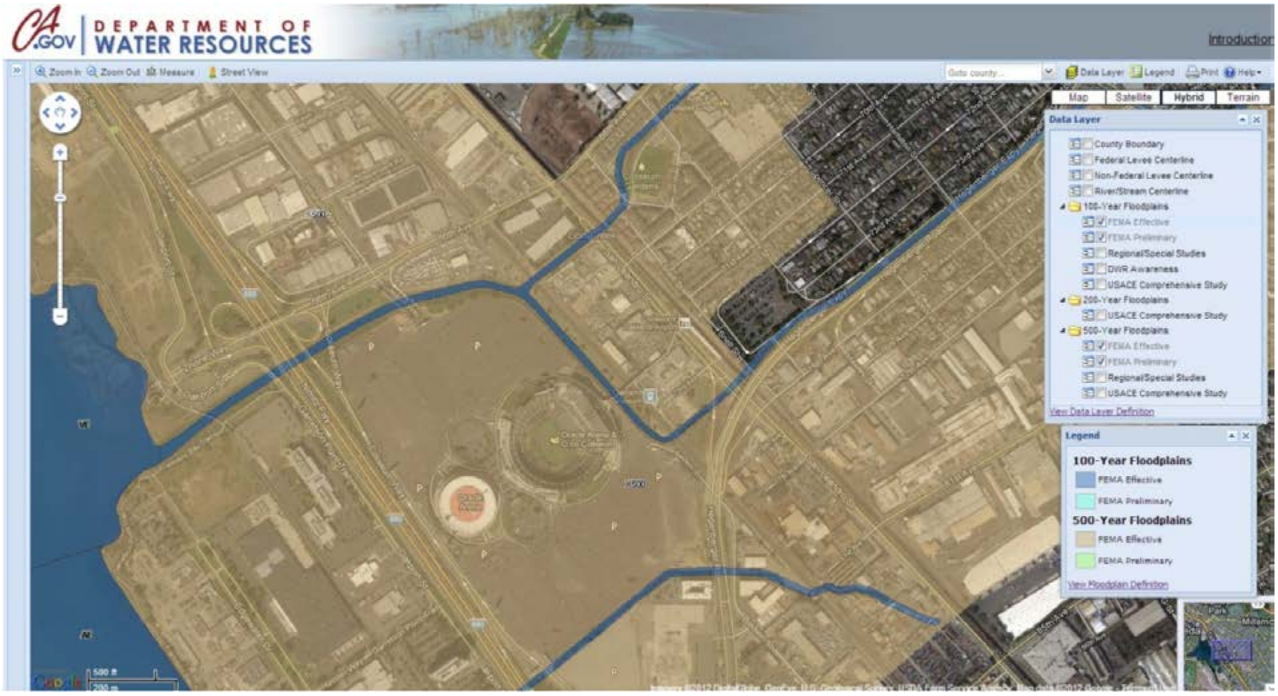


Figure 3-18 *Oakland Coliseum Area 100- and 500-Year FEMA Floodplains*

Baseline Risk Assessment

Future Hazard Scenario

Table 3-8 shows the baseline risk estimate under the future hazard scenarios.

Table 3-8

Future Baseline Risk metric for Oakland Coliseum Traction Power

Hazard Scenario	*Likelihood*	*Consequence*	*Risk*
16 in. SLR	3	4	High
55 in. SLR	5	5	Very High
Downpour/localized flooding	3	3	Medium
Riverine flooding	5	4	Very High

Present Hazard Scenario

At present, sea-level rise is not a threat to the Oakland Coliseum traction power facility because it is well above the sea level. Downpour is slightly less of a threat than expected to be in 2100, but still potentially damaging due to the condition of the equipment housing. Riverine flooding may occur, but only in the 1-in-500-year floodplain.

Fruitvale Train Control Room

Physical Assets

The Fruitvale train control room has the following structural, mechanical, and electrical physical assets:

- Roof
- Walls
- Train control equipment (MUX, operation alarms, interlocking system)
- Communications equipment (emergency and maintenance telephone, remote monitoring, elevator intercom, station communications)
- Power equipment (backup battery, distribution)
- Electrical conduits
- Roof drains
- Floor drains
- HVAC equipment
- Gates
- Security systems

Existing Risk Control Measures

The existing risk control (protection) measures at the train control room include roof and floor drains, and the building structure itself.

The Fruitvale train control room has drains on the roof that convey water from the roof down to the storm drain system. In addition to the drains, a cutout along the roof lip allows water to overflow down the side of the building in the event that the roof drains are insufficient.

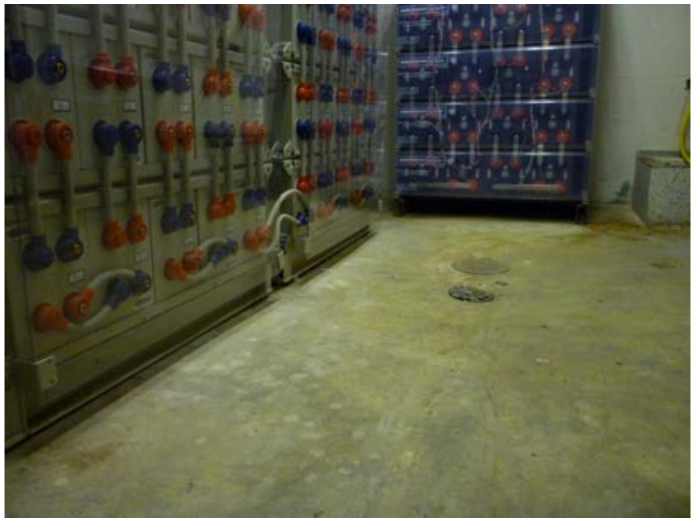
Figure 3-19

Roof with Drain at Fruitvale Train Control Room

The floor drains within the control room drain water that has spilled or run into the room to the storm drain system.

Figure 3-20

Floor Drain in the Fruitvale Train Control Room



The building itself also provides some protection against water hazards; however, the doors do not appear to be watertight.

Adaptive Capacity

The Fruitvale train control room has a moderate adaptive capacity. The train control room could be raised or relocated above future high water levels, at moderate to high expense. Other strategies to prevent water from entering the building can also provide additional protection. BART can continue to operate trains without this train control room, but only in manual operation mode and at slower speed.

Vulnerability to Hazard

Sea-Level Rise—16 in. in 2050

The area is not anticipated to be affected by inundation, storm events, or wind waves under 16 in. of sea-level rise.

Figure 3-21 *Sea-Level Rise Scenarios in 2050 near Fruitvale Train Control Room*

Sea-Level Rise—55 in. in 2100

The area is not anticipated to be affected by inundation, storm events, or wind waves under 55 in. of sea-level rise scenarios.

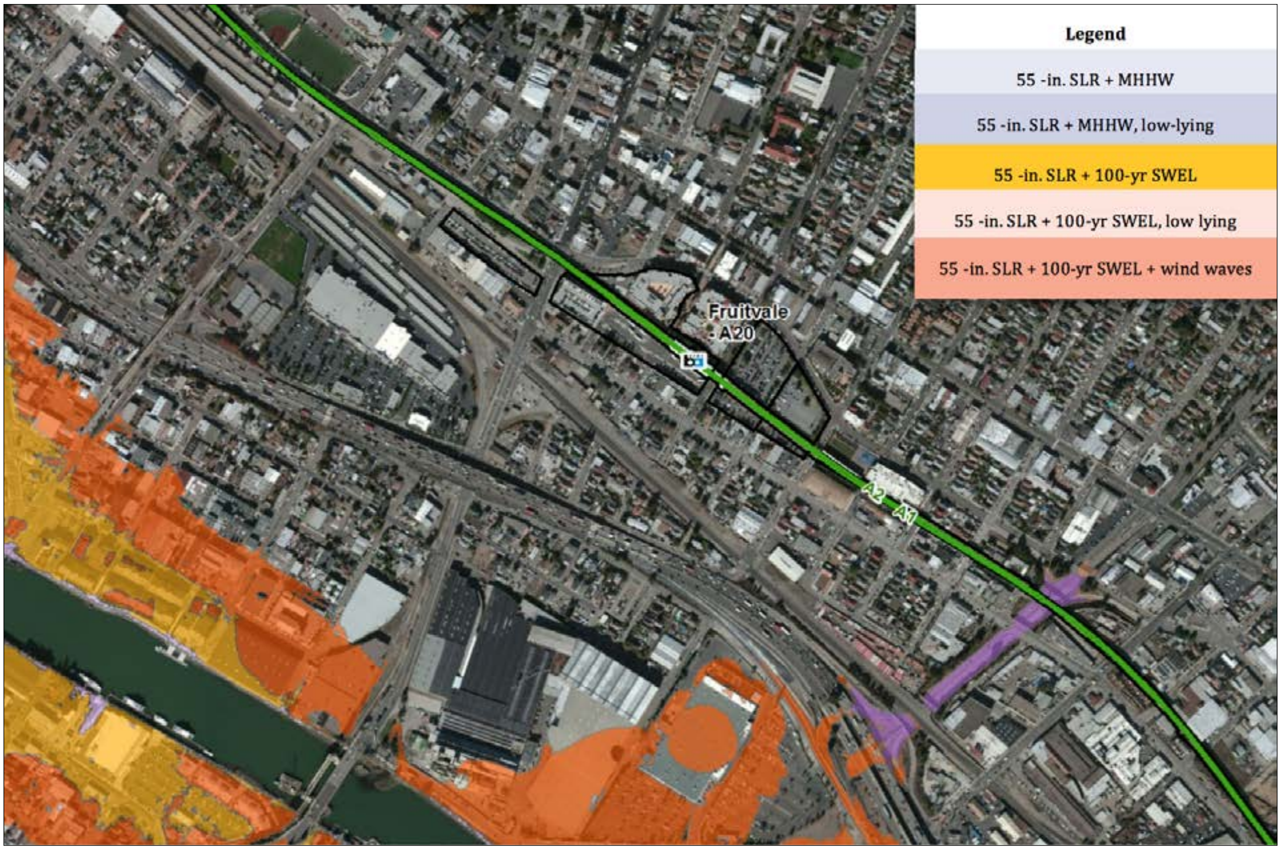


Figure 3-22 *Sea-Level Rise Scenarios in 2100 near Fruitvale Train Control Room*

Downpour

The train control is vulnerable to downpour. In December 2012, the system was discovered to be unconnected to the storm drain system underneath the sidewalk just outside the train control room, with the pipe discharging directly into the soil during storm events. The unconnected pipe backed up and leaked into the train control room.

Downpour has also been reported to leak into and damage train control rooms through cracked roof structures. While adequate drainage is required from train control room roofs, drainage failures have been reported in roofs of other control rooms in the system.

Flooding

The station is within a 1-in-500-year FEMA floodplain, and the train control room is immediately adjacent to the floodplain. The floodplain has a designation of X500, which does not have elevations of floodwater determined. The station and control room area could potentially see a few inches to multiple feet of water during a 1-in-500-year flood event. This could cause extensive damage to the electrical equipment in the train control room.

The station and train control room are close to a 1-in-100-year FEMA floodplain in Sausal Creek. The floodplain in this area appears to extend beyond the day-lit portion of the creek along the extension of the storm drain system.

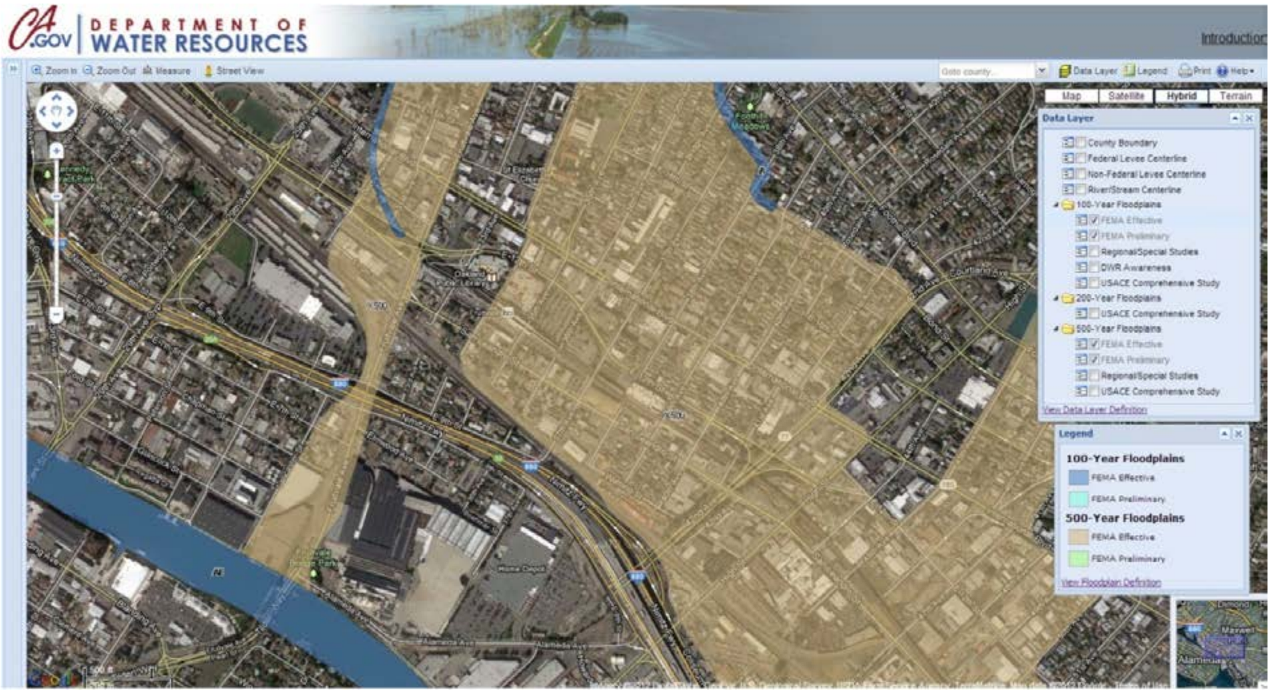


Figure 3-23 *Fruitvale Area 100- and 500-Year FEMA Floodplains*

Baseline Risk Assessment

Future Hazard Scenario

Table 3-9 shows the baseline risk estimate under the future hazard scenarios.

Table 3-9
Future Baseline Risk Metric for Fruitvale Train Control Room

Hazard Scenario	*Likelihood*	*Consequence*	*Risk*
16 in. SLR	1	3	Low
55 in. SLR	1	4	Low
Downpour/localized flooding	3	5	High
Riverine flooding	5	5	Very High

Present Hazard Scenario

At present, sea-level rise is not a threat to the Fruitvale train control room because it is well above sea level. Downpour is slightly less of a threat than expected to be in 2100, but still potentially damaging due to the condition of the train control room. Riverine flooding may occur, but only in the 1-in-500-year storm event.

SECTION 4

Element 3—Adaptation Strategies

As discussed in previous sections, climate change is projected to have a varying impact on different BART assets. This section identifies potential adaptation strategies that will help BART reduce its risk exposure to climate change impacts through changes in four areas: land use and planning, design and construction, operations, and maintenance. However, it may not be possible or feasible to wholly eliminate BART's exposure to climate change hazard risks.

Best Practices: A Review of Climate Adaptation Strategies

To develop a suite of adaptation strategies relevant to BART, a review of climate adaptation strategies in the transportation sector was conducted. The review spanned from efforts from foreign organizations to efforts on the local level such as the FHWA ART study. General findings from this review are summarized in this section.

Although the scope and severity of climate change effects vary across the world, the types of impacts expected are not unfamiliar to the rail industry. In particular, both local and international system operators have experienced the impacts of flooding due to severe storms. From Boston and New York to Copenhagen, Tehran, and Singapore, rail systems have experienced and/or planned for future high flood levels using a variety of strategies. There is no U.S. standard for how transit agencies should address flooding, such as which hazard scenarios flood flow rates, and threshold levels to consider (FTA 2011).

Rail transit operators are concerned with flooding and heavy rains storms, particularly those with underground tracks and facilities. Each system's design and context varies, and appropriate strategies must be tailored to unique situations. However, system operators are pursuing common strategies in several areas that are relevant to BART, including pumps, ventilation grates, physical barriers, and green infrastructure (FTA 2011; Arup 2012).

- **Pumps**: Locally and internationally, many operators design for large storms and redundancy. Some also account for groundwater intrusion, where applicable. For example, Tokyo Metro uses three water pumps in tunnels with known inundation problems, aiming to ensure sufficient pumping capacity even in the event of a pump failure. However, even if pump capacity is sufficient, pumps can only function when drains are clear.

- **Ventilation grates**: Ground- or sidewalk-level ventilation grates are critical entry points for water inundation, either from flooding or heavy downpours. Some operators, including Tokyo Metro, have manually or automatically closable ventilation shafts. Others, such as the New York MTA, have simply raised ventilation grates above sidewalk levels to reduce the likelihood of inundation by flooding. However, even elevated grates may be at risk in a heavy downpour.
- **Physical barriers**: Many operators have implemented barrier systems to prevent water entry into stations and tunnels. These range from simple flood boards and sandbags to fitted station entrance flood barriers (rising from sidewalks, lowering over doors, or manually installed), raised station entrances, floodgates in tunnels and on track portals, flood protection dikes around track portals, and track portal (dive structure) walls above peak flood levels.
- **Green infrastructure**: Some operators have begun adopting low-impact development techniques that add pervious surfaces in and near facilities, reducing surface runoff. Elements may include permeable paving, green roofs, and additional vegetation/plantings.

If a system's flood defenses are overwhelmed and water does enter a facility or asset, transit operators are typically dependent on the local storm water drain system. To evacuate water from an underground station, for instance, there must be capacity in the local storm water system and it must be functioning properly. In the event of localized or riverine flooding, an insufficient drain system can back up and leave the operator with nowhere to divert excess water. Beyond physical interventions such as low-impact development and on-site water collection, coordination with local municipalities to assess the capacity and function of the drain system is another alternative.

Salt or brackish water inundation resulting from climate change or storm events can intensify the consequences of water damage to the assets. In addition to causing immediate damage to sensitive equipment, salt water intrusion can also lead to more rapid decline in other equipment, including critical electro-mechanical equipment. Operators around the world have experienced the consequences of salt water intrusion.

Approach to Adaptation Strategies

Strategy Development

Adaptation strategies for each BART asset have been identified. Numerous adaptation strategies for municipalities and agencies exist; however, only strategies relevant and valuable to BART as a transit agency have been included for consideration.

The strategies fall into one of four categories:

- **Land Use and Planning**—changes to BART policies and support of local codes/incentives that impact the physical and infrastructure context in which an asset is situated
- **Design and Construction**—structural/physical improvements to assets
- **Operations**—changes to BFS, policies, management systems
- **Maintenance**—modified maintenance programs and training

Each strategy has many dimensions, but the cost, benefit, and implementation timeframe of the intervention are critical considerations for which actions to prioritize and pursue. It will also be important to consider not just how a particular strategy may provide additional benefits to BART, but what types of intra- and inter-agency partnerships will be beneficial.

Both systemwide and asset-specific strategies are listed in Element 3. A more complete list of possible strategies is included in Appendix B.

Prioritization of Strategies

Although there are numerous possible adaptation strategies, each can be "scored" based on potential costs, benefits, and implementation timeframe. The matrix in Table 4-1 outlines the relative cost and benefit ratings corresponding with each score.

Table 4-1

Cost/Benefit Matrix

		Benefit		
		Low (1)	*Moderate (2)*	*High (3)*
Cost	Low (3)	**4**	**5**	**6**
	Moderate (2)	**3**	**4**	**5**
	High (1)	**2**	**3**	**4**

Each strategy is assigned a relative cost and benefit on a three-tiered scale of low, moderate, or high. A strategy receiving the highest possible score of 6 will have a comparatively high level of benefit at a low cost. Strategies receiving the lowest score of 2 will have high costs but produce a comparatively low level of benefit. Generally, strategies with higher scores should be prioritized first.

Approximate ranges for low, moderate, and high cost scores are estimated less than \$5M, \$5M–\$400M, and greater than \$400M, respectively. These cost ranges were assessed based on interpolations from projects of similar scope and scale listed on BART's Capital Needs Inventory (CNI) list.

In addition to costs and benefits, each strategy was also assigned a time score, based on a now, medium-term, or long-term scale. Both the urgency and the amount of time required to implement a given strategy will vary, and this may influence the decision of when to begin implementation. For instance, a high benefit but high cost strategy with a long implementation time may warrant higher priority, especially if the cost of implementation can be spread over the duration.

The benefit from each strategy is determined by calculating the difference between the baseline risk score and the residual risk score. The residual risk score is based on a combination of professional judgment and input from BART staff.

