Capitol Corridor Joint Powers Authority

Sea Level Rise Vulnerability Assessment

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CAPITOL CORRIDOR

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Executive Summary

Global sea level is expected to rise as a result of climate change, and the rise is inexorable even if the world takes drastic measures to mitigate global greenhouse gas emissions now. Accompanied by storms, high winds, waves, and high tide, even a small amount of sea level rise has the potential to cause flooding in vulnerable areas. Extreme storms already present current flooding risks in many areas along the Capitol Corridor route, and frequency of extreme storms are expected to increase in the future due to climate change, therefore adaptation planning needs to begin as early as possible.

The Capitol Corridor Joint Powers Authority (CCJPA) Sea Level Rise Vulnerability Assessment identifies various types of vulnerabilities (physical, functional, governance, and information) for different assets in six focus areas along the Capitol Corridor route through a process of Geographic Information Systems (GIS) analysis and consulting with various asset managers.

The Assessment is intended to help CCJPA staff in planning for future impacts to the Capitol Corridor passenger train service due to climate change by identifying the vulnerabilities of assets crucial to passenger train service, such as railroad tracks and stations, to various impacts of climate change, from more frequent and severe flooding events to increased rates of shoreline erosion.

Asset Vulnerabilities

Overall, all the assets assessed in this study experience some mix of physical, functional, governance, and information vulnerabilities. Assets assessed include railroad tracks at grade, railroad signal system, railroad bridges, stations, and a maintenance facility. The following are key takeaways of the vulnerability assessment:

- The linear character of the **railroad system** inherently lacks redundancy, and any disruption to one section or one