Systemwide Strategies

The strategy scoring process revealed a set of four strategies that apply to all asset types and can be considered relevant across the entire BART system. These strategies address all hazard types and fall into the Land Use/Planning, Design and Construction, and Maintenance categories. They are comparatively low-cost and are recommended for implementation predominantly in the near term.

Local storm drain system capacity (LP3): BART is reliant on the local storm drain systems in the cities, towns, and counties in which it operates. To maintain its facilities free and clear of water, it must be able to pump and gravity drain water out into these systems. If, for some reason, local storm drains fail or become overfilled (such as in an extreme storm event), or the system gradually loses efficacy (as sea-level rise impacts the ability of the system to drain through San Francisco Bay outfalls, for example), BART will be unable to use normal water evacuation systems. BART should work with local jurisdictions to ensure sufficient capacity in event of flooding, particularly near critical facilities, and to identify where insufficient capacity needs to be addressed most critically. This is a low-cost strategy that is recommended to be implemented now.

Drain capacity and backflow prevention (DC2): BART should ensure that drain capacity is sufficient for predicted water ingress rates for different locations across the BART system. In addition, where not already present, BART should install one-way drain valves to prevent backflow into facilities, as deemed necessary (e.g. critical facilities requiring drains, such as train control rooms). This is a low-cost strategy that is recommended to be implemented over the medium-term.

Maintenance reporting accessibility (M1): BART should standardize maintenance reports across all teams and improve the accessibility of the information reported to remove jargon, shorthand, and/or obscure language. Reports in a standardized format and using common language that are accessible through BART's asset management system will allow for better ability to analyze common climate-related (and otherwise) problems. This will allow BART to identify "trouble spots" for water inundation, roof leaks, drainage problems, and/or equipment failures as a result of climate change impacts. This is a low-cost strategy and is recommended to be implemented now. It should be noted that the value of strategy M1 (implementing a standardized maintenance reporting format) would be enhanced by also implementing strategy Op1, a georeferenced, query-able asset management system. Including spatial information with real-time maintenance reports will allow BART to more quickly identify where "hotspots" of maintenance issues are developing. For instance, multiple reports of water inundation from heavy rainfall at one particular station might indicate the need for additional monitoring or an engineering solution.

Test on-site roof and storm drain system (M5): One particular issue for BART is proper drain performance and maintenance across all asset types. Maintenance staff should regularly perform dye tests[2] on building roof, track, and floor drains to check that they are meeting their expected performance levels. This strategy will help ensure that the drainage system is functioning properly and identify where follow-up maintenance is required. This is a low-cost strategy and is recommended to be implemented now.

Table 4-2

Systemwide Adaptation Strategies

Systemwide Strategies		Hazard Exposure			Time	Cost
Code	*Strategy*	*Sea-Level Rise*	*Downpour*	*Flooding*		
LP3	Local storm drain system capacity	Yes	Yes	Yes	Now	Low
DC2	Drain capacity and backflow prevention	Yes	Yes	Yes	Medium-term	Low
M1	Maintenance reporting accessibility	Yes	Yes	Yes	Now	Low
M5	Test on-site roof and storm drain system	Yes	Yes	Yes	Now	Low

A comprehensive list of all the strategies considered in this study is provided below and in Appendix B-1. Appendix B-1 includes the hazards exposure, time rating, and cost rating.

[2] Dye testing can be performed to assure that storm drains are draining freely, without blockages—a small amount of dye is placed in a storm drain inlet, and a downstream point is checked to make sure that the storm drain is not blocked.

Table 4-3 *Master List of Adaptation Strategies*

Code	Strategy
Land Use/Planning	
LP1	**Area-wide flood barriers**: Coordinate with local jurisdictions/port regarding construction/maintenance of levee, sea wall, other flood barriers.
LP2	**Location**: Require new and upgraded existing structures to be built outside (new structures) or above (existing structures) 500-yr flood elevation.
LP3	**Local storm drain system capacity**: Work with local jurisdictions to ensure sufficient capacity in event of flooding, particularly near critical facilities.
LP4	**Low impact development**: Work with local jurisdictions to enact low-impact development standards/ incentives near assets; implement standards on BART property.
Design & Construction	
DC1	**Pump capacity/redundancy**: Change pump standards for increased flood and downpour conditions.
DC2	Drain capacity and backflow prevention: Ensure drain capacity is sufficient; install one-way valves to prevent backflow where applicable (e.g. critical facilities requiring drains).
DC3	**Portal wall retrofits**: Evaluate portal wall height, water-resistance; develop a solution for non-water tight gate structures (retrofit or replacement) and maintain/retrofit walls to address cracking.
DC4	**Tunnel flood protection**: Construct flood gates for underground structures.
DC5	**Technology**: Early warning system to trigger automated response.
DC6	**Flood level resistance:** Elevate entrances, vent and access shafts, stair/elevator access above peak predicted flood levels (e.g. 3 feet above peak predicted flood levels in 500-year event).
DC7	**Flood barriers**: Engineered (e.g. deployable, demountable) barriers around entrances/portals.
DC8	**Temporary measures**: Pre-engineering and site mobilization for temporary mitigation structures.
DC9	**Elevate or relocate equipment**: Elevate or move sensitive equipment (e.g. small gauge electrical components, signal and communications equipment, ticketing machines, generators).
DC10	**Waterproofing and corrosion retrofits**: Retrofit existing and build new structures with waterproof, side penetrations and use non-corrosive materials.
DC11	**Roof structures**: Retrofit building roofs and update BFS to require pitched roofs (5 degrees minimum), avoid penetrations, and eliminate "bathtub" roof design.
DC12	**Rain exposure**: Design/retrofit buildings to protect against rainfall/rain and wind conditions—do not leave gaps in facades, open roofs, etc.
DC13	**Climate Change checklist**: Use a climate change “checklist” to ensure principles are integrated into capital project design and construction.
DC14	**Perimeter walls and entries:** Build new or retrofit existing perimeter wall/barrier to be watertight, including gates and doors.
DC15	**Transformer Upgrade**: Replace open (Cask) transformers with closed (oil-filled) transformers and update BFS accordingly.
DC16	Headhouse enclosures for entrances: Build and/or maintain headhouses around ingress/egress points (e.g., stairs, escalators, elevators) to ensure weather tightness.
DC17	**Pump and fan monitoring and alarm system**: Improve ability to monitor sump pump and ventilation fan runtime by adding high water alarms to pumps and selecting an appropriate hardware and software system to enable data reporting to the Operations Control Center and Asset Management Database.
DC18	**Electric power**: Provide power redundancy for pumps, equipment; provide backup power/additional generators.
DC19	**Equipment redundancy**: Identify or develop redundancy program in the event of a failure of critical equipment (such as train control equipment, MUX boxes, etc.).

Code	Strategy
Operations	
Op1	**Georeferenced asset management**: Incorporate georeferenced/spatial querying, real-time updates into asset management system.
Op2	**Operational alternatives review/update**: Review and update system alternatives plans (e.g., bus bridge service across disabled assets) to reflect climate change impacts; establish mutual aid agreements with other transit operators.
Op3	**Evacuation plans and drills**: Review and update passenger evacuation plans in high flood prone areas; incorporate climate change considerations into regional emergency drill exercises.
Op4	**Local/regional emergency coordination**: Evaluate local, regional, and state emergency response plans to improve coordination and develop contingency plans if resources are inadequate.
Op5	**Flood control district communications**: Maintain frequent communication with local flood control districts regarding changes in operations of district facilities.
Op6	**Establish groundwater model**: Work with local jurisdictions to establish baseline groundwater models to monitor and predict impacts of sea-level rise.
Op7	**Educate and integrate**: Disseminate climate change information and train staff on how to integrate climate considerations into their work.
Maintenance	
M1	**Maintenance reporting accessibility**: Improve accessibility and standardize maintenance reports in order to identify "trouble spots" for water inundation, roof leaks, drainage problems, and/or equipment failures. Integrate with asset management system.
M2	**Trash/sediment removal**: Increase frequency of trash and sediment removal (which can cause blocked drain inlets) from neighboring streets and aerial tracks.
M3	**Equipment useful life monitoring**: Increase monitoring of deterioration of some system elements due to water submersion (e.g., cloth cable sheathings).
M4	**Critical equipment monitoring**: Increase monitoring of critical equipment (e.g., MUX boxes, switches, transformers, life safety systems/communications).
M5	**Test on-site roof and storm drain system**: Perform dye test on roof, track, and floor drains to check for expected performance.

Asset-Specific Adaptation Strategies

In addition to the benefits provided by the systemwide strategies, targeted strategies are recommended for each asset type. These strategies offer a cost-benefit score of 4 or greater, are recommended to be implemented in the near- to medium-term, and have low to moderate costs to implement. Other strategies not included here may also provide additional benefit, but incur high costs.

A full list of applicable asset-specific strategies for each asset may be found in Appendices B-2 to B-5 and includes the overall cost-benefit ratings, the hazards exposure, time rating, and cost rating.

Lake Merritt Station Entrance

- **Low impact development (LP4)**: BART should work with the City of Oakland to enact low-impact development standards and/or incentives near the Lake Merritt station, as well as on-site. Given the urban context of the station, providing more porous surfaces (such as rain gardens, green roofs, and permeable paving) will reduce runoff and localized flooding. This policy change is recommended to be enacted now, as it will require time for implementation to take place, and can be accomplished at low cost.
- **Rain exposure (DC12)**: BART should retrofit buildings and station features to protect against rainfall; in particular, Lake Merritt station's large atrium is equivalent to an open roof and leaves the lower level of the station exposed to water ingress, particularly during a heavy downpour. This opening is recommended to be enclosed with a roof structure in the medium-term, at moderate cost.
- **Headhouse enclosures for entrances (DC16)**: BART should maintain headhouses around ingress/egress points (stairs, escalators, elevators) to ensure weather tightness. The Lake Merritt station entrance stairs and escalators are already enclosed, which provides a first line of defense that will slow water ingress, but the weather tightness of these entrances should be evaluated and upgraded. In addition, elevator entrances represent a weakness, as poor seals could allow water to flow directly into the elevator mechanism, potentially disabling the lift, allowing water into the lower level of the station, and creating a significant emergency egress risk for customers and staff who are unable to use stairs/escalators. Retrofits and new elevator protections represent moderate costs and are recommended to begin implementation now.
- **Flood control facility operation (Op5)**: BART should maintain regular communication with Alameda County Flood Control District to stay informed of any potential changes in operations of district facilities, particularly those impacting nearby Lake Merritt and the canal. This monitoring activity is recommended to begin now and represents a low cost.

Table 4-4

Lake Merritt Station Entrance Site-Specific Adaptation Strategies

Systemwide Strategies		Hazard Exposure			Time	Cost
Code	*Strategy*	*Sea-Level Rise*	*Downpour*	*Flooding*		
LP4	Low impact development in/near station	-	Yes	Yes	Now	Low
DC12	Rain exposure retrofits	-	Yes	-	Medium-term	Moderate
DC16	Headhouse enclosures for entrances	Yes	Yes	Yes	Now	Moderate
Op5	Flood control district communications	Yes	-	Yes	Now	Low

Oakland West Track Portal

- **Portal wall retrofits (DC3)**: The Oakland West portal is protected from localized flooding at street level by a concrete wall, extending above the portal retaining walls. The wall's height should be evaluated to ensure it is of sufficient height to protect against localized flooding and overtopping in storm events. Importantly, the wall has an opening to allow for a street level service entrance for maintenance vehicles. This opening is protected by a gate, but is not waterproofed. This gate should be retrofitted to provide a waterproof barrier while still allowing service vehicles to enter. The solution could include an engineered, supplemental barrier that is normally in place except when access is needed for maintenance. In addition, cracks in the lower portion of the retaining wall should be fixed to prevent water ingress. This is a high-benefit solution recommended to be implemented over the medium-term at moderate cost.
- **System alternatives review/update (Op2)**: BART should review and update system alternatives plans (e.g. bus bridge service across disabled assets) to reflect climate change impacts. This track portal is a particularly important part of the BART system as it is the only connection to San Francisco. BART should review and update their "bus bridge" and other alternative service plans for the event that the portal must be closed or is disabled due to a climate change hazard (such as water inundation due wind waves during an extreme storm). Mutual aid agreements with other transit operators are an option that should be considered. The cost of updating contingency plans is low, and this strategy is recommended to be pursued now.
- **Establish groundwater model (Op6)**: As the region experiences rising sea levels due to climate change, the impacts will extend beyond higher ocean and bay water levels. The increased levels could lead to increased saline levels and higher ground water tables. The track portal is currently impacted by water intrusion through cracks in the concrete retaining walls, and an increase in salinity may mean the water will have a more corrosive impact in the future. BART should work with local jurisdictions (including the Port of Oakland, the City of Oakland, and the Alameda County Flood Control District) to establish baseline groundwater models to monitor and predict the impacts of sea-level rise. This strategy will incur a low cost and is recommended to be implemented now so monitoring and evaluation can begin.
- **Trash/sediment removal (M2)**: Track and drain clearing and trash removal should be performed over shorter intervals in order to prevent blocked drain inlets. This strategy addresses all hazards at the Oakland West track portal and is particularly important as water ingress into the tunnel and Transbay Tube puts the system at risk of being disconnected at one of its most critical points. Tunnel pumping and drain systems appear to have sufficient capacity, but blocked drains will reduce capacity or render then ineffective. In addition, local street drains should be cleared to prevent or

reduce localized street flooding. This is particularly important for the track portal because localized flooding could prevent maintenance or emergency access to the portal, even if the portal itself is operational. This strategy is recommended to be implemented now and represents a moderate cost.

Table 4-5

Oakland West Track Portal Site-Specific Adaptation Strategies

Strategies		Hazard Exposure			Time	Cost
Code	*Strategy*	*Sea-Level Rise*	*Downpour*	*Flooding*		
DC3	Portal wall retrofits	Yes	Yes	Yes	Medium-term	Moderate
Op2	System alternatives review/update	Yes	Yes	Yes	Now	Low
Op6	Establish groundwater model	Yes	-	-	Now	Low
M2	Trash/sediment removal	Yes	Yes	Yes	Now	Moderate

Oakland Coliseum Traction Power Substation

- **Waterproofing and corrosion retrofits (DC10)**: Water entry into traction power substation equipment can cause shorting and fires, resulting in extended downtime and costly repairs. Based on staff reports, conduit penetrations into equipment should be relocated from the top to the side of casings. Other equipment "hardening" to prevent water intrusion should also be performed to help prevent damage to critical devices/equipment. This strategy will incur a moderate cost and is recommended to be implemented in the medium-term, in conjunction with traction power substation painting, upgrade, and replacement programs.
- **Perimeter walls (DC14)**: The Coliseum traction power substation is mostly surrounded by a perimeter wall, but gaps and gate structures prevent the wall from stopping flood water inundation. Given the importance of the facility and the fact that it is projected to be impacted by sea-level rise, this perimeter wall should be retrofitted to be watertight, including the gate. This will incur moderate costs and is recommended to be accomplished over the medium-term.
- **Establish groundwater model (Op6)**: The increased sea levels could lead to increased saline levels and higher ground water tables, including in the Coliseum traction power substation's location. BART should work with local jurisdictions (including the City of Oakland and the Alameda County Flood Control District) to establish baseline groundwater models in order to monitor and predict the impacts of sea-level rise. Rising groundwater tables could impact the storm drain system's ability to function, so developing a better understanding of groundwater levels is particularly important. This strategy will incur a low cost and is recommended to be implemented now so monitoring and evaluation can begin.
- **Equipment useful life monitoring (M3)**: The traction power substation is not protected against inclement weather, heat, or cold. Over time, the protective features of equipment and cabling can deteriorate and increase

the risk of water damage. BART should create or expand monitoring programs for known failure items (such as cloth cable sheathing and rubber cabling gaskets) to prevent damage or disruption to service. This strategy represents a moderate cost and is recommended to be implemented now.

- **Critical equipment monitoring (M4)**: BART should increase monitoring of critical equipment to ensure that assets are not only operating properly but also retain sufficient water-resistance. As a critical facility in the BART system, the traction power substation should be subject to an increased monitoring regimen to ensure that protections (such as equipment housings) remain effective. This strategy represents a moderate cost and is recommended to be implemented now.

Table 4-6

Oakland Coliseum Traction Power Substation Site-Specific Adaptation Strategies

Strategies		Hazard Exposure			Time	Cost
Code	*Strategy*	*Sea-Level Rise*	*Downpour*	*Flooding*		
DC10	Waterproofing and corrosion retrofits	Yes	Yes	Yes	Medium-term	Moderate
DC14	Perimeter walls and entries	Yes	-	Yes	Medium-term	Moderate
Op6	Establish groundwater model	Yes	-	-	Now	Low
M3	Equipment useful life monitoring	Yes	Yes	Yes	Now	Moderate
M4	Critical equipment monitoring	Yes	Yes	Yes	Now	Moderate

Fruitvale Train Control Room

- **Low impact development (LP4)**: BART should work with the City of Oakland to enact low-impact development standards and/or incentives near the Fruitvale station, as well as on-site. Given the high level of impermeable surface adjacent to the station, providing more porous surfaces (such as rain gardens, green roofs, and permeable paving) will reduce runoff and localized flooding at the station. This policy change is recommended to be enacted now, as it will require time for implementation to take place, and can be accomplished at low cost.
- **Roof structure retrofits (DC11)**: Based on BART's experience with drain back-ups and roof leaks onto extremely sensitive, life-safety critical equipment inside the control room, the flat "bathtub" and drain roof design should be replaced with a peaked roof with at least 5 degrees of pitch. This strategy will be effective against heavy downpours, and will incur a moderate additional cost. However, it is recommended as a long-term strategy that can wait until other less expensive and easier strategies (such as M2 below) can be implemented.
- **Perimeter walls and entries (DC14)**: Although the train control room equipment is surrounded by a building, the facility is at risk of local flooding under the entrance doorway. This door should be upgraded to be

watertight, as well as any other openings or gaps in the building wall that are below future flood high water levels. This strategy will incur a moderate cost and is recommended to be implemented in the medium-term.

- **Flood control facility operation (Op5)**: BART should maintain regular communication with Alameda County Flood Control District to stay informed of any potential changes in operations of district facilities. This monitoring activity is recommended to begin now and represents a low cost.
- **Trash/sediment removal (M2)**: Track and drain clearing and trash removal should be performed over shorter intervals to prevent blocked drain inlets. The Fruitvale train control room is located directly under the trackway and has experienced roof leaks in the past. In an effort to prevent BART's own infrastructure from causing a roof failure, care should be taken that drains do not become clogged and lead to an overflow onto the train control room roof. In addition, local street drains should be cleared to prevent or reduce localized street flooding. This strategy is recommended to be implemented now and represents a moderate cost.

Table 4-7

Fruitvale Train Control Room Site Specific Adaptation Strategies

Strategies		Hazard Exposure			Time	Cost
Code	*Strategy*	*Sea-Level Rise*	*Downpour*	*Flooding*		
LP4	Low impact development	-	Yes	Yes	Now	Low
DC11	Roof structure retrofits	-	Yes	-	Long-term	Moderate
DC14	Perimeter walls and entries	Yes	-	Yes	Medium-term	Moderate
Op5	Flood control district communications	Yes	-	Yes	Now	Low
M2	Trash/sediment removal	Yes	Yes	Yes	Now	Moderate

SECTION

5

Element 4—Link Strategies to BART Organizational Structures and Activities

To minimize the risk exposure of BART's critical assets from climate change impacts, BART will incorporate climate change adaptation strategies into its organizational structure and activities. This section explores where within the BART organization adaptation strategies can be implemented appropriately and in a manner that effectively mainstreams the strategy.

Approach

In harmony with FTA's approach to adaptation strategies, BART is committed to integrating climate change adaptation strategies into BART's core policies, planning, practices, and programs.

BART's approach to incorporating adaptation strategies into BART's organization is through mainstreaming climate change strategies through four primary areas of activity: land use and planning, design and construction, operations, and maintenance.

The following subsections go into detail on the four areas of activity. Each section was developed to discuss 1) the current business practices or programs, 2) the impact climate change adaptation will have on the organization and business practices, and 3) the new responsibilities that will be assumed by the organization.

The development of this section included 1) extensive review of BART documents, including the BART Facilities Standards (BFS), emergency plans, planning policies, maintenance reports, preliminary asset reports, and 2) interviews with key personnel within each of BART's major departments.

BART recognizes that there is no "one size fits all" solution to climate change adaptation. As indicated in Element 2, vulnerability can vary for each asset depends on the location and the type of the asset. In addition, some BART assets are more critical to BART operations than others. For example, open spaces and parking lots are less critical than tracks and train control assets. Non-critical assets may be allowed temporary flooding at acceptable frequencies and may not require climate change adaptation. Climate change adaptation will likely require the implementation of an array of strategies dependent on the location and asset type.

Outreach and Awareness

Education (Op7) is a critical element to mainstreaming a successful climate change adaptation program. By increasing awareness and informing employees of the climate change impacts and adaptation strategies, they will be able to assist and take responsibility in achieving strategy objectives. Because climate change adaptation strategies connect with different business functions, staff will have different educational needs.

Outreach is also important to those organizations that BART works with. Cooperation and support from those organizations is needed to successfully implement a comprehensive climate change adaptation strategy. Organizations important to BART's success in adaptation include cities, counties, flood control districts, agencies, emergency responders, the community, and others.

Impacts

Communication and awareness to the following personnel in BART's organization are significant to the success of climate change adaptation. The personnel and their roles related to climate change adaptation are identified below. There may be other departments and/or personnel not identified by this study, that may play a role in climate change adaptation.

- Executive managers—allocate resources and funding to adaptation efforts
- Planners—inclusion of climate change in the planning phase
- Designers and engineers—modifications to BFS and design approach
- Emergency managers and responders—response to catastrophic storm event scenarios
- Maintenance managers and staff—modifications to maintenance protocols
- Asset management managers and staff—climate change considerations in the asset management program

Development of this section has already initiated climate change adaptation discussions with various groups within the organization.

New Responsibilities

Responsibility to implement climate change adaptation will be assumed across all departments. In addition, advocacy of climate change adaptation will fall on the Office of District Architect.

As climate change science advances, continued outreach will be needed to keep these groups informed and ensure that a comprehensive climate change strategy remains current and integrated into the core business practices and a part of the decision making process.

Land Use and Planning

BART's planning department has two groups that conduct planning activities: Strategic Planning and Station Planning. BART's planning department works closely with local cities on projects on and/or adjacent to BART property. BART actively participates in city planning efforts by engaging in technical advisory committees which comprise stakeholders on city planning projects. Technical advisory committees are created by the city to get stakeholder feedback.

Impact

BART's planning, alongside the Office of District Architect, will need to work with the Bay Area Joint Policy Committee (JPC) as applicable on future climate change planning efforts that may require partnerships. The JPC may also assist BART to stay abreast with other adaptation efforts in the region. With respect to this study, BART can first direct adaptation efforts toward the City of Oakland. The City of Oakland is currently developing plans near the Coliseum and West Oakland areas, which are two of the four areas on which this study focuses. BART should advocate for climate change considerations as it applies to the development of these plans. The Planning Department would be responsible for this effort.

New Responsibilities

The planning department will be responsible for considering climate change adaptation in the planning phase of future projects.

With respect to adaptation strategies that will be a part of a regional effort or require partnerships, planners will need to coordinate these efforts.

The Planning department will be responsible for seeking and securing grants in support of climate change adaptation projects.

Design and Construction

Design and construction activities fall under BART's Planning and Development Department as well as the Maintenance & Engineering Department. These departments are responsible for the design /construction of new facilities and the rehabilitation of existing facilities. All projects are completed in accordance with the BFS.

Design and construction involves all technical disciplines including Civil, Structures, Trackwork, Train Control, Mechanical, Electrical, and Communications.

BART Facilities Standards

BART facility and infrastructure projects are designed in accordance with the BFS, which is maintained by the Office of the District Architect. In addition, specific departments have ownership over respective sections of the BFS. The BFS is meant to provide guidance and minimum standards that regulate and control the design, construction, quality of materials, use and occupancy, location, equipment and installation of facilities within BART jurisdiction. Development of the BFS was launched in 2002 and has continued to be a living document subject to changes and updates.

Sections in the BFS pertinent to this study include:

- Environmental Design and Sustainability
- Architecture
- Civil
- Electrical
- Mechanical
- Electronics
- Structural

Impact to BFS Environmental Design and Sustainability Standards

The BFS includes a section for environmental design and sustainability. The objective of these requirements is to encourage the integration of sustainable design with facility development and maintenance. The standards currently do not discuss climate change adaptation.

BART shall update The Environmental Design and Sustainability standards to include climate change considerations and adaptation strategies. The section may serve as a primary point of reference for climate change design and may serve as a repository for the climate change solutions. Discussions with the Office of the District Architect, who is responsible for this section of the BFS, will be needed to determine the exact content of the modification and additions as it pertains to climate change.

BFS revisions resulting from this pilot study will be limited to the study's scope of climate change impacts. At this time, revisions will not consider other types of impacts. However, future revisions may include additional considerations upon further research. These climate change impacts may include other precipitation impacts (landslides, heavy snowfall, droughts) and temperature-related impacts (buckled rails, overheated vehicles or equipment, wildfires, blackouts), for example. Furthermore, as climate change science continues to improve, the BFS may need periodic updates updated to attune to the current science.

Impact to Station Entrances Design

Modifications to the BFS that relate to the station entrances and water inundation can be found in following facility design criteria:

- Architecture—Passenger Stations: Section 6, Station Ingress and Egress and Circulation
- Civil—Basic Design Policies: Section 9, Flood Control & Evacuation Under Flood Conditions
- Civil—Drainage: Section 2.1.5, Access Areas into BART Stations

These sections specify criteria for station access and circulation design and flood protection. As defined in the BFS, access areas into BART underground stations are designed for a 100-year storm event.

These changes must be aimed at improving future construction of station entrances to be more resilient against water-related climate changes. The approach to design standard improvements can be expanded to address 1) entrances at other facilities such as maintenance yards and 2) other types of entrances such as vents, access shafts, or other gaps that could serve as entry points for water.

In addition, BART has Station Access Guidelines that focus on priorities for station access by foot, bicycle, transit, auto, carpool or other means. This guideline may benefit from inclusion of climate change considerations into the document as well. BART will need to engage with the planning department for revision to this guideline.

Impact to Track Portal Design

Potential modifications to the BFS sections relevant to track portals and water inundation protection can be found in following facility design criteria:

- Civil—Trackway
- Mechanical—Line Sections: Section 5, Sump Pumps to Protect Underground Trainway
- Civil—Basic Design Policies: Section 9, Flood Control & Evacuation Under Flood Conditions
- Civil—Drainage: Section 2.1.6, Flooding

These sections specify criteria for flood protection and trackways. As defined in the BFS, trackways are designed to prevent flooding from a 100-year storm event.

These changes will affect all future track portal construction and repair work and any future work with the Oakland West track portal.

Impact to Train Control Room Design

Potential modifications to the BFS for train control and water inundation protection inundation can be found in following facility design criteria:

- Electronics—Automated Train Control System: Section 10, Train Control Rooms
- Civil—Basic Design Policies: Section 9, Flood Control & Evacuation Under Flood Conditions
- Civil—Drainage: Section 2.1.6, Flooding

These sections specify criteria for flood protection and train control rooms, which are regarded as critical facilities. The BFS states that flood levels shall be determined at all critical locations of the alignment. As defined in the BFS, train control facilities are designed to prevent flooding from a 500-year flood stage.

Impact to Traction Power Substation Design

Potential modifications to the BFS for traction power and water inundation protection can be found in following facility design criteria:

- Electrical—Traction Power: Section 3.4, Traction Power Facilities
- Civil—Basic Design Policies: Section 9, Flood Control & Evacuation Under Flood Conditions
- Civil—Drainage: Section 2.1.6, Flooding
- Architecture—Wayside Facilities: Section 3.4, Traction Power Facilities

These sections specify criteria for flood protection and traction power facilities, which are regarded as critical facilities. The BFS states that flood levels shall be determined at all critical locations of the alignment. As defined in the BFS, traction power facilities are designed to be set above a 500-year flood stage.

New Responsibilities

Owners and stakeholders of the BFS will be responsible for making the appropriate changes with respect to climate change. BFS revisions are subject to review by a committee from the specific department. Revisions to BFS will require translation of the climate change considerations and adaptation strategies into standards in a manner that is appropriate for the asset and accessible to the engineer.

Operations

BART's Operations Branch is responsible for Transportation & System Services, which encompass Rail Operations, Station Operations, Scheduling, Central Operations, Yard Operations, and Operating Support & Review.

Emergency Response

Emergency response and preparedness activities within BART are managed between the system safety department and the BART police department. The BART emergency plan is divided into two types of emergencies: 1) those that require significant outside resources (through city, county, state, and federal agencies) that warrant the activation of an Emergency Operations Center (EOC), and 2) those that do not require resources beyond those available within BART except the fire department, emergency medical services, and coroner support. The latter type of emergencies is managed only by the Operation Control Center (OCC). Both types of emergencies may be expected from climate change impacts.

The only climate change-related impact currently with a Standard Operating Procedure (SOP) is flooding, which has an SOP at the non-EOC-level of emergency. There are no disaster-specific SOPs or considerations for EOC-level emergencies. EOC-level emergency drills are conducted annually.

Local and regional plans include:

- Regional Catastrophic Earthquake Mass Transportation/Evacuation Plan
- San Francisco Bay Area Regional Transportation Emergency Management Plan, Baseline Operating Plan
- San Francisco Bay Area Regional Emergency Coordination Plan

These plans were developed with the participation of BART. Like the BART emergency plan, the local and regional plans do not contain disaster-specific SOPs or considerations.

While no specific plans are in place, BART, under emergency conditions, may call upon other transit agencies to provide bridging of services over affected BART areas (Op2). BART has a mutual aid agreement with other transit operators in the Bay Area to share resources and services under emergency services. Signed in 1994 and amended in 2008 to include additional organizations, the agreement includes 13 organizations committed to provide equipment, personnel, supplies, and other goods and services to each other under emergency conditions so that transit services experience minimal interruption and recover rapidly.

Impact

BART shall review its emergency plans (Op3) and include climate change considerations in the next emergency plan review/revision period. At present, the plan alone is not adequate to manage a catastrophic storm and/or flooding event. A good emergency plan has a standard methodology that can be used to address any emergency situation. Lists of specific planning considerations for each type of disaster should be included as part of the emergency plan.

BART's emergency preparedness manager from the police department will be preparing a white paper to BART executive management that will recommend making revisions in the emergency plan to standardize the document format to industry standards, to include planning considerations of specific disasters, and to include missing sections. It is not yet determined when this submittal will be made. The findings from the study may contribute to revisions to the emergency plan.

As a participant in the development of local and regional plans, BART needs to encourage the review and revision of these plans (Op4) to include climate change considerations. These plans can benefit from the addition of disaster-specific planning considerations.

New Responsibility

The police department shall be responsible for the review and Revision to the BART emergency plan with respect to climate change.

Flood Control District Communications

The BART system extends into four different counties, each with its own flood control or management district/department:

- Alameda County Flood Control and Water Conservation District (ACFCWCD)
- Contra Costa County Flood Control and Water Conservation District
- San Mateo County Flood Control District
- San Francisco Citywide Floodplain Management Working Group

The City and County of San Francisco does not have a flood control district but instead has a Citywide Floodplain Management Working Group which includes different city departments. The working group is charged with implementing the San Francisco Floodplain Management Program.

BART operations currently have minimal communications with the local flood control districts.

Impact

BART should establish a line of communication with the AFCWCD so that BART operations may be responsive to any flood control issues or notices that may impact BART transportation services.

BART should prioritize the implementation of this adaptation strategy (Op5) with the ACFCWCD because all four of the pilot study's asset scenarios and the ART study area are within Alameda County. ACFCWCD helps provide flood protection in Alameda County caused by winter rains and the San Francisco Bay tides.

In addition, the ACFCWCD is also cognizant of the issues regarding climate change impacts and is also taking steps to conduct a study that will refine the sea-level rise water inundation model developed in the ART study This opens up the opportunity for BART and ACFCWCD to partner share new information on climate change.

Monitoring and Alert Systems

At critical locations, BART maintains high water alarms equipped on the sump pumps (DC17) to detect dangerous water levels. Data from these sensors are directed to the OCC. The sump pumps are also equipped with manual flow meters which are read periodically by maintenance staff.

At present, BART does not have in place a notification system for receiving early warnings on severe weather-forecasts (DC5). An early weather warning system would be valuable to BART to detect the advent of severe storm events.

Impact

BART should move towards automated devices including replacement of manually read flow meters in favor of digitally-read meters on all critical sump pumps. Real-time information of the flow data can be used to trend the inflow of water during storm events. These data can contribute to evaluating resiliency against flooding. For the OCC to receive these data, minor upgrades will be required to install a connection between the flow meter to the existing network infrastructure.

As a potential revision to the BFS, BART may require that all new sump pumps include a digitally-read flow meter. BART will need to engage with the mechanical engineering group as well as the systems engineering group on this matter.

BART should consider developing a system to receive relevant weather warnings from the NOAA National Weather Service, or equivalent. Early knowledge of such an event is crucial to preparations such as sand bagging, allocating additional personnel, and other temporary measures. Early warnings can be directed to the OCC which currently receives early warnings for earthquakes from UC Berkeley. Further research is needed to understand how to best develop this system.

New Responsibilities

The Operations Branch should be tasked into exploring and researching an early warning system and any other valuable technological improvements.

Maintenance

The Maintenance and Engineering Department oversees all maintenance-related activities. Maintenance encompasses Rolling Stock & Shops (preventive maintenance; heavy repairs to traction motors, axles, wheels, and alternators; accident repairs; friction breaks work; door repairs; and car cleaning) and Power & Way Maintenance (maintenance of BART's electrical and mechanical equipment, train control and computer equipment governing and controlling train movements, tracks and structures including fire protection and suppression equipment, automotive and heavy work equipment). Power and Way Maintenance may be further categorized into the following groups: Power and Mechanical, Way and Facilities, and Non-Revenue Vehicle.

All assets require some level of maintenance including the four types of assets included in this pilot study: stations and maintenance facilities, tracks, train control, and power. The following is a discussion of the different types of maintenance activities that BART conducts with pertinent to the asset types and climate change.

Generally, maintenance may be characterized into two categories: Preventive Maintenance and Corrective Maintenance. The schedule of preventative maintenance is often determined from past experience of system. Corrective Maintenance work refers to work done in response to a request for maintenance (RFM). RFMs originate from the observations or inspections from station agents, electricians, train operators, public, structural inspectors, and others.

Storm Drain Systems

Storm drain maintenance relates to all four asset types, as each will have some storm drain system in place near or at the asset. Storm drain maintenance is managed by the Way and Facilities group. Preventive Maintenance activities include 1) clearing of vent structures and ditches along tracks and 2) visual inspections of "hot spots." The vent structures and ditches are cleared of debris on a monthly basis. The visual inspections are performed in preparation of the wet season. Visual inspections are limited to the "hot spots." On a regular basis, debris and sediments are cleared from station pits and tunnels. BART currently relies on visual inspection and does not use dye tests (M5). In addressing storm drain issues, snake cameras are used to help diagnose the blockage.

Impact

As a result of climate change, maintenance activities may have to shift to prioritize storm drains at locations that are sensitive to climate change impacts. This may result in an increase in frequency of maintenance activities to service storm drains.

Storm drain maintenance schedules are a product of experience and knowledge of the trouble areas. In the future, the asset management program will benefit the maintenance program by streamlining the maintenance schedules. Information and trends derived from the system can be used to more precisely optimize the schedule.

The Way and Facilities Group should work with the Asset Management Team to incorporate maintenance and inspection work into Maximo (M1).

New Responsibilities

The Way and Facilities Group will continue to be responsible for implementing storm drain maintenance. In an environment of limited funds and resources, the Way and Facilities Group will have to identify and voice to executive management any budget or staffing shortfalls that may result from any changes to maintenance needs.

Equipment Monitoring

Monitoring of equipment such as sump pumps, transformers, etc. is managed by the Power and Mechanical Group. BART's current maintenance monitoring program over traction power substations includes monthly and annual facility inspections. Monthly inspections include checks on the condition of the equipment and facility. Annual inspections include inspection of the interior of the equipment housings that contain high failure items such as cloth cable sheathings and rubber cabling gaskets. The maintenance staff documents the inspections through inspection reports.

Impacts

Inspection forms should be reviewed and updated to include specific checks for water damage or deterioration of the substation facility and equipment (M3, and M4) as a result of climate hazards. Including these as part of the routine inspection procedure will create the baseline data needed to respond to the impacts of climate change proactively and evaluate performance of adaptation projects.

Power and Mechanical Group should continue working with the Asset Management Team to incorporate inspection reporting into Maximo (M1). The Maximo system is streamlining the reporting process by improving report accessibility and standardizing the report. This data will be instrumental in comparing actual asset life against asset life used in State of Good Repair (SGR) models.

New Responsibilities

The Power and Mechanical Group will continue to be responsible for implementing maintenance including equipment monitoring. In an environment of limited funds and resources, the Power and Mechanical Group will have to identify and voice to executive management any budget or staffing shortfalls that may result from any changes to maintenance needs.

Replacement and Repair

Replacements and repairs are continuous activities within BART's maintenance and engineering department. BART's current replacement and repair initiation process includes two methods. One is a submission of a project to the capital needs inventory (CNI). The index is a list of proposed capital projects which is ranked by several criteria to determine priority of need. Those determined to be of high priority are accepted for implementation. The second method for a project initiation is submission of a white paper to the department head. The department head will determine if the project warrants initiation.

Impact

The impact to the CNI will be a revision to the inventory ranking process to include climate change considerations. BART should modify the evaluation criteria to recognize projects that are high risk to climate change impacts and such that the project's rehabilitation or improvement will add climate change resiliency to the system and reduce climate risk.

It's also important to integrate or group, where feasible, adaptations with other rehabilitation projects. These types of projects become multi-objective meeting rehabilitation and resiliency needs. Multi-objective projects are more holistic and can potentially reduce overall project costs compared to individual single-objective projects.

In any rehabilitation work, it's important to leverage existing programs and initiatives. For repairs to leaking assets, the maintenance and engineering department should rely on the findings from the Water Intrusion Program. In 2008, BART developed the rehabilitation program to address water intrusion issues in BART's infrastructure. The project developed a systematic rehabilitation methodology, introduced investigative techniques and technologies, and researched remedial technologies and solutions.

New Responsibilities

The maintenance and engineering department will be responsible for updating the evaluation criteria to reflect climate change as a significant priority.

SECTION
6

Element 5—Asset Management and Life-Cycle Cost Analysis

Introduction

The purpose of Element 5 is to advance the pilot by addressing climate adaptation needs through a transit asset management approach, and providing a framework for comparatively evaluating the costs to implement adaptive strategies on a life-cycle basis. Integrating asset management and a life-cycle cost analysis into the decision-making process for climate adaptation actions will enable BART to better understand if a climate adaptation measure makes financial sense for the agency, what the least-cost solution might be, and how to integrate the solution into its budgeting process. The approach, using a case study example, can be applied on a programmatic level to inform prioritization and budgetary decision-making processes.

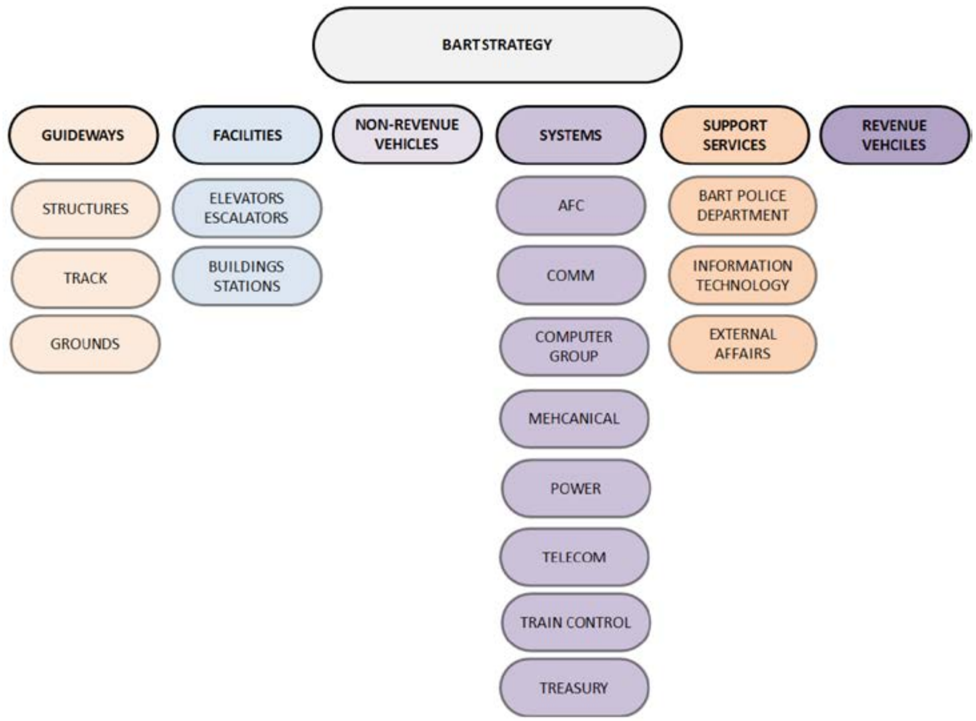
For illustrative purposes, the Fruitvale train control room was selected as an example asset to demonstrate the life-cycle cost evaluation framework for a business-as-usual (BAU) scenario versus adaptive scenario.

Asset Management

BART's system is aging and about 34 percent of its assets are currently at risk. It is estimated that it would take about $6B in investments over the next 10 years to maintain good performance and bring these assets into an acceptable or normal state of good repair. If funding levels are not changed, this number is expected to grow by an estimated 30 percent over the next 10 years. Despite this, BART performs at a very high level because of prior capital investments and the skills and experience of BART's people. These people are very effective at managing increasing risks as assets reach the end of their useful operating life. In order to maintain a state-of-good-repair and manage future risks to service reliability, BART is embarking on the development of a robust asset management strategy. This strategy, consistent with MAP-21 requirements, will be based on 1) asset management plans, 2) risk-based decisions, and 3) performance (e.g., condition, function, capacity, and risk). In the last year, BART has developed a preliminary asset management program report, generated its first comprehensive inventory of assets, including a bottom-up assessment of the condition of assets. From these assessments, BART has been able to prioritize a relatively stable list of State-of-Good-Repair projects. Asset management plans are also underway for the following five major asset classes: (1) Guideways, (2) Facilities, (3) Systems, (4) Revenue Vehicles, and (5) Support Services. Figure 5-1 illustrates the six total asset classes and 18 sub-classes evaluated through "dashboards" covering high-level information on the District's expenditure projections, level of risk, and resulting change in performance in 10 years.

Figure 6-1

BART Asset Classes and Sub-Classes



Source: BART Preliminary Asset Management Report, 2013

BART uses IBM spatial asset management software, Maximo, a technology that can systematically monitor and respond to BART's tangible assets in a geospatial perspective. The advantage of an asset management system is an increased organization and quality of information which can benefit decision making in planning, design, operations, and maintenance. The asset management team, who is responsible for the implementation of the asset management program, is currently undertaking the large effort to catalogue BART assets and to apply quality control on existing data.

Impacts on the Enterprise Level

At the enterprise level, the asset management strategy will play a key role for managing replacement and repair of BART assets across its six major asset classes and directing resources appropriately. Table 6-1 provides an outline of the asset management components at the enterprise level and specific opportunities where BART can integrate climate adaptation considerations.

Table 6-1 *Enterprise Level Opportunities to Integrate Climate Adaptation*

Asset Management Component	Opportunities to Integrate Climate Adaptation	BART Status / Notes
Asset Management Policy and Strategy	Consider climate change in asset management goals, policies, and/or plans.	• Climate change considerations to be added to asset registry • Environmental/Climate change and Asset Management Team Coordination
Risk-Based Asset Management Approach	Map areas vulnerable to projected climate risks. Inventory critical assets, create risk profiles, and develop risk mitigation strategies.	SLR maps completed for ART East Bay area Prioritized list of SOGR assets identified
Asset Management Activities	Develop adaptation strategies at enterprise, asset-class and lifecycle asset management planning levels.	AMPs for 5 asset classes are underway
Financial Requirements	Incorporate climate risk mitigation strategies into short- and long- range plans, capital and/or O&M budgeting processes.	
Continuous Improvement	Monitor asset condition in conjunction with climate change indicators to determine if/how climate change affects performance.	

Climate change considerations may be used as one of the criteria for risk assessments in the asset management program. Specific areas where this can be incorporated include the asset registry and asset management plans. Additionally, asset vulnerability to climate change can be added as one of the attributes within Maximo to support the overall prioritization of rehabilitation or replacement projects. Future repair and retrofit work will potentially rely heavily on direction from the asset management system. Therefore, it is critical that a high quality, comprehensive and reliable asset management program is developed. In the next phases of the asset management program, BART plans to include GIS data in Maximo (Op1).

The asset management team is a cross-department coordination effort including stakeholders from Rolling Stock and Shops, Maintenance and Engineering, IT, Police Department, Capital Development/Budget, office of External Affairs, and Procurement. The asset management team is working with maintenance and engineering stakeholders in connecting asset management to maintenance reports (M1). Stakeholder meetings are held weekly to discuss standardization and improvement of the maintenance reporting system. Maintenance reports from the Power and Mechanical Division are currently being connected to asset management. The Way and Facilities Division is not connected to asset management but will be in the future. Timely coordination between the asset management team work and the environmental team working on the climate adaptation strategy can also help mainstream climate change considerations with BART's current asset management planning efforts.

BART is also currently improving the maintenance reporting system to allow the user to input water inundation specific problem codes. As part of a work order, the maintenance staff may indicate root causes of problems via a problem or failure code. Examples of potential water-inundation problem codes are "rain," "flood," and "drainage blocked." The development of these codes is an example of the asset management team's efforts to improve the maintenance reporting process and identification of trouble spots. Communication to the maintenance staff will be required to be aware of the availability of these codes. This will be incorporated as part of the responsibility of the asset management team.

Impacts on the Asset Level

At the asset level, Table 6-2 outlines opportunities where BART can integrate climate change considerations in the lifecycle management planning of its assets. This level of planning will help identify potential risks or issues that may affect one asset in a particular location that may not affect another in a different location, even if they are within the same asset class.

Table 6-2 *Asset Level Opportunities to Integrate Climate Adaptation*

Life Cycle Management Component	Opportunities to Integrate Climate Change Adaptation
Roles and Responsibilities	Identify resource (person, organization, or program) for climate risk data and how it will be maintained.
Asset Inventory	Overlay or relate inventory to climate-related data.
Condition Assessment & Performance Monitoring	Document condition and performance monitoring in conjunction with climate conditions to understand how an asset performs under various climate extremes and if a climate risk mitigation strategy that has been implemented is effective and responsive.
Preventive/ Reactive Maintenance Plan	Update preventive and reactive/corrective maintenance practices to address different operating conditions.
Asset Policy and Strategy	Include goals for level of service requirements and climate change-related outcomes.
Asset Lifecycle Management	Consider climate risks to asset throughout each phase: (1) Design/procure, (2) Use/operate, (3) Maintain/monitor, (4) Rehabilitate, (5) Dispose/reconstruct/replace.
Capital Programming and O&M Budgeting	Consider costs of climate-related strategies (incl. costs to replace vs. retrofit vs. abandon) and the value or benefit of the measure to facilitate prioritization.
Performance Modeling	Conduct performance modeling in conjunction with climate conditions.
Continuous Improvement	Update asset lifecycle management plans as conditions and performance change.

Source: Parsons Brinckerhoff 2013

New Responsibilities

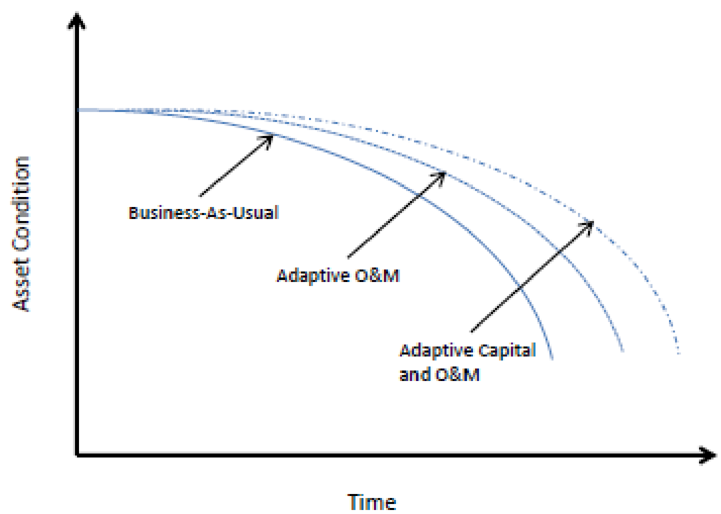
The Asset Management Team in collaboration with the Office of District Architect will be responsible for identifying and incorporating climate risk to assets in its asset registry and Maximo. Further efforts should include coordination with MTC and/or other regional entities to understand if and/or how climate risks are being integrated into their respective asset management system for regional consistency.

Life-Cycle Cost Analysis Methodology and Framework

The purpose of this framework is to provide a starting point for identifying an appropriate Life-Cycle Cost Analysis (LCCA) approach that addresses climate change adaptation. In a typical LCCA model, the focus is on capital improvements; however, the proposed approach would consider an adaptive strategy also including different O&M activities that would reduce risk to the asset over the life-cycle, thereby improving asset and system resiliency. Adaptive maintenance and operations activities would reduce risks to performance and safety and extend service life. Similarly, adaptive capital improvement activities are expected to not only reduce risks but also O&M costs. The O&M activities (as well as capital work) would be designed to reduce the impact of time on condition and hence treatment cycles (see Figure 6-2).

Figure 6-2

Adaptive Impacts on Asset Condition Over Time



The life-cycle cost comparison of a "business-as-usual" (BAU) scenario versus "adaptive" scenario for critical assets can inform decision-making processes related to capital and O&M improvements and project prioritization. The framework is based on the USDOT LCCA methodology and involves the following five steps, as illustrated in Table 6-3.

Table 6-3

Life-Cycle Cost Analysis Framework for Critical Assets[3]

Step 1	Establish alternative scenarios
Step 2	Determine activity timing
Step 3	Estimate costs (agency and user)
Step 4	Compute life-cycle costs
Step 5	Analyze the results

[3] Adapted from *Life-Cycle Cost Analysis Primer*, USDOT, August 2002. Accessed December 2013: http://isddc.dot.gov/OLPFiles/FHWA/010621.pdf.

Step 1: Establish Alternative Scenarios

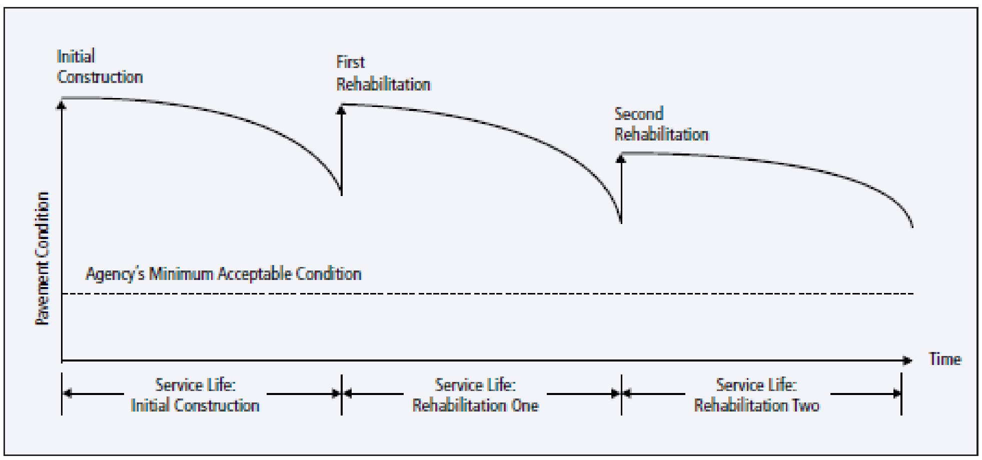
In this first step, an asset has already been selected for improvement, and a range of possible alternatives has been identified for achieving this improvement. The analysis period is determined, allowing enough time to compare total costs between each alternative, including initial construction and at least one rehabilitation cycle. A BAU scenario of asset performance without adaptive (i.e., capital or process) improvements is established along with an adaptive scenario. Activities throughout the life-cycle of the asset (e.g., construction, operations/ maintenance, etc.) under each scenario are identified.

Step 2: Determine Activity Timing

In this second step, current and future maintenance and rehabilitation schedules are identified for each scenario. Timing of rehabilitation should be based on existing maintenance and performance records and should be made as accurate as possible (see Figure 6-3). The adaptive scenario would also incorporate any changes in maintenance cycles as a result of capital and/or O&M improvements.

Figure 6-3

Example Lifetime of One Design Alternative[4]



Step 3: Estimate Costs (Agency and User)

Upon development of scenarios and timing of activities, costs are identified for the agency ("direct costs") and the user ("indirect costs").

Direct Cost Factors

Direct cost factors impact the agency and management of an asset throughout its life-cycle, including design/procurement, operation, maintenance, rehabilitation, and disposal/reconstruction/replacement. Key agency costs will typically include initial (usually initial construction), operation (revenue loss), maintenance (routine, preventive, and corrective), rehabilitation, future project support, and

[4] *Id.*

remaining service life value costs.[5] Future project support would apply upon major failure of asset and a repair contract is needed under the "business-as-usual" scenario. It typically will include the costs of design, environmental review, project management, construction, construction administration, inspection, etc. Remaining service life-value would apply if an activity has a service life that exceeds the analysis period. The difference between the service life and end of analysis period is known as the Remaining Service Life Value (RSV). The RSV of a project alternative (in this case, "adaptive action" scenario) at the end of the analysis period is calculated by prorating the total construction cost (agency and user costs) of the last scheduled rehabilitation activity.

Indirect Cost Factors

Indirect cost factors typically include costs that impact users of the system, but can also include other indirect economic (e.g., impacts to local businesses), social (e.g., accessibility impacts to transit dependent workers), and environmental (e.g., changes in energy and other resource consumption required to operate under scenario conditions, including riders that may opt to drive personal vehicles as a result of an incident) impacts. Costs to users cover increased travel time (e.g., due to train delays) and related vehicle operating costs incurred by the traveling public due to system delays, particularly when users switch modes and choose to drive to work in response to a system delay).

Step 4: Compute Life-Cycle Costs

Understanding life-cycle costs of the BAU versus adaptive scenarios involves computation of associated direct and indirect costs of each scenario over the analysis period. As estimated dollars spent at different times have different present values, life-cycle costs will be directly compared using a present value, with the application of a discount rate.

Step 5: Analyze the Results

In this last step, the life-cycle costs of the BAU and the adaptive scenarios are reviewed to determine if adjustments or modifications to any of the alternative scenarios might be needed prior to finalizing and then moving forward with a recommendation based on either total-lowest-cost alternative (considers both agency and user costs), or lowest-agency-cost alternative.

[5] Caltrans. *Life-Cycle Cost Analysis Procedures Manual*, 2013. Accessed November 2013: http://www.dot.ca.gov/hq/maint/Pavement/Offices/Pavement_Engineering/LCCA_index.html.

Research and Data Collection

Information to confirm activity components, maintenance and rehabilitation schedules, and costs under each alternative was obtained through the following means:

- Expert Interviews – Interviews with BART asset management, systems, and facilities maintenance groups were conducted to better understand the processes, practices, impacts to equipment, costs, and delays. Discussions included routine and corrective maintenance issues, their root causes, and possible adaptations to mitigate the issues in the future.
- OCC Log – The OCC maintains a daily log of all reported incidents along the system. Information on station or train control location, date, description (e.g., rainy days were recorded under "rain files" and brief descriptions of service disruption or repair required), and sometimes length of train delay were available as far back as 2007.
- Literature Review – Existing reports and studies also were reviewed to obtain and leverage relevant information for this study. These included:
  - BART Water Intrusion Investigation Program Report
  - Transbay Tube Surface Water Intrusion Study
  - USDOT Life-Cycle Cost Analysis Primer
  - Caltrans Life-Cycle Cost Analysis Procedures Manual
  - USDOT Revised Departmental Guidance on Valuation of Travel Time in Economic Analysis
  - Relevant As-Built BART Drawings
- Site Visit – For the case study example, a tour of the Fruitvale Train Control Room was conducted with an expert cost estimator to perform a visual assessment of the roofing features and areas of previous damage to equipment inside the train control room due to water intrusion.

Case Study Example: Fruitvale Train Control Room

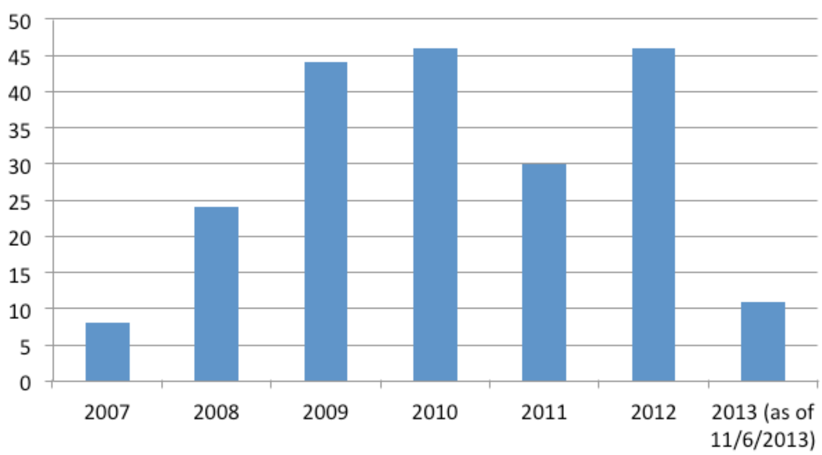
Water Intrusion and BART's Train Control Rooms

One of the typical challenges imposed upon transit operating systems is water intrusion. Water intrusion occurs in many forms and can result in cracks, breaching waterproof membranes, drainage malfunctions, or joint failures. Water intrusion subjects civil and structural infrastructure to corrosion, advanced aging, and structural safety and affects transit system performance and customer experience. When water intrusion occurs within power and train control equipment and networks, it can cause immediate and vital impacts to the operating system, which can lead to irreversible damage to the system and adversely affect safety of human lives.

BART's train control rooms, for example, have increased in vulnerability to water-related events in the last three to five years, as observed in the OCC log history. BART has an estimated 34 train control rooms across its system, in addition to a number of train control huts. While most water-related incidents occurred as water intrusion from rainstorms, other climate-related incidents, whether directly or indirectly resulting from increased precipitation and a rising water table, occurred from increased humidity resulting in water saturation of cables and other equipment. BART's OCC log, containing incident files from 2007 onward, was reviewed to understand how many reported rainy days affected service and how many rain-related incidents impacted BART's train control rooms. The number of "Rain File" days was higher (30–46 incidents) between 2009 through 2012 than from 2007 through 2008 (see Figure 6-4).

Figure 6-4

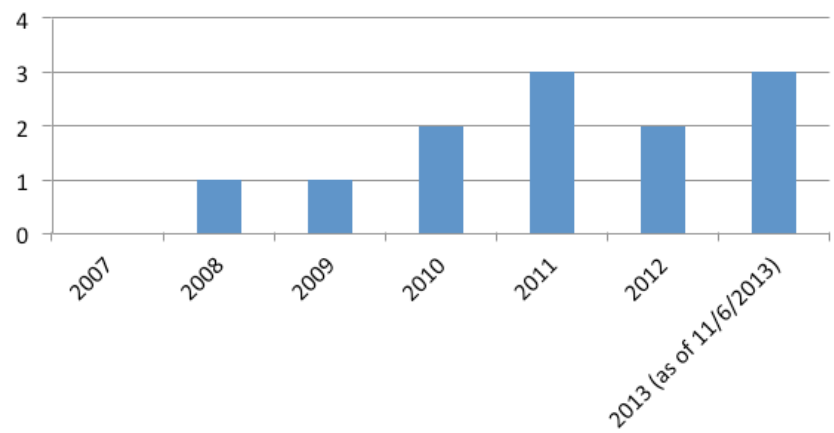
Annual Number of Days with Reported Rain Files



As the number of days with reported rain files generally increased, so did the number of reported rain-related train control room incidents that affected train delays or repair/replacement of train control equipment. The affected equipment pieces in this time period included SORS computers, Net.com, Vital Processing Interlocking Control System (VPI), and non-vital operation boards. Figure 6-5 illustrates the slight increase in reported rain-related train control room incidents in recent years.

Figure 6-5

Annual Number of Rain-Related Train Control Incidents Reported



Through interviews with key Train Control Systems ("systems maintenance") and Buildings Maintenance staff at BART, a number of specific adaptive options were identified as possible solutions to train control room water intrusion events.

Adaptive solutions included:

- Waterproofing vaults and including sump pumps with remote alarms for sub-grade train control rooms
- Exploring enforcement of drip loop use
- Implementing weather control in train control rooms and huts
- Installing remote train control room sensors for high humidity, high temperature, and water intrusion
- Modernizing structures
- Updating BART Facilities Standards to include new guidelines for:
  - Pitched roofs
  - Elevated floors for train control rooms (to prevent bottom entry water intrusion)
  - Relocating or raising cables off the flooring of train control rooms
  - Bottom entry cabinets and cables (instead of top entry and vertically positioned)

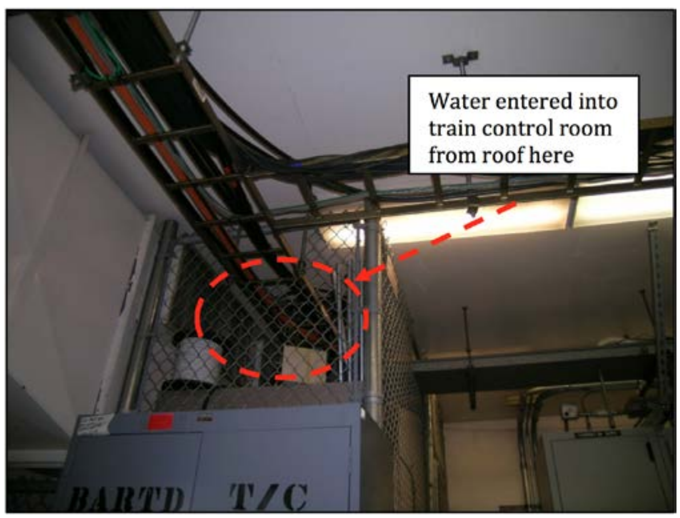
Within the study area of BART's climate adaptation assessment, the Fruitvale train control room was identified as a critical asset sensitive to leaks and damage as a result of existing cracked roof structures and insufficient drainage during storms. Although the Fruitvale train control room has drains on the roof that convey water down to the storm-drain system and a cutout along the roof lip allowing additional water to overflow down the side of the building, there have been issues with drain backup and roof leaks as a result of its flat, "bathtub" design.

Fruitvale Train Control Room Incident, November 30, 2012

A recent water intrusion event took place on November 30, 2012, that caused VPI failure and train delays impacting up to 21,000 riders. The incident was related to increased precipitation and water held on the rooftop. A blockage in the drain pipe had caused water to collect in the drain pipe up to the train control roof. Because of the roof's "bathtub" design, a substantial amount of water was accumulated. The accumulated rooftop water leaked through the cable openings, as shown in Figure 6-6, traveling across the cable trays and causing damage to train control equipment. Separately, because the interior floor drain and roof drainage were connected, collected water exuded from the floor drain and caused flooding in the room interior. Buildings maintenance was summoned to investigate and repair. Snaking and jetters were used but were not successful. Ultimately, the buildings maintenance crew disconnected the roof drain line, allowing the water to drain out, and re-piped it to a different drain line to solve the issue, totaling approximately two and a half weeks to complete. To safeguard the train control room and equipment from water intrusion, one of the adaptive strategies for consideration would include replacement of the "bathtub" designed roof with a pitched roof. The life-cycle cost analysis of BAU versus adaptive, focusing on replacement of the train control room roof, is detailed in the following section.

Figure 6-6

Fruitvale Train Control Room Water Intrusion Event



"Business-As-Usual" (BAU) and "Adaptive" Scenarios

The project team interviewed key BART staff to understand current actions to address train control room water intrusion events. The adaptive scenario builds on the BAU scenario and identifies specific points where both process- and capital-related improvements could be made to manage risks to performance, safety, or reliability of the asset. A summary of actions in sequential order for these two scenarios are described in further detail below.

BAU Scenario

Water intrusion events at BART's train control rooms are addressed on an as-needed, case-by-case basis, but they have not yet been systematically addressed at a programmatic level. BART's train control rooms have not yet been evaluated system-wide for these vulnerabilities and impacts, and a rehabilitation program has not yet been developed to address climate-related vulnerabilities. As a result, maintenance staff have addressed the aging infrastructure and associated challenges to the best of their abilities, given limited resources. For example, in one instance, building maintenance temporarily tarped the structure to prevent further leakage while an emergency proposal was put together to fix the roof. Typically, building maintenance staff are responsible for stopping the water intrusion, and system maintenance staff are responsible to repairs or replacements to damaged equipment. Although there is not yet a formalized process at BART for addressing water intrusion events at the various train control room locations, the six broad steps as outlined in Table 6-4 have been taken in response to recent water intrusion events at the Fruitvale train control room.

Table 6-4
Summary of BAU Scenario

1	System maintenance staff conduct regular passive, visual inspections for water intrusion, and reports at beginning and end of each shift during rainy season.
2	Building maintenance staff conduct routine maintenance in preparation for rainy season ("winterization").
3	Request for Maintenance (RFM) reported per water intrusion incident.
4	Staff receiving RFM assemble crew and proceed to location.
5	Conduct problem troubleshooting, take reactive maintenance actions to immediately resume standard service levels.
6	Prepare Project Service Request (PSR) or emergency repair package (e.g., emergency reroofing), if applicable, upon assessment of water intrusion issue.

Adaptive Scenario

The adaptive scenario identifies specific points in the BAU scenario where both process and capital improvements can be made. Although several different adaptation/retrofit and replacement alternatives[6] could be assessed to address water intrusion, for the purposes of this pilot case study example, the adaptive scenario focuses on implementation of train control room sensors and a roof replacement. In a site investigation conducted at the Fruitvale train control room nearly one year later, on November 22, 2013, it was determined from visual observations that the roof may have exceeded its life-cycle and replacement was necessary. The drain leader from the roof to the storm drain had clogged,

[6] Interviews with system maintenance personnel have brought up improvements involving the location of cables in train control rooms, roof types, floor height, sump pumps, climate control and/or sensor equipment for humidity, temperature, and water intrusion.

causing water to leak into the train control room and potentially damaging vital operational train control equipment. By replacing the roof and creating a greater pitch, rainwater would run off to the eastern parapet and integrated scupper. Other options discussed at the site, such as gabling the roof using polystyrene tapered panels, did not appear to be feasible due to the lack of available drainage facilities immediately to the west.

The adaptive scenario involves the 10 broad steps outlined in Table 6-5, with actions 1, 2, 3, 9, and 10 identified as process or capital improvements.

Table 6-5

Summary of Adaptive Scenario

1	Conduct asset condition assessments; identify critical assets.
2	Monitor environmental conditions impacting assets through humidity, temperature, and water intrusion sensors/alarms in train control rooms.
3	Support preparedness for heavy precipitation events through implementation of early weather warning system.
4	Building maintenance staff conduct routine maintenance in preparation for rainy season ("winterization").
5	Request for Maintenance (RFM) reported per water intrusion incident
6	Staff receiving RFM assemble crew and proceed to location.
7	Conduct problem troubleshooting, take reactive maintenance actions to immediately resume standard service levels.
8	Prepare Project Service Request (PSR) or emergency repair package (e.g., emergency reroofing), if applicable, upon assessment of water intrusion issue.
9	Monitor and evaluate underperforming assets and identify adaptation measures required. Conduct LCCA on identified adaptation strategy when necessary.
10	Integrate into capital needs prioritization and budgeting processes for implementation upon chosen adaptation strategy per LCCA findings

Estimated Costs and Assumptions

Fruitvale Train Control Room – Water Intrusion Event (11/30/2012)

Direct Costs

The water intrusion event that occurred on November 30, 2012, incurred a direct cost of about $30,195 (See Table 6-6), including $24,938 in labor for buildings (about 300 staff hours) and systems (about 12 staff hours) maintenance groups to fix the problem. Costs also included the following materials:

- PLM card and power supply for VPI (estimated at $4,757.00)
- Pipe replacement pieces (estimated at $500)
  - 10' × 4" cast iron pipe (1)
  - 4"no-hub clean-out (1)
  - No-hub couplings (2)
  - Plug (1)

- No-hub 45% elbows (2)
- Wall brackets (4)
- 10' length unistrut with hardware (1)
- Fill sand (2 yds)

Table 6-6

Direct Costs of Water Intrusion Event at Fruitvale TCR (11/30/12)

Activity	Estimated Cost
Corrective Maintenance Labor	$24,938
Materials	$5,257
Total	$30,195

In this scenario, BART assumes that there is no revenue loss as a result of this incident. In other words, passengers upon realizing the delay, decide to maintain their transportation choice and do not choose an alternative means of transportation. In reality, revenue is lost as a result of delays due to changes in transportation choice. Although it is difficult to associate revenue loss due to a single event, multiple delays over time compound the impacts on reliability and reputation. Damage to reputation can cause loss of ridership because the public will perceive a lower reliability than actual.

Indirect Costs

In addition to labor and material costs to BART, there are also delay costs (primarily in terms of value of time) to passengers and unpredictable costs related to changes in passenger satisfaction or reduced ridership due to system delays. Changes in travel time can either increase or decrease personal value when translated into more or less time for work or pleasure. The value of lost passenger time due to train delays was not included in this case study because the total delay caused by the water intrusion incident was not quantifiable. A late train's speed, for example, can be higher than scheduled in order to recover schedule adherence. Its lateness depends on all previous (and subsequent) delays and so is not predictable based on a single event. For this reason, delays are treated statistically in many respects. As far as a single event or cause, BART refers to the immediate impact at the location and over statistically-large datasets. BART also refers to the probability or frequency of characteristic impacts for various causes. It was noted by BART Reliability Engineers that while water intrusions that cause delay, events make a small fraction of all delay events appear to be occurring with increasing frequency in the past five years. These incidents have a high probability—about a 50 percent chance per year—of causing a very significant or major delay.[7]

[7] A major delay is defined by 10 or more trains delayed (at least 5 minutes and, in some cases, up to or exceeding 60 minutes). The worst events are of high delay to a large number of trains; these events alone can severely impact train on-time performance for the day or even the month.

BAU Scenario

The BAU scenario assumes information gathered from the November 2012 water intrusion event at the Fruitvale train control room in addition to routine maintenance practices, especially during the rainy season, performed by BART's systems and building groups. Before the rainy season hits, building maintenance staff conduct a process called "winterization," in which scuffers and drains are cleaned out to ensure proper drainage with anticipated increases in precipitation. "Winterization" occurs annually across the system and costs BART about $100,000 each year. Since this routine preventive maintenance activity would occur in both the BAU and adaptive scenarios, it is omitted from the lifecycle analysis. In addition to "winterization," the systems maintenance staff conduct routine passive, visual inspections for any leaks during a rain event, which requires about one hour per shift for three shifts per day for each train control room.

Table 6-7

Estimated Costs for BAU Scenario

Activity	Estimated Cost	Frequency
Direct Costs		
Systems Seasonal Inspection	$8,103[8]	Annual Per Train Control Room
Total Corrective Maintenance Labor	$24,938	Every 3 yrs[9]
Repair Materials (Systems)	$4,757	Every 9 yrs[10]
Repair Materials (Buildings)	$500	Every 3 yrs
Emergency Project Service Request[11]	$93,000	Every 30 yrs
Revenue Loss (Due to System Delay and subsequent ridership loss)	$0[12]	N/A
Indirect Costs		
Value of Passenger Time Loss	N/Q	N/A
Other External Cost Impacts (Environmental, Economic, Social)	N/Q	N/A

n/q = not quantified, n/a = not applicable

[8] This value is calculated based on the average number of rain files per year as identified in the OCC log from 2007 to 2013, average salary of systems maintenance staff, and one hour spent per shift for visual inspections for each day with a rain file.

[9] Based on available OCC log data, a water intrusion event into the train control room could occur every 0–5 years. Since the number of rain events has increased in more recent years, the frequency assumption uses a rounded mid-point value of 3 years.

[10] The BAU scenario conservatively estimates that water intrusion events will impact train control equipment 1 out of 3 times.

[11] The scenario assumes that normal wear and tear will require rehabilitation of the roof. Cost was derived from Project Manager Isaac Lim for emergency roof repair.

[12] The BAU scenario assumes no loss of ridership from the system delay incident.

Adaptive Scenario

In the adaptive scenario, roof replacement, indoor environmental monitoring and control equipment, and implementation of an early-weather warning system were explored. A summary of estimated costs under the adaptive scenario is provided in Table 6-8, followed by descriptions and assumptions for each major adaptive component. Implementation of the adaptation is assumed to occur in the scenario in 2014.

Table 6-8

Estimated Costs for Adaptive Scenario

Activity	Estimated Cost	Frequency
Direct Costs		
Systems Seasonal Inspection	$0[13]	Annual per Train Control Room
Indoor Environmental Monitoring and Control	N/Q	N/A
Labor Costs (data collection, evaluation, and planning related to asset condition assessments and indoor environmental monitoring)	N/Q[14]	N/A
Total Corrective Maintenance Labor	$24,938	Every 3 yrs, starting year 13 of analysis[15]
Repair Materials	$500	Every 3 yrs, starting year 13 of analysis
Roof Replacement	$263,320	Replace every 35 yrs
Indirect Costs		
Value of Passenger Time Loss	N/Q[16]	N/A
Other External Cost Impacts (environmental, economic, social)	N/Q	N/A

n/q = not quantified, n/a = not applicable

[13] In the adaptive scenario, costs for seasonal inspections conducted by systems maintenance are assumed to be relieved by implementation of indoor environmental monitoring and control equipment.

[14] The additional labor costs associated with these activities would need to be researched further but are anticipated to be negligible, as BART already has asset condition templates as part of its asset management program underway, and indoor environmental monitoring and control equipment would be added to an existing infrastructure that monitors thousands of alarm points.

[15] The study estimates that implementation of the adaptation will significantly reduce corrective maintenance costs. This is expressed as zero corrective maintenance cost in the first 12 years of the adaptation, after which the study conservatively resumes regular corrective maintenance needs.

[16] Although the value of passenger time loss is not quantified in the adaptive scenario, the study expects that indirect costs to users would be less as a result of reduced delays from train control room water intrusion events.

Roof Replacement

The Fruitvale train control room currently has a flat, "bathtub" style roofing structure and is positioned directly under the guideway. In the adaptive scenario, a modernized pitched metal roofing structure was proposed to mitigate the collection of water on the roof and risks of leaks into the train control room and equipment. The proposed roof system would be standing-seam and heavy-gauge, and the utility services would be rerouted and/or weather-sealed to minimize or eliminate water intrusion via conduits. Cost estimates for the roof replacement include the removal of the existing roof assembly, redesign, and construction (see Table 6-9). The study assumes the roof system to have a lifetime of 35 years. Industry warranties for metal roofing can range from 25 to 50 years.

Table 6-9

Estimated Costs for Fruitvale TCR Roof Replacement

Activity	Estimated Cost
Labor	$70,000
Materials ($30/sq ft)	$54,000
Equipment	$5,000
Subtotal	*$129,000*
Contractor OH&P (30%)	$38,700
Design (20% of $129,000)	$33,540
Construction Management (30% of $167,000)	$7,618
Contingency (10% of $167,000)	$16,770
Total	**$263,320**

To successfully complete the roof replacement operation, the suspended systems raceway and conduits would be slightly elevated to allow installation of the polystyrene taper panels and roof membrane. Once elevated, the panels and follow-on EPBM material could be applied to the prepared roof surface. It is anticipated that the membrane will need to be placed in two sections because of the elevated conduits and raceways that interface with the roof (the EPBM material is capable of being spliced and seamed). The two sections are noted as the western section and the eastern section, both bisect the building in the longitudinal direction. There are also a series of large-diameter train control conduits that project from a curbed metal chase way that sits on the roof. The seal at this location would need a new metal flashing and counter flashing. Removing and replacing the flashing would require skilled sheet metal trades people. Disconnecting train control conductors and fiber communication cabling did not appear to be an option. The new metal chase-way would need to be spliced and soldered on site to fit around existing equipment. Reglets and counter flashings would need to be installed at the curbed parapets.

Roof replacement should be scheduled in the driest months of the year so rain will not enter and damage the equipment in the train control room.

Indoor Environmental Monitoring and Control

One process improvement in the adaptive scenario is providing for monitoring and climate control devices, including HVACs or dehumidifiers. Such devices can eliminate train control equipment failures that are related to humidity and temperature issues. Installation of such devices would be connected to BART's existing communication infrastructure.

HVAC and dehumidifiers and their complementary sensors do not address the issue of water leaks. Research should be conducted to explore available technologies that may address water leaks and how the technology would be configured. Development costs to integrate sensor technology into BART systems and ongoing costs to monitor alarms should be studied. A train control room sensor pilot program may be useful as part of this research, as sensor data could have tremendous value for BART for input to state-of-good repair and long-term trending studies.

Early-Weather-Warning System

Other process improvements in the adaptive scenario may include implementation of an early-weather warning system to support preparedness for an extreme weather event that poses risks to critical assets, such as train control rooms. An early-weather warning system could be implemented through a partnership with a local university (e.g., University of California, Berkeley) or other organization such as the National Oceanic and Atmospheric Administration (NOAA), where alerts would be sent to appropriate BART personnel with enough advance warning to deploy resources (e.g., equipment or staff) for preventive maintenance actions and plan for any necessary recovery actions.

Inspections

The study expects that capital or physical asset adaptations (roof replacement) and O&M adaptations (indoor environmental monitoring and control, early-weather warning system) will relieve the current need for system maintenance to conduct visual inspections every shift during the rainy season. Winterization activities by the building maintenance group, however, still would be conducted as standard practice. The deferred maintenance hours spent by the systems group in conducting the inspections would be restored as a result, and time that was previously spent on visual inspections could then be spent conducting other necessary systems maintenance work.

Life-Cycle Cost Comparison

A planning level life-cycle cost calculation based on best available information was developed to compare the life-cycle costs of the adaptive scenario against the BAU scenario (see Table 6-10). The analysis was built to understand, at a high level, the relative costs or savings from implementing adaptive capital and O&M actions through 2050. It incorporates assumptions (e.g., frequency of maintenance activities and associated costs) identified through interviews with key BART personnel and capital cost assumptions supplied by vendors. Routine maintenance activities during the rainy season are included in the LCCA with anticipation that the adaptive action scenario will result in reduced maintenance activities.

Table 6-10

2050 Life-Cycle Cost Comparison of BAU vs. Adaptive Scenario[17,18]

	BAU Scenario	Adaptive Scenario
O&M	$1,330,000	$500,000
Capital	$360,000	$1,140,000
TOTAL (2013–2050 in year-of-expenditure dollars)	$1,700,000	$1,640,000

Cost calculations are reported as total expenditures through 2050, with a base year of 2013, acknowledging the differential value of the dollar today to its value in future years. For public agencies, a 3–3.5 percent inflation rate is typically used. For this analysis, a 3.5 percent inflation rate is applied for a more conservative estimate of future benefits. The 2050 life-cycle values for the BAU and adaptive scenarios are based on the actual costs of activities and materials in response to the November 2012 water intrusion event.

In comparing the two scenarios, the adaptive scenario is more favorable by $60,000 (4%) in direct costs than the BAU scenario on a life-cycle basis. If indirect costs (costs to the user) were to be included, however, there would be a greater cost differential between the two scenarios.

[17] Table 6-10 presents the resulting life-cycle costs (rounded to the nearest ten thousand) of the BAU scenario vs. adaptive scenario based on actual costs expended in response to the November 30, 2012, water intrusion incident at the Fruitvale train control room.

[18] Low- and high-impact scenarios were developed (see Appendix A) illustrating sensitivity to changes in material and capital costs and other variable factors. In the case of the November 30, 2012, water intrusion event at the Fruitvale train control room, the level of risk to the VPI was mitigated, and, fortunately, a complete replacement of the VPI board was not required. However, in the event the VPI boards did need to be replaced or would need to be replaced in the future, the high-impact scenario considers the costs associated with the risk of VPI failure and board replacement, estimated to cost up to $1,000,000. Considering this level of risk to the VPI board posed by a water intrusion event, the proposed physical asset adaptations (replacing the roof structure and rerouting utilities to prevent water intrusion through conduits) could potentially save BART about $10M in life-cycle costs over the analysis period on the high-impact scenario. The high-impact inputs also considered a greater number of rainy days. In the low-impact scenario, the BAU scenario was found to be more favorable than the adaptive scenario. The low-impact inputs considered fewer rainy days, which meant fewer inspections and lower corrective maintenance needs.

In the future, BART expects that the life-cycle analysis will skew further in favor of the adaptive scenario. As the Bay Area experiences more extreme weather events in the future, climate-related incidents are more likely to occur.

Discussion

Integrating asset management and an LCCA into the decision-making process for climate adaptation action will enable BART to better understand if a climate adaptation measure makes financial sense for the agency, what the least-cost solution might be, and how to integrate the solution into its budgeting process. The LLCA approach can help guide BART in decision-making for adaptation capital investments.

Although this particular case study focused only on one specific type of asset within the study area—the Fruitvale train control room—the framework can be applied programmatically across the system and evaluated for its applicability to other critical assets at BART and other adaptations.

Further consideration would address the implications of this analysis for a programmatic approach to adaptation that would focus on priority adaptive capital work at all facilities. This would explore what the most cost effective approach is for extending service life and reducing risk/impacts with different funding constraints.

Additional opportunities should be sought to better link the train control room maintenance or modernization needs with available funding sources or potential new funding sources. Such sources might include FTA grant opportunities to improve resiliency or leveraging BART's $5M water mitigation fund to support critical asset needs.

SECTION
7

Conclusion

Climate change adaptation strategies will include both structural and non-structural measures. Structural adaptation strategies are those with physical changes to assets. Non-structural adaption strategies are institutional changes that affect our business practices and policy decision-making. Successful climate change adaptation requires both structural and non-structural interventions. Implementing climate change strategies will impact our current business practices and will require BART to take on new responsibilities.

Severe weather events like heavy down pouring and flooding are unpredictable and are going to happen more frequently. These climate events will cause severe disruption to transit services and damage transit infrastructure. Furthermore, many adaptation strategies, structural and non-structural, will take a significant time period to implement. The findings of this pilot provide sufficient and critical insights that urge BART, as an indispensable work horse for the mobility of the San Francisco Bay Area region, to respond timely towards climate change adaptation.

The Vulnerability Is Real

The project study area is in the East Bay coastal area from West Oakland to Hayward. BART operates approximately 12 miles of track and 7 passenger stations in the study area, with one station situated below grade. The assets that are selected for the pilot represent a diverse set of assets: the track portal west of West Oakland Station, the station entrances at Lake Merritt Station, the train control room at Fruitvale Station, and the traction power substation at Coliseum Station. Based on the best available climate change science and risk assessment, the likelihood of an extreme weather event to occur in the Bay Area and impact the asset is assessed. A simplified summary of the likelihood is as follows:

- Lake Merritt Station Entrance (station) – Remote
- Oakland West Track Portal (track) – Occasional
- Oakland Coliseum Traction Power Substation (traction Power) – Probable
- Fruitvale Train Control Room (train control) – Occasional

Comparing the configuration and geographical location of the four sample assets to other similar assets throughout the BART operating system, the author estimates that there may be a substantial number of assets that may become impacted from extreme weather events at other locations within the operating system. Pending findings of a risk assessment with the rest of the BART system, the trajectory may show that overall vulnerability of our entire operating system is real.

The Risks Are High

A simplified summary of the risk from the overall climate change scenarios considered in the pilot is as follows:

- Lake Merritt Station Entrance (station) – High
- Oakland West Track Portal (track) – Medium
- Oakland Coliseum Traction Power Substation (traction Power) – Medium
- Fruitvale Train Control Room (train control) – High

The summary shows that half of the sample assets have a high risk. Comparing the configuration and geographical location of the four sample assets to other similar assets throughout the BART operating system, the author estimates that there may be substantial risk from climate change at other locations within the operating system. Pending findings of a risk assessment with respect to climate change scenarios impacting the remaining majority of BART system, trajectory can show an alarming overall risk to BART entire operating system.

Resiliency Is Attainable

Implementing climate change adaptation strategies will result in greater resiliency to our operating systems and critical assets. Resiliency can more easily achieved for assets with greater adaptive capacity; the higher it is, the easier resiliency can be achieved. A simplified summary of the attainability of resiliency to overall climate change scenarios considered in the pilot are as follows:

- Lake Merritt Station Entrance (station) – Moderate
- Oakland West Track Portal (track) – Low
- Oakland Coliseum Traction Power Substation (traction Power) – Moderate
- Fruitvale Train Control Room (train control) – Moderate

The average value of resiliency from the four sample assets is moderate. Comparing the configuration and geographical location of the four sample assets to other similar assets throughout the BART operating system, the author estimates that system wide there is average adaptive capacity with respect to climate change scenarios applied in the pilot. Therefore, there it is realistic potential to apply practical adaptations to assets to enhance their resiliency.

As an immediate step following this study, a funding plan should be devised so that a comprehensive, system-wide, vulnerability and risk review of BART operating systems and assets can be performed. It is a value-added approach by leveraging the findings from several regional and federal climate change adaptation projects, by applying the methodologies developed through this pilot, and by continuing the broad teamwork that came together during this pilot.

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APPENDIX

A

Project Documentation

Meeting Minutes

Meeting List

Project Team Meeting List

Date	Purpose	Other stake holders present
10/05/12	Project kickoff	
10/30/12	Progress update	
12/14/12	Site visit	Ken Meyers, Facilities Supervisor
01/04/13	Progress update	
01/11/13	Progress update	
01/16/13	ART led meeting on adaptation	
01/22/13	Progress update	
01/31/13	Progress update	
02/05/13	Adaptation Strategy Workshop #1	• Dean Giebelhausen, Section Manager Power Mechanical • Cristiana Lippert, Division Manager Mechanical Engineering • Ken Meyers, Facilities Supervisor • John Scaria, Group Manager Systems Engineering • Barney Smits, Principal Mechanical Engineer
02/27/13	Adaptation Strategy Workshop #2	• Dan Hartung, Deputy Police Chief • Mark Pfeiffer, Manager Electrical and Mechanical Engineering • Abdul Shaik, Manager, Traction Power • Pepe Vallenas, Acting Seismic Engineering Manager
03/08/13	Draft report review	
4/25/2013	Element 4 development—Asset management	Frank Ruffa
4/26/2013	Element 4 development—BART police	Marla Blagg, Kevin Franklin
4/26/2013	Element 4 development—Planning	Val Menotti
4/26/2013	Element 4 development—System Safety	Jeffery Lau
4/27/2013	Element 4 development—NRV	Joe Torrisi
5/6/2013	Element 4 development—BART police	Marla Blagg
5/9/2013	Element 4 development—Way and Facilities	Richard Leonard, Tracy Johnson
5/10/2013	Element 4 development—Asset Management	Cathy Lee
5/15/2013	Element 4 development	
5/17/2013	Element 4 development—Asset Management	Joel Koford, Domingo Laureles
5/17/2013	Element 4 development—JPC	Bruce Riordan (JPC)
5/21/2013	Element 4 development—Planning	Tim Chan
5/22/2013	Element 4 development—Sump Pumps	Dean Giebelhausen
5/29/2013	Element 4 development—ACFCWCD	Rohin Saleh (ACFCWCD)
9/10/2013	Element 4 development—Asset Management	Frank Ruffa, Tiffany Batac (PB)
10/30/2013	Element 5 Research	Ken Meyers, Isaac Lim
11/5/2013	Element 5 Research	Felix Marten, Raul Millena
12/18/2013	Element 5 Research	Scott Fanning

Minutes

ARUP

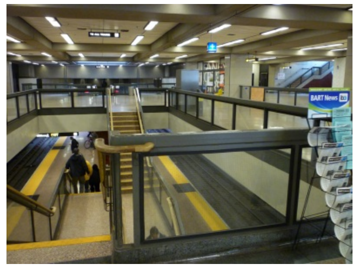
BART Sea Level Rise Adaptation		Job number 227377	
Meeting name and number	Site Visit to BART Assets	File reference	
Location	BART Headquarters, Lake Merritt Station, Fruitvale Station, Portal at Oakland Shops, Oakland Coliseum Station, Oakland West Portal	Time and date	9am-3pm December 14, 2012
Weather	Gray skies, some drizzle in afternoon.		
Purpose of meeting	Site visit to project study locations.		
Present	Herbert Diamant (BART), Stephen Burges (Arup), Jessica Fosbrook (Arup)		
Apologies			
Circulation	Those present Tian Feng (BART), Renee Lee (Arup), Tim Bates (Arup)		

1. Met at BART offices at 300 Lakeside Drive in Oakland

2. Visited Lake Merritt Station

Visited station including: above ground area with four station entrances and other (possibly mechanical or electrical) equipment housing, below ground turnstile area, fountain area, track platform, BART's central train control room, BART police headquarters, and large exposed grate over station vent in Madison Ave. Observed dampness on stairs between fountain and turnstile entrance area. Discussed Lake Merritt flood project and Arup will investigate if any publicly available documents regarding project exist.

Prepared by	Jessica Fosbrook
Date of circulation	1/2/13
Date of next meeting	


Figures from left-right: Lake Merritt station looking towards fountain, Lake Merritt station looking down to tracks, large exposed vent grate in Madison Ave.

3. Spoke with Ken Meyers at Oakland shops

Discussed recent drainage problem at Fruitvale train control room during recent storms on 12/2/12. Drainage issues were attributed to a roof drain down pipe that was not connected into the storm drain system during construction of adjacent new development. Ken recommended speaking to Richard Leonard regarding other recent problem areas at BART assets.

4. Visited Fruitvale Station

Focus of visit was on train control room. Saw inside and outside of room, and observed recent drainage problem from roof drain to below ground discharge. Problem attributed to lack of tie-in to storm drain system during construction of adjacent new development. Also viewed roof of train control room from track platform. Observed areas of leaks inside the train control room, and the current fix of the problem – a temporary hose connecting the roof down pipe to the outside of train control room.



Figures from left-right: Leak stains in Fruitvale train control room, end of down pipe outside of train control room, temporary connection inside of train control room from down pipe to outside walkay.

5. Oakland Coliseum Station

Visited station including: station entrance, underpass to parking lot with drainage pumping station (observed constant flows into the pump sump, assumed from groundwater infiltration source), elevated track, and outside of traction power facility. While inside the station, observed water marks on columns and beams, and large open air gaps between windows and roof structure. Viewed the airport connection project (under construction) from elevated track, and a daylighted portion of a canal, west of San Leandro St and east of the Hegenberger Rd onramp. Also reviewed draft plans for substation upgrade which show the ground level to be raised with the addition of 4" inches of asphalt cement. A future survey could confirm relative elevations between traction power facility, station entrances, and any flood elevations of the nearby canals.

Figures from left-right: Open area between station walls and roof at Oakland Coliseum, pump sump at underpass, train control room.

6. Oakland Shops Portal

Viewed portal at Oakland shops from elevated walkway and perimeter fence. Observed cracks in retaining wall, and some drains were partially covered in silt or sand. Walked along 8th St to view the eastern area of the tracks uphill of the station.

Figures from left-right: Portal entrance, track uphill of portal entrance facing east, partially covered track drain.

7. West Oakland Portal

Viewed West Oakland portal from perimeter fence. Observed gate along 7th St. Also observed retaining wall cracks, some of which had greenery growing in the cracks.

Figures from left-right: Plants growing in retaining wall cracks, gate along 7th St, track portal looking east.

Climate Change Adaptation Chapter 4

Meeting Minutes

April 25, 2013 1pm to 2pm

Present: Norman Wong, Tian Feng, Frank Ruffa

Next meeting: TBD

I. Discussion

Tian gives overview of climate change adaptation project to Frank.

Two relevant adaptation strategies to asset management are

1) Georeference asset management system. Allow for real time updates and querying
2) Improve maintenance reports with regard to water inundation, drainage, equipment failures. Tie into asset management.

Frank Ruffa gives overview of asset management project

1) FTA did not award grant money to BART for the asset management project. Work is currently under BART's operating budget
2) Currently, there is a rough inventory of BART assets (40,000+). This is at 80% completion.
3) The plan is to integrate this inventory into Maximo.
4) Maximo is the engine that connects these different attributes.
5) There are plans to prepare 6 asset management plans, 1 for each type of asset.
    a. The plans will break down the assets further into 18 different disciplines.
    b. Assets in the future may be further broken down to individual components.
6) Domingo Laureles is a Senior Maintenance Engineer who has been key in the development of the current asset inventory.
7) There is currently a preliminary report of the inventory.
8) Asset management program planned to include a risk management aspect. No specific risk management approach/guideline. References made to ISO 31,000, ISO 55,000, and International Infrastructure Management Manual (IIMM).
9) Asset management planned to include three action scenarios as part of an evaluation tool:
    a. Do nothing.
    b. Fix now.
    c. Defer later to fix.

Norman would be an ideal candidate to provide the environmental perspective on asset management. Inclusion into the governance committee.

II. Action Items

Frank Ruffa

1) Send Norman and Tian the preliminary report
2) Send Norman and Tian the current inventory spreadsheet.

Norman Wong

1) Align Chapter 4 approach/contents with asset management approach/methodology accordingly.
2) Drop by Frank's office next week for further discussions.
3) Provide input in future asset management efforts.

Climate Change Adaptation Chapter 4

Meeting Minutes

April 26, 2013 3pm to 4pm

Present: Norman Wong, Tian Feng, Marla Blagg, Kevin Franklin

Next meeting: TBD

I. Discussion

Tian gives overview of climate change adaptation project to Marla and Kevin.
Marla gives overview of emergency response /preparedness plan.

1) Tsunami considerations are earthquake focused, not water inundation focused.
2) Downpours are not accounted for and are a serious concern for among the emergency response community.
3) Flood scenario drills have been done previously. One scenario considered flooding and Alameda County Flood District pump stations are disabled.
4) Golden Guardian drill planned for week of May 15th. This is an earthquake drill state level.
5) NOAA & USGS recently gave a presentation on flooding issues. The USGS presenter is Dale A. Cox, regional hazards coordinator. NOAA contact is Logan Johnson, warning coordinator meteorologist.
6) State expects BART to make its own water damage assessments w/o outside assistance in an emergency scenario. This is because BART is a special district.

Temporary measures would be categorically an emergency response.
Operational backup option: reroute train control functions to a mobile backup?

II. Action Items

Marla

1) Send Norman Regional Transportation Plan

Norman Wong

1) Review Emergency Response plan and follow up with Marla.

Climate Change Adaptation Chapter 4

Meeting Minutes

April 26, 2013 4pm to 5pm

Present: Norman Wong, Tian Feng, Val Menotti

Next meeting: TBD

I. Discussion

Val is already familiar with the project.
Norman gives update on current status and what we want to achieve with planning.
Val gives feedback.

1) Land use planning is done with the city. BART is a participant in that planning effort.
2) Tim Chan is a key person with City of Oakland Planning.
3) OCC is planned to be expanded to account for the expansion with VTA.
4) At Lake Merritt station, BART owns 3 parcels: MTC building, parking lot, station plaza. Arup is evaluating what are the constraints for development of those parcels.
5) In the West portal area, the City of Oakland has plans for development in the surrounding area that may be relevant.
6) Joe Lipkos is doing work at the Coliseum regarding capacity.
7) Strategic plan needs to be updated.
8) Tim Chan and property development should be involved.
9) Check in with capital corridor dept, Jim Allison R. They may have good input.
    a. They are a good example of an external partner.
10) Bruce Riordan of the Bay Area Join Policy Committee is interested in Bay Area adaptation strategies. And would be a good person to keep in the loop.
    a. What is the status of this work?
    b. Did it get funded?
    c. Is it part of the second FHWA project?
    d. Is it for just the ART Project area in Alameda County or the larger BART system?

II. Action Items

Norman

1) Bring Tim Chan and property development into the fold. Give a high level overview of project.

Climate Change Adaptation Chapter 4

Meeting Minutes

April 26, 2013 11am to 12pm

Present: Norman Wong, Tian Feng, Jeffery Lau, Herb Diamant

Next meeting: TBD

I. Discussion

Tian gives overview of climate change adaptation project to Jeff.
Jeff gives overview of emergency response /preparedness plan.

1) System safety works with the BART police in emergency response matters.
2) The most recent plan has been updated for tsunami.
3) There is a response for flood, but maybe not storms.
4) System safety interfaces with all local fire depts for emergency matters.
5) Emergency drills are conducted with the fire depts.
6) Other emergency drills are conducted with other transit agencies.
   a. This is a good example to mainstream. Climate change adaptation considerations will transfer to other transit agencies in this manner. A climate change emergency scenario could be used in a future drill exercise
7) Plan is reviewed every year. Updated as-needed (not necessarily every year).
8) Marla Blagg works in the police department. She previously worked in the fire department and is very knowledgeable in emergency protocols. She works very closely with system safety. She is also the editor of the emergency plan. Suggestions for revision need to go through her.
9) The mutual aid agreement partners BART with other transit agencies to help each other out (such as route bridging) in emergency situations.

Implementation approach will be to modify existing emergency plan to account for climate change.
Jeff will be point person on this project for system safety matters.
Jeff offer to review document findings when draft is complete.

II. Action Items

Jeff Lau

1) Send Norman hardcopy of current emergency response plan
2) Send Norman copy of the mutual aid agreement.

Norman Wong

1) Send the current draft report to Jeff.
2) Send proposal to Jeff.
3) Upon receipt from Tian, maintain project time file for the duration of the project.

Tian

1) Set up field trip Monday 9:30am 4/29/13 for emergency operations center (EOC) field trip.
2) Upon receipt from Herb, update project time file of remaining gaps.

Herb

1) Update the project time logging file of the past 6 weeks. And send to Tian.

Climate Change Adaptation Chapter 4 – Discussion with Joe Torrisi

Meeting Minutes

May 1, 2013 9:00am to 9:30am

Present: Norman Wong, Joe Torrisi

Next meeting: TBD

I. Phone Discussion

- Joe Torrisi is the manager of non revenue vehicles, parking lot sweeping, patio pressure washing, among other activities.
- Parking lots are swept approximately once a week depending on the station.
- Patios (station entrance ways) are pressure washed daily to weekly depending on the station.
- Work is contracted out. BART internally sends out inspectors to confirm completion of work. Inspection reports are completed and the contractor also completes their own completion reports.
- Schedule/frequency for this work is built upon years of experience. Schedule is also dependent upon availability and constraints of the neighborhood/location. For example, noise complaints prevent work occurring in the evening in residential-heavy locations.
- Special scheduling can occur, but generally coincides with a special event that requires discussion at board meetings.
- Schedules for sweeping and pressure washing may be found on WebBART>BART websites> iBART>track allocations>
- Other schedules may be found in this site.

II. Action Items

N/A

Climate Change Adaptation Chapter 4 – Discussion with Marla

Meeting Minutes

May 6, 2013 1130am to 1:00pm

Present: Norman Wong, Marla Blagg

Next meeting: TBD

I. Discussion

- BART Emergency plan could be improved. There are missing gaps including SOPs in plan.
- Marla is preparing a white paper to make the needed changes. One of the key changes is standardizing the plan format so that BART's plan is compatible with other emergency plans. The plan is currently not NIMS compliant (FEMA is the regulatory agency). Standardization of BART plans would help make it more cohesive with state and regional plans.
- Volume I can be improved by including disaster-specific planning considerations.
- The challenge is that in emergency drills, there is little collaboration between counties and transit agencies. Improvement can be made to hold more all-inclusive drills.
- BART is included in the planning committee of the local and regional plans. The planning committee is where the decision making of what goes into the plans.

II. Action Items

N/A

Climate Change Adaptation Chapter 4

Meeting Minutes

May 9, 2013 10am to 11am
Present: Norman Wong, Tracy Johnson, Richard Leonard
Next meeting: N/A

I. Discussion

Norman introduces the climate change study.
Storm drain maintenance:

1) Sand used in muni train break systems intrudes BART's storm water drain system
2) Proactive maintenance work
   a. There is some proactive work, but it is not comprehensive
   b. In SF along market street, pumps are constantly running to lower the water table to prevent water infiltration in the BART system. Christiana Lippert has more information on this.
   c. In the first week of every month, vent structures and ditches along tracks are cleared.
   d. In preparation for the wet season, visual inspections of the "hot spot" storm drains are done for the stations, electrical substations, and train control rooms. The schedule for this effort is not formalized and is built from experience.
   e. There is limited formalized schedule of proactive maintenance work.
3) Reactive maintenance work
   a. Occurs from request for maintenance (RFM)
   b. RFMs (some formal, some not) comes via the observation or inspection from station agents, electricians, train operators, public, structural inspectors.
4) Dye tests are not used currently. Snake cameras are used to diagnose problems as-needed. Done per RFM, not proactive.
5) Christiana Lippert has system maps for sump pumps, electrical substations, and train control rooms.
6) Once a week, the high rail truck goes through the entire track way. Maintenance issues relating to storm drains may be observed in this manner and are reported accordingly.
7) Ed (last name?), regularly clears trash and sediments from station pits and tunnels.
8) The major challenge with maintenance is finding the funding and resources to support improved maintenance processes. Funding and resources are at present already limited.

Waste disposal:

1) Concrete and dirt collect in the back of OKS is recycled whenever feasible. Recycling does not occur when there unknown material.
2) Green waste from grounds maintenance is applied wayside as groundcover. It serves as a weed abatement measure. This waste otherwise goes to a reuse facility/
3) Repellant

II. Action Items

Richard Leonard, Tracy Johnson:

1) Review draft summary write-up when complete.

Norman

1) Contact Christiana Lippert for system maps (sump pumps, electrical substations, train control rooms)

Climate Change Adaptation Chapter 4

Meeting Minutes

May 10, 2013 10pm to 10:40pm

Present: Norman Wong, Cathy Lee

Next meeting: TBD

I. Discussion

Norman gives overview of the climate change adaptation project.
Two relevant adaptation strategies to asset management are

1) Georeference asset management system. Allow for real time updates and querying
2) Improve maintenance reports with regard to water inundation, drainage, equipment failures. Tie into asset management.

Cathy Lee's feedback

1) GIS overlay not happening yet. It is in the plan. Asset management is not mature enough right now.
2) Joel Koford is leading the effort with M&E and the SMP (strategic maintenance program) to standardize their reports and get them compatible with Maximo.
3) Track and ground currently not participating in asset management development process. Their needs are different because their assets are linear (tracks). They want to use Op Train connected to Maximo. Asset management team will eventually connect them.
4) Power and way, non-revenue vehicle are participating in the asset management development.
5) There is an issue of a discipline for staff to use asset management.
6) RFMs are getting incorporated by John Yen's group. Work orders are another important aspect.
7) The asset management team is developing classifications. Classifications can be made for "rain, drain, floods".

II. Action Items

Norman Wong

1) Send Cathy current draft of report. Send Cathy final report when complete.
2) Check with Joel Koford on the standardization process. What inspection reports are getting incorporated? Are water inundation classifications being developed for those reports?

Climate Change Adaptation Chapter 4

Meeting Minutes

May 17, 2013 8:30am to 9:30am

Present: Norman Wong, Joel Koford, Domingo Laureles

Next meeting: NA

I. Discussion

Norman gives overview of the climate change adaptation project.

Relevant adaptation strategies to asset management are

1) Improve maintenance reports with regard to water inundation, drainage, equipment failures. Tie into asset management.

Joel and Domingo feedback

1) The asset management group is building Maximo to be compatible to maintenance work/reports. It is not changing the reports of maintenance.
2) Preventative maintenance is built into Maximo as job plans.
3) Maintenance schedules are built into Maximo as part of the job plan.
4) A job plan issues a work order (inspection or repair) to the designated person. The designated person will complete the work order. Completion of the work order includes the work itself and documentation of the work completed.
5) Personnel may designate problem codes and/or failure codes as part of a work order.
6) Problem/failure codes need to be associated with the functional asset group. Functional asset group refers a type of asset.
7) Brainstorm of useful problem codes for climate change: flood, drainage program, natural disaster/causes, heavy storm/rain, leak.
8) New problem codes can be incorporated into the system by early June 2013.
9) There will be many windows of opportunity to include new problem codes. But now is ideal because it can be incorporated with the major changes that IT is currently handling.
10) Multiple problem codes can be used to narrow down type of issue. For instance, natural causes and flood will rule out a sewer main break issue.
11) The maintenance dept needs to be aware of the problem codes available to them. Otherwise they may not use them.

II. Action Items

Norman Wong

1) Propose to Domingo and Joel a list of problem codes that will be useful for climate change impacts. Domingo/Joel will review these to existing codes. Send list by next week Tuesday.

Asset management group

2) Review proposed problem codes. Connect them to appropriate asset groups.

Climate Change Adaptation

Meeting Minutes

May 17, 2013 4pm to 5pm

Present: Norman Wong, Tian Feng, Val Menotti, Bruce Riordan

Next meeting: TBD

I. Discussion

Caltrans, BCDC, MTC, and BART are coming together as a submitter for the FHWA supported study. Technical lead is not decided. MTA is administrative lead. It is still to be determined scope of study. $300,000 grant from FHWA. All will be used for consultant. ARUP is interested in continuing this type of study. AECOM is interested and has offered to volunteer.

FTA project will contribute to the FHWA project because of similar study area. Focused on SLR. Focused on real changes. Provides the groundwork to be able to make some changes. Study does not make changes now.

It's ok to take baby steps for adaptation.

Station improvement guideline/ access guideline to be updated to include considerations.

There's a lag in the system. You get information now but it takes. planning decisions in transportation industry were made 10 years previously.

SLR will be part of SES, in legislation. BCDC will lead.

Previously, flood issues have been man-made. Lake Merritt fire hydrant broke in a previous occasion

Potential need in future is to expand to other climate change impacts (heat, blackouts, ocean acidification)

There are total 7 pilots (including BART) that FTA is funding in different regions.

San Francisco is very sensitive, with a lot of potential infrastructure at risk.

Adaptation center aims to connect work and who else needs to get involved

Electricity: if PG&E fail, then substations are designed with some redundancy. In a fire situation, we have evacuation plan but relies on electricity to be available.

What is the drill situation w/o electricity/power? Interesting scenario unsure what is evacuation plan is. BART is moving forward on diversifying electricity sources.

Water agencies are doing more inter ties between systems for more security.

Water supply:

Example adaptation: Contra Contra is moving the water supply intake feed further up the delta because of brackish water issues.
Is water supply an issue with BART? Water supply is not critical to operation. Non critical use: washing.

Fire
Fire issue in tunnel or underground is problematic. If there is fire it would be preferred to be exposed to the air.

Storm:
Storms can cause damage to roofs.

Other issue:
Due to climate change, bay area could foresee an influx of populations from other areas of the region/nation. This could increase ridership and dependency on BART.

Are there impacts in other areas of the world that will affect us? Example: some pieces of vehicles parts are manufactured elsewhere that could impact BART.

Adaptation center (AC) will have a coordinating council to understand what efforts different organization are doing and understand where connections are. Where we need other organizations to get involved. AC to serve as a library or a resource.

Previous meetings with organizations have been to understand what the needs are and develop services to meet those needs.

The AC will likely be separate from regulatory agencies to serve as a neutral entity.

II. Action Items

None.

Climate Change Adaptation Chapter 4

Meeting Minutes

May 21, 2013 4pm to 5pm

Present: Norman Wong, Tim Chan

Next meeting: TBD

I. Discussion

Norman gives overview of the climate change project.
Tim Chan gives feedback.

1) Planning creates the plan, help bring people together, help identify goals, but it does not always focus on implementing the plan. That is starting to change.
2) In a planning process, cities often create technical advisory committee (TAC) made of stakeholders which often includes city staff, county staff, transit staff. Cities will also have Community advisory committee too to help guide the process. These committees are used to engage stakeholders to garner support for proposed plans and projects.
3) City councils generally do not adopt plans if not supported by the community; city plans control the land use zoning and the size and type of development.
4) Opportunity for BART is via this planning process; advocate for sustainability within a TAC. Within the committee, BART can recommend a specific project or make the case to investigate a concern of BART's. BART cannot dictate, only recommend. BART can also help advocate in different forums.
5) Bay Fair Example (illustrates the complexity of planning): A flood control canal is adjacent to the Bay Fair station and needs to be upgraded to the 100-year flood zone. The Army Corp of Engineers has oversight. Flood control district also has oversight,but does not have funds to make proper upgrade. The City of San Leandro is developing a plan in the surrounding area to upzone. In all likelihood, the city will move forward regardless of whether or not the Army Corp will upgrade the canal.
6) BART Seismic retrofit upgrades required a ballot measure to fund the project and to move it forward. Funding for Climate change adaptation may follow a similar route (ballot propositions / measures, etc)
7) BART plans and policies: Station areas plans can reference sustainability as a policy goal, as well as specify actions to meet said goal. We need to include action items which are more powerful and provide more direction/guidance. This is a potential conversation between Tian, Val, Norman, Tim.
8) Overall what needs to happen: Conversations one on one, partnering with other agencies to begin dialogue, define what are BART needs, what are the projects that need to be done?
9) Possible option for sustainability: Create a technical advisory committee to address issues with important internal and external stakeholders .One-on-one meetings with BART folks to educate what to advocate for. Commenting on plans and EIRs (planning + development, government/community relations, folks and Janie Layton) about climate change issues.
10) Contact Molly Burke (SF county) and Rodd Lee (alameda county). These folks hold quarterly internal meetings discuss any projects that are happening in the given region.
11) Diedre is a planner for the contra costa area.
12) Planning does rely on BFS for guidance in the development of capital projects

13) Planning is very person-oriented, (ex access issues, rider needs, low-income demographic). It also considers other environmental factors.

II. Action Items

Norman

1) NA

Climate Change Adaptation Chapter 4

Meeting Minutes

May 22, 2013 3pm to 3:30pm

Present: Norman Wong, Dean Gieblhausen

Next meeting: TBD

I. Phone Discussion

Sump Pump maintenance program:

1) Sump pump maintenance schedule is in Maximo.
2) Generally the frequency of inspection is bi monthly or monthly.
3) Inspection includes probes and controls etc.
4) All line sump pumps are dual.
5) Some sump pumps have high level alarm. Not all.
6) May or may not have flow gauge.
7) Sump pumps may be found on the line, stations, in maintenance yards.
8) Those on the line and station are more critical than elsewhere
9) Frequency of inspection is based on experience and manufacturer recommendation.

II. Action Items

Norman

1) NA

Climate Change Adaptation Chapter 4

Meeting Minutes

May 29, 2013 230pm to 3pm

Present: Norman Wong, Rohin Saleh (Alameda County Flood Control District)

Next meeting: TBD

I. Phone Discussion

Norman gives overview of the climate change project.

Rohin feedback

1) EBMUD would be good source for groundwater level data
2) Underground Fremont BART section may be vulnerable to rise in groundwater
3) The city of Fremont currently is focused on aquifer recharge to push back saltwater intrusion in its jurisdiction. Recharge is accomplished through groundwater injection and the quarry lakes
4) ACFCWD is going to revisit the sea level rise/ inundation model used in the ART study. ACFCWD is concerned that the model is not representative of reality and is oversimplified. ART's model is a static model that compares sea level elevation to topographic elevation. Positive differences in these elevations is regarded as inundation by the model.
5) ACFCWD is conducting a study that will take a dynamic approach to the model. The study will remap where the inundation areas are. The model is expected to have significant complexities. Study duration is expected to be 2 or 3 years. ACFCWD will contract with the same consultant used for the ART study.

Norman's concerns:

1) How will SLR affect groundwater levels? This is a concern for BART's underground infrastructure. How much increased groundwater seepage will BART encounter?
2) How will this affect salt water intrusion? Will BART underground infrastructure be affected?
3) In Addition, elevated groundwater levels will reduce runoff infiltration capacity.

II. Action Items

Norman

1) Set up in person meeting ~2 months from now to get together to have conversation when respective projects are more developed.

Climate Change Adaptation Chapter 4
Meeting Minutes

June 12, 2013 11am to 12pm
Present: Norman Wong, Richard Watson
Next meeting: TBD

I. Discussion Items

1) Primary structures in a substation are the equipment housings, conduits, wires (exposed and not exposed), and bay which serves as secondary containment to the transformers that have oil.
2) Water runs into the street.
3) Stainless steel roofs have been added to the stations. To protect from rain exposure.
4) Transformers: Ac house, dc house, rectifier.
5) Switch gear components are maintained in an enclosure away from rain exposure. Water intrusion may occur which is evidenced by observing rust on the roof. Roofs get replaced when necessary.
6) Substation inspections are performed monthly.
7) The substation maintenance reporting is getting integrated with Maximo
8) Maximo will not hold information on rust. Maximo integration is still at the developmental stages
9) Workers have a place to place notes/logs/narrative.
10) Inspection form has checklist of items to inspect. PM sheet. Water-related issues are not part of this check list. This is a valuable opportunity here.
11) Cloth cable sheathings and rubber cabling gaskets are checked as part of a 1KB bus annual inspections. These are done in the grave shift, when everything is powered down.
    a. These are done to the best extent with available manpower.
    b. Currently short of manpower to do all of it. Group is currently short of 8-9 electricians
    c. Currently, efforts are focused on high priority stations.
12) Section proposed write-up
    a. Business practice
    b. Opportunities:
        i. Improving Maximo
        ii. Improving checklist
        iii. Make available for use during inspection
    c. Challenges:
        i. More manpower
        ii. Compatibility of Maximo.

Relevant adaptation strategies to Maintenance are

1) **M1: Maintenance Reporting Accessibility**: Improve accessibility and standardize maintenance report in order to identify “trouble spots” for water inundation, roof leaks, drainage problems, and/or equipment failures. Integrate with asset management system.
2) **M3: Equipment useful life monitoring:** Increase monitoring of deterioration of some system elements due to water submersion (e.g. cloth cable sheathings)

3) **M4: Critical equipment monitoring:** Increase monitoring of critical equipment (e.g. MUX boxes, switches, transformers, life safety system/communications).

Climate Change Adaptation

Meeting Minutes

June 14, 2013 2pm to 4pm

Present: Norman Wong, Tony Hitchings

Next meeting: TBD

I. Discussion

1) Three phase approach has been used for seismic risk assessment and mitigation:
    a. Phase 1: Screening report of all the facilities identifying major issues. Preliminary assessment with potential impacts and fixes. Presented to the board as a system of the whole. First look at the vulnerabilities. Lay out a timeline for program management.
    b. Phase 2: Detailed look
    c. Phase 3: Construction
2) Climate change adaptation pilot is in Tony's opinion is a few steps too ahead. The report is overly focused on the details. The overall scale and timeline are issues that need to be addressed.
3) Efforts need to be directed towards the big picture. This means looking at a higher level assessment of the impacts and a "rough" estimate of the overall costs. Estimates can be made (front-end engineering) without making too many calculations.
4) The program management aspects are important. Because timeline for construction and permitting can be long.
5) Tony does not think BCDC will take a leadership role in implementation actions. The agency assumes regulatory authority only.
6) Sea level options:
    a. Levee placement plus pumping stations
    b. Evacuate; recede homes (unlikely)
    c. Raise the ground level (similar to Seattle after the 1989 fire, to avoid tideland flooding). (unlikely option because it is highly disruptive)
7) New Orleans have flood gates.
8) A flood wall is only effective if built on the regional level.
9) So the entire problem is fixed by dike around the bay. SLR cannot be fixed by fixing local problems alone.
10) Tom Horton set up the earthquake safety program. Look at how that program was set up. It's possible that BART may partially model climate adaptation after the earthquake safety program.
11) First determine who will lead the regional effort. Will it be the State of California (one of its existing agencies or a new State agency); can an existing local body do it (such as ABAG) or will the Bay Area may need to form a new local body or organization that is charged with leading the regional solution.
12) The biggest challenge will not be engineering; it will be Program Management and funding; in addition to getting the various local bodies to come to the necessary agreement on a wide variety of issues.
13) BART's Climate Change Response work should be moved from Office of District Architect to Planning for all the near term effort.

II. Action Items

Norman Wong

1) Question: Does the ART study indicate any permanent SLR inundations for BART infrastructure?

Asset Management meeting

Meeting Minutes

September 10, 2013 2pm to 3:30pm

Present: Norman Wong, Tian Feng, Frank Ruffa, Tiffany Batac

Next meeting: *NA*

I. Discussion

1) MARTA efforts
    a. FTA asset management guide used as a framework base for MARTA's asset management.
    b. MARTA looked at climate stressors for climate adaptation. Overlaying with asset management program.
    c. MARTA is using trapeze asset management inc. software program.
    d. Beta testing a new module that includes a climate risk flag.
    e. Taking prioritization to the next level to be able to compare investments across asset classes.
2) Frank Ruffa summary of BART efforts
    a. BART still developing and completing the asset registrar.
    b. Upcoming step will be to connect into Maximo and create a hierarchy structure.
    c. Need to identify qualifications/attributes to characterize asset vulnerability
    d. Four primary aggregate performance measures BART is advocating:
        i. Capacity
        ii. Risk
        iii. Function
        iv. Condition
    e. How do we assess specific asset vulnerability?
        i. BART wants to be consistent across the region on methodology.
    f. In the midst of developing Maximo.
        i. Implementing a Strategic Maintenance Program (SMP) to modernize/manage our maintenance work that incorporates asset info, attributes, keep history of maintenance work.
        ii. Instrumenting Maximo to be a work authorization system
            1. require work order for any maintenance work
            2. collect relevant empirical data for trending/analysis for deterioration.
    g. Map 21 requirements
        i. Manage operation based on
            1. asset management plan
                a. BART will have 5 plans. One for each class/category
                    i. guide ways
                    ii. facilities
                    iii. systems
                    iv. revenue vehicles
                    v. support services
                        1. IT, police, external affairs, etc

            2. risk based investment decisions
            3. measured performance
    h. BART expects 5 classes, 18 subclasses, 265 elements, ~40,000 sub elements,
    i. Developing towards risk of affecting reliability of service.
        i. Not safety risk. Safety risk is addressed immediately
    j. Some assets are more critical than others (criticality)
    k. We acknowledge that there is not enough funds to rehabilitate the whole system.
        i. The key is to extend the useful life of key assets by intervening early.
        ii. Systematic prioritization of those assets based on risk
    l. Governance process
        i. Will be culturally disruptive for BART
        ii. Working towards a systematic way to make decisions on risk, prioritize efforts, and maximize investments
    m. Working with RSS, informally Frank Ruffa is driving the process and reporting directly to GM
    n. In parallel, BART uses a capital needs inventory spreadsheet for implementing projects
        i. Identifies ~500 projects and associated funding shortfalls.
        ii. Use 9 criteria for evaluation
        iii. Every project manager tasked ranking everybody else's projects
        iv. Chief Engineer does a sanity check to make sure prioritized list is appropriate.
        v. Has been so far effective
        vi. Normalize prioritize across
    o. Developing knowledge management
        i. Centralizing information for the user to perform job.
        ii. Current information is located in multiple places: databases, spreadsheets, hard files, hand written notes, people's heads.
    p. BART will not create a separate asset management dept
        i. Re-center organization around asset
        ii. Ownership of AM should be a shared practice/philosophy
        iii. Stakeholders includes all organizational groups including RSS, M&E, IT, Bart police department (BPD), Capital Development, Budget folks, procurement, external affairs.
        iv. Executive steering committee – Bob Powers, Paul Overseer, Carter Mao
3) Environmental consideration not incorporated in the asset management program.
    a. That effort would accelerate the awareness
    b. The BFS is a vehicles for doing good design
    c. Project management guide is in development
    d. BART has not envisioned further than a factor

II. Action Items

1) N/A

APPENDIX

B

Adaptation Strategy Tables

Appendix B includes the following tables:

- Appendix B-1: Master List of Adaptation Strategies
- Appendix B-2: Lake Merritt Station Entrance Expanded Strategies List
- Appendix B-3: Oakland West Track Portal Expanded Strategies List
- Appendix B-4: Oakland Coliseum Traction Power Substation Expanded Strategies List
- Appendix B-5: Fruitvale Train Control Room Expanded Strategies List

The Master List is a comprehensive list of all the strategies considered in this study and includes hazards exposure, time rating, and cost rating for each strategy. Each of the Expanded Strategies List includes select applicable strategies from the Master List for the given asset. The Expanded Strategiest List includes an overall cost-benefit score.

Appendix B-1

Master List of Adaptation Strategies

Code	Strategy	Sea-level rise	Downpour	Flooding	Time	Cost
Land use/Planning		**Hazard Exposure**				
LP1	**Area-wide flood barriers:** Coordinate with local jurisdictions/port regarding construction/maintenance of levee, sea wall, other flood barriers	Yes	-	Yes	Long-term	High
LP2	**Location:** Require new and upgraded existing structures to be built outside (new structures) or above (existing structures) 500-yr flood elevation	Yes	-	Yes	Now	High
LP3	**Local storm drain system capacity:** Work with local jurisdictions to ensure sufficient capacity in event of flooding, particularly near critical facilities	Yes	Yes	Yes	Now	Low
LP4	**Low impact development:** Work with local jurisdictions to enact low-impact development standards/incentives near assets; implement standards on BART property	-	Yes	Yes	Now	Low
Design & Construction		**Hazard Exposure**				
Code	Strategy	Sea-level rise	Downpour	Flooding	Time	Cost
DC1	**Pump capacity/redundancy:** Change pump standards for increased flood and downpour conditions	Yes	Yes	Yes	Now	Low
DC2	**Drain capacity and backflow prevention:** Ensure drain capacity is sufficient; install one-way valves to prevent backflow where applicable (e.g. critical facilities requiring drains)	Yes	Yes	Yes	Medium-term	Low
DC3	**Portal wall retrofits:** Evaluate portal wall height, water-resistance; develop a solution for non-water tight gate structures (retrofit or replacement) and maintain/retrofit walls to address cracking.	Yes	Yes	Yes	Medium-term	Moderate
DC4	**Tunnel flood protection:** construct flood gates for underground structures	Yes	Yes	Yes	Medium-term	High
DC5	**Technology:** early warning system to trigger automated response	Yes	Yes	Yes	Medium-term	Moderate
DC6	**Flood level resistance:** Elevate entrances, vent and access shafts, stair/elevator access above peak predicted flood levels (e.g. 3 feet above peak predicted flood levels in 500-year event)	Yes	Yes	Yes	Long-term	High
DC7	**Flood barriers:** Engineered (e.g. deployable, demountable) barriers around entrances/portals	Yes	Yes	Yes	Medium-term	High
DC8	**Temporary measures:** Pre-engineering and site mobilization for temporary mitigation structures	Yes	Yes	Yes	Now	Low
DC9	**Elevate or relocate equipment:** Elevate or move sensitive equipment (e.g. small gauge electrical components, signal and communications equipment, ticketing machines, generators)	Yes	Yes	Yes	Medium-term	High
DC10	**Waterproofing and corrosion retrofits:** Retrofit existing and build new structures with waterproof, side penetrations and use non-corrosive materials	Yes	Yes	Yes	Medium-term	Moderate
DC11	**Roof structures:** Retrofit building roofs and update BFS to require pitched roofs (5 degrees minimum), avoid penetrations, and eliminate "bathtub" roof design	-	Yes	-	Long-term	Moderate
DC12	**Rain exposure:** Design/retrofit buildings to protect against rainfall/rain and wind conditions -- do not leave gaps in facades, open roofs, etc.	-	Yes	-	Medium-term	Moderate
DC13	**Climate Change checklist:** Use a climate change "checklist" to ensure principles are integrated into capital project design and construction	Yes	Yes	Yes	Now	Low
DC14	**Perimeter walls and entries:** Build new or retrofit existing perimeter wall/barrier to be watertight, including gates and doors.	Yes	-	Yes	Medium-term	Moderate
DC15	**Transformer Upgrade:** Replace open (Cask) transformers with closed (oil-filled) transformers and update BFS accordingly	-	Yes	-	Now	High
DC16	**Headhouse enclosures for entrances:** Build and/or maintain headhouses around ingress/egress points (e.g. stairs, escalators, elevators) to ensure weather tightness	Yes	Yes	Yes	Now	Moderate
DC17	**Pump and fan monitoring and alarm system:** Improve ability to monitor sump pump and ventilation fan runtime by adding high water alarms to pumps and selecting an appropriate hardware and software system to enable data reporting to the Operations Control Center and Asset Management Database.	Yes	Yes	Yes	Medium-term	Moderate
DC18	**Electric power:** Provide power redundancy for pumps, equipment; provide backup power / additional generators	Yes	Yes	Yes	Medium-term	Moderate
DC19	**Equipment redundancy:** Identify or develop redundancy program in the event of a failure of critical equipment (such as train control equipment, MUX boxes, etc)	Yes	Yes	Yes	Medium-term	Moderate
Operations		**Hazard Exposure**				
Code	Strategy	Sea-level rise	Downpour	Flooding	Time	Cost
Op1	**Georeferenced asset management:** Incorporate georeferenced/spatial querying, real-time updates into asset management system	Yes	Yes	Yes	Now	Moderate
Op2	**Operational alternatives review/update:** Review and update system alternatives plans (e.g. bus bridge service across disabled assets) to reflect climate change impacts; establish mutual aid agreements with other transit operators	Yes	Yes	Yes	Now	Low
Op3	**Evacuation plans and drills:** Review and update passenger evacuation plans in high flood prone areas; incorporate climate change considerations into regional emergency drill exercises	Yes	Yes	Yes	Now	Low
Op4	**Local/regional emergency coordination:** Evaluate local, regional, and state emergency response plans to improve coordination and develop contingency plans if resources are inadequate	Yes	Yes	Yes	Now	Low
Op5	**Flood control district communications:** Maintain frequent communication with local flood control districts regarding changes in operations of district facilities	Yes	-	Yes	Now	Low
Op6	**Establish groundwater model:** Work with local jurisdictions to establish baseline groundwater models to monitor and predict impacts of sea-level rise	Yes	-	-	Now	Low
Op7	**Educate and integrate:** Disseminate climate change information and train staff on how to integrate climate considerations into their work.	Yes	Yes	Yes	Now	Low
Maintenance		**Hazard Exposure**				
Code	Strategy	Sea-level rise	Downpour	Flooding	Time	Cost
M1	**Maintenance reporting accessibility:** Improve accessibility and standardize maintenance reports in order to identify "trouble spots" for water inundation, roof leaks, drainage problems, and/or equipment failures. Integrate with asset management system.	Yes	Yes	Yes	Now	Low
M2	**Trash/sediment removal:** Increase frequency of trash and sediment removal (which can cause blocked drain inlets) from neighboring streets and aerial tracks	Yes	Yes	Yes	Now	Moderate
M3	**Equipment useful life monitoring:** Increase monitoring of deterioration of some system elements due to water submersion (e.g. cloth cable sheathings)	Yes	Yes	Yes	Now	Moderate
M4	**Critical equipment monitoring:** Increase monitoring of critical equipment (e.g. MUX boxes, switches, transformers, life safety systems/communications)	Yes	Yes	Yes	Now	Moderate
M5	**Test on-site roof and storm drain system:** Perform dye test on roof, track, and floor drains to check for expected performance.	Yes	Yes	Yes	Now	Low

Appendix B-2

Lake Merritt Station Entrance Expanded Strategies List

Land use/planning		**Hazard Exposure**			**Time**	**Cost**	**Overall Cost Benefit Score**		
Code	Strategy	Sea-level rise	Downpour	Flooding			SLR Strategy	Downpour Strategy	Flooding Strategy
LP3	Local storm drain system capacity: Work with local jurisdictions to ensure sufficient capacity in event of flooding, particularly near critical facilities	Yes	Yes	Yes	Now	Low	4	5	5
LP4	Low impact development: Work with local jurisdictions to enact low-impact development standards/incentives near assets; implement standards on BART property	-	Yes	Yes	Now	Low		5	5
Design & Construction		**Hazard Exposure**			**Time**	**Cost**	**Overall Cost Benefit Score**		
Code	Strategy	Sea-level rise	Downpour	Flooding			SLR Strategy	Downpour Strategy	Flooding Strategy
DC2	Drain capacity and backflow prevention: Ensure drain capacity is sufficient; install one-way valves to prevent backflow where applicable (e.g. critical facilities requiring drains)	Yes	Yes	Yes	Medium-term	Low	5	5	5
DC6	Flood level resistance: Elevate entrances, vent and access shafts, stair/elevator access above peak predicted flood levels (e.g. 3 feet above peak predicted flood levels in 500-year event)	Yes	Yes	Yes	Long-term	High	2	3	3
DC7	Flood barriers: Engineered (e.g. deployable, demountable) barriers around entrances/portals	Yes	Yes	Yes	Medium-term	High	2	3	3
DC8	Temporary measures: Pre-engineering and site mobilization for temporary mitigation structures	Yes	Yes	Yes	Now	Low	4	4	4
DC10	Waterproofing and corrosion retrofits: Retrofit existing and build new structures with waterproof, side penetrations and use non-corrosive materials	Yes	Yes	Yes	Medium-term	Moderate	3	4	3
DC12	Rain exposure: Design/retrofit buildings to protect against rainfall/rain and wind conditions -- do not leave gaps in facades, open roofs, etc.	-	Yes	-	Medium-term	Moderate		4	
DC16	Headhouse enclosures for entrances: Build and/or maintain headhouses around ingress/egress points (e.g. stairs, escalators, elevators) to ensure weather tightness	Yes	Yes	Yes	Now	Moderate	3	4	4
Operations		**Hazard Exposure**			**Time**	**Cost**	**Overall Cost Benefit Score**		
Code	Strategy	Sea-level rise	Downpour	Flooding			SLR Strategy	Downpour Strategy	Flooding Strategy
Op1	Georeferenced asset management: Incorporate georeferenced/spatial querying, real-time updates into asset management system	Yes	Yes	Yes	Now	Moderate	3	3	3
Op5	Flood control district communications: Maintain frequent communication with local flood control districts regarding changes in operations of district facilities	Yes	-	Yes	Now	Low	4		5
Maintenance		**Hazard Exposure**			**Time**	**Cost**	**Overall Cost Benefit Score**		
Code	Strategy	Sea-level rise	Downpour	Flooding			SLR Strategy	Downpour Strategy	Flooding Strategy
M1	Maintenance reporting accessibility: Improve accessibility and standardize maintenance reports in order to identify "trouble spots" for water inundation, roof leaks, drainage problems, and/or equipment failures. Integrate with asset management system.	Yes	Yes	Yes	Now	Low	4	5	5
M2	Trash/sediment removal: Increase frequency of trash and sediment removal (which can cause blocked drain inlets) from neighboring streets and aerial tracks	Yes	Yes	Yes	Now	Moderate	3	3	3
M5	Test on-site roof and storm drain system: Perform dye test on roof, track, and floor drains to check for expected performance.	Yes	Yes	Yes	Now	Low	5	5	5

Appendix B-3

Oakland West Track Portal Expanded Strategies List

Land use/planning		**Hazard Exposure**			**Time**	**Cost**	**Overall Cost Benefit Score**		
Code	Strategy	Sea-level rise	Downpour	Flooding			SLR Strategy	Downpour Strategy	Flooding Strategy
LP1	Area-wide flood barriers: Coordinate with local jurisdictions/port regarding construction/maintenance of levee, sea wall, other flood barriers	Yes	-	Yes	Long-term	High	4		3
LP3	Local storm drain system capacity: Work with local jurisdictions to ensure sufficient capacity in event of flooding, particularly near critical facilities	Yes	Yes	Yes	Now	Low	5	5	5
Design & Construction		**Hazard Exposure**			**Time**	**Cost**	**Overall Cost Benefit Score**		
Code	Strategy	Sea-level rise	Downpour	Flooding			SLR Strategy	Downpour Strategy	Flooding Strategy
DC2	Drain capacity and backflow prevention: Ensure drain capacity is sufficient; install one-way valves to prevent backflow where applicable (e.g. critical facilities requiring drains)	Yes	Yes	Yes	Medium-term	Low	5	5	5
DC3	Portal wall retrofits: Evaluate portal wall height, water resistance, develop a solution for non-water tight gate structures (retrofit or replacement) and maintain/retrofit walls to address cracking	Yes	Yes	Yes	Medium-term	Moderate	5	4	4
DC4	Tunnel flood protection: construct flood gates for underground structures	Yes	Yes	Yes	Medium-term	High	3	2	3
DC5	Technology: early warning system to trigger automated response	Yes	Yes	Yes	Medium-term	Moderate	3	3	3
DC7	Flood barriers: Engineered (e.g. deployable, demountable) barriers around entrances/portals	Yes	Yes	Yes	Medium-term	High	3	3	2
Operations		**Hazard Exposure**			**Time**	**Cost**	**Overall Cost Benefit Score**		
Code	Strategy	Sea-level rise	Downpour	Flooding			SLR Strategy	Downpour Strategy	Flooding Strategy
Op1	Georeferenced asset management: Incorporate georeferenced/spatial querying, real-time updates into asset management system	Yes	Yes	Yes	Now	Moderate	3	3	3
Op2	Operational alternatives review/update: Review and update system alternatives plans (e.g. bus bridge service across disabled assets) to reflect climate change impacts; establish mutual aid agreements with other transit operators	Yes	Yes	Yes	Now	Low	5	5	5
Op6	Establish groundwater model: Work with local jurisdictions to establish baseline groundwater models to monitor and predict impacts of sea-level rise	Yes	-	-	Now	Low	5		
Maintenance		**Hazard Exposure**			**Time**	**Cost**	**Overall Cost Benefit Score**		
Code	Strategy	Sea-level rise	Downpour	Flooding			SLR Strategy	Downpour Strategy	Flooding Strategy
M1	Maintenance reporting accessibility: Improve accessibility and standardize maintenance reports in order to identify "trouble spots" for water inundation, roof leaks, drainage problems, and/or equipment failures. Integrate with asset management system.	Yes	Yes	Yes	Now	Low	5	5	5
M2	Trash/sediment removal: Increase frequency of trash and sediment removal (which can cause blocked drain inlets) from neighboring streets and aerial tracks	Yes	Yes	Yes	Now	Moderate	4	4	4
M3	Equipment useful life monitoring: Increase monitoring of deterioration of some system elements due to water submersion (e.g. cloth cable sheathings)	Yes	Yes	Yes	Now	Moderate	3	3	3
M4	Critical equipment monitoring: Increase monitoring of critical equipment (e.g. MUX boxes, switches, transformers, life safety systems/communications)	Yes	Yes	Yes	Now	Moderate	3	3	3
M5	Test on-site roof and storm drain system: Perform dye test on roof, track, and floor drains to check for expected performance.	Yes	Yes	Yes	Now	Low	5	5	5

Appendix B-4

Oakland Coliseum Traction Power Substation Expanded Strategies List

Land use/planning		Hazard Exposure			Time	Cost	Overall Cost Benefit Score		
Code	Strategy	Sea-level rise	Downpour	Flooding			SLR Strategy	Downpour Strategy	Flooding Strategy
LP1	Area-wide flood barriers: Coordinate with local jurisdictions/port regarding construction/maintenance of levee, sea wall, other flood barriers	Yes	-	Yes	Long-term	High	4		4
LP2	Location: Require new and upgraded existing structures to be built outside (new structures) or above (existing structures) 500-yr flood elevation	Yes	-	Yes	Now	High	3		4
LP3	Local storm drain system capacity: Work with local jurisdictions to ensure sufficient capacity in event of flooding, particularly near critical facilities	Yes	Yes	Yes	Now	Low	5	5	5
Design & Construction		**Hazard Exposure**			**Time**	**Cost**	**Overall Cost Benefit Score**		
Code	Strategy	Sea-level rise	Downpour	Flooding			SLR Strategy	Downpour Strategy	Flooding Strategy
DC2	Drain capacity and backflow prevention: Ensure drain capacity is sufficient, install one-way valves to prevent backflow where applicable (e.g. critical facilities requiring drains)	Yes	Yes	Yes	Medium-term	Low	5	5	5
DC7	Flood barriers: Engineered (e.g. deployable, demountable) barriers around entrances/portals	Yes	Yes	Yes	Medium-term	High	3	3	3
DC9	Elevate or relocate equipment: Elevate or move sensitive equipment (e.g. small gauge electrical components, signal and communications equipment, ticketing machines, generators)	Yes	Yes	Yes	Medium-term	High	3	3	3
DC10	Waterproofing and corrosion retrofits: Retrofit existing and build new structures with waterproof, side penetrations and use non-corrosive materials	Yes	Yes	Yes	Medium-term	Moderate	4	5	4
DC14	Perimeter walls and entries: Build new or retrofit existing perimeter wall/barrier to be watertight, including gates and doors.	Yes	-	Yes	Medium-term	Moderate	5		5
DC15	Transformer Upgrade: Replace open (Cask) transformers with closed (oil-filled) transformers and update BFS accordingly	-	Yes	-	Now	High		3	
Operations		**Hazard Exposure**			**Time**	**Cost**	**Overall Cost Benefit Score**		
Code	Strategy	Sea-level rise	Downpour	Flooding			SLR Strategy	Downpour Strategy	Flooding Strategy
Op1	Georeferenced asset management: Incorporate georeferenced/spatial querying, real-time updates into asset management system	Yes	Yes	Yes	Now	Moderate	3	3	3
Op5	Flood control district communications: Maintain frequent communication with local flood control districts regarding changes in operations of district facilities	Yes	-	Yes	Now	Low	4		4
Op6	Establish groundwater model: Work with local jurisdictions to establish baseline groundwater models to monitor and predict impacts of sea-level rise	Yes	-	-	Now	Low	5		
Maintenance		**Hazard Exposure**			**Time**	**Cost**	**Overall Cost Benefit Score**		
Code	Strategy	Sea-level rise	Downpour	Flooding			SLR Strategy	Downpour Strategy	Flooding Strategy
M1	Maintenance reporting accessibility: Improve accessibility and standardize maintenance reports in order to identify "trouble spots" for water inundation, roof leaks, drainage problems, and/or equipment failures. Integrate with asset management system.	Yes	Yes	Yes	Now	Low	5	5	5
M2	Trash/sediment removal: Increase frequency of trash and sediment removal (which can cause blocked drain inlets) from neighboring streets and aerial tracks	Yes	Yes	Yes	Now	Moderate	3	4	4
M3	Equipment useful life monitoring: Increase monitoring of deterioration of some system elements due to water submersion (e.g. cloth cable sheathings)	Yes	Yes	Yes	Now	Moderate	4	4	4
M4	Critical equipment monitoring: Increase monitoring of critical equipment (e.g. MUX boxes, switches, transformers, life safety systems/communications)	Yes	Yes	Yes	Now	Moderate	4	4	4
M5	Test on-site roof and storm drain system: Perform dye test on roof, track, and floor drains to check for expected performance.	Yes	Yes	Yes	Now	Low	5	5	5

Appendix B-5

Fruitvale Train Control Room Expanded Strategies List

Land use/planning		Hazard Exposure			Time	Cost	Overall Cost Benefit Score		
Code	Strategy	Sea-level rise	Downpour	Flooding			SLR Strategy	Downpour Strategy	Flooding Strategy
LP3	Local storm drain system capacity: Work with local jurisdictions to ensure sufficient capacity in event of flooding, particularly near critical facilities	Yes	Yes	Yes	Now	Low	5	5	5
LP4	Low impact development: Work with local jurisdictions to enact low-impact development standards/incentives near assets; implement standards on BART property	-	Yes	Yes	Now	Low		5	5
Design & Construction		**Hazard Exposure**			**Time**	**Cost**	**Overall Cost Benefit Score**		
Code	Strategy	Sea-level rise	Downpour	Flooding			SLR Strategy	Downpour Strategy	Flooding Strategy
DC2	Drain capacity and backflow prevention: Ensure drain capacity is sufficient; install one-way valves to prevent backflow where applicable (e.g. critical facilities requiring drains)	Yes	Yes	Yes	Medium-term	Low	4	5	5
DC6	Flood level resistance: Elevate entrances, vent and access shafts, stair/elevator access above peak predicted flood levels (e.g. 3 feet above peak predicted flood levels in 500-year event)	Yes	Yes	Yes	Long-term	High	3	3	3
DC9	Elevate or relocate equipment: Elevate or move sensitive equipment (e.g. small gauge electrical components, signal and communications equipment, ticketing machines, generators)	Yes	Yes	Yes	Medium-term	High	2	3	4
DC10	Waterproofing and corrosion retrofits: Retrofit existing and build new structures with waterproof, side penetrations and use non-corrosive materials	Yes	Yes	Yes	Medium-term	Moderate	3	5	4
DC11	Roof structures: Retrofit building roofs and update BFS to require pitched roofs (5 degrees minimum), avoid penetrations, and eliminate "bathtub" roof design	-	Yes	-	Long-term	Moderate		5	
DC12	Rain exposure: Design/retrofit buildings to protect against rainfall/rain and wind conditions -- do not leave gaps in facades, open roofs, etc.	-	Yes	-	Medium-term	Moderate		4	
DC14	Perimeter walls and entries: Build new or retrofit existing perimeter wall/barrier to be watertight, including gates and doors.	Yes	-	Yes	Medium-term	Moderate	3		4
DC18	Electric power: Provide power redundancy for pumps, equipment; provide backup power / additional generators	Yes	Yes	Yes	Medium-term	Moderate	3	4	4
DC19	Equipment redundancy: Identify or develop redundancy program in the event of a failure of critical equipment (such as train control equipment, MUX boxes, etc)	Yes	Yes	Yes	Medium-term	Moderate	3	4	4
Operations		**Hazard Exposure**			**Time**	**Cost**	**Overall Cost Benefit Score**		
Code	Strategy	Sea-level rise	Downpour	Flooding			SLR Strategy	Downpour Strategy	Flooding Strategy
Op1	Georeferenced asset management: Incorporate georeferenced/spatial querying, real-time updates into asset management system	Yes	Yes	Yes	Now	Moderate	3	3	3
Op5	Flood control district communications: Maintain frequent communication with local flood control districts regarding changes in operations of district facilities	Yes	-	Yes	Now	Low	4		4
Maintenance		**Hazard Exposure**			**Time**	**Cost**	**Overall Cost Benefit Score**		
Code	Strategy	Sea-level rise	Downpour	Flooding			SLR Strategy	Downpour Strategy	Flooding Strategy
M1	Maintenance reporting accessibility: Improve accessibility and standardize maintenance reports in order to identify "trouble spots" for water inundation, roof leaks, drainage problems, and/or equipment failures. Integrate with asset management system.	Yes	Yes	Yes	Now	Low	5	5	5
M2	Trash/sediment removal: Increase frequency of trash and sediment removal (which can cause blocked drain inlets) from neighboring streets and aerial tracks	Yes	Yes	Yes	Now	Moderate	4	4	4
M3	Equipment useful life monitoring: Increase monitoring of deterioration of some system elements due to water submersion (e.g. cloth cable sheathings)	Yes	Yes	Yes	Now	Moderate	4	4	4
M4	Critical equipment monitoring: Increase monitoring of critical equipment (e.g. MUX boxes, switches, transformers, life safety systems/communications)	Yes	Yes	Yes	Now	Moderate	4	4	4
M5	Test on-site roof and storm drain system: Perform dye test on roof, track, and floor drains to check for expected performance.	Yes	Yes	Yes	Now	Low	5	5	5

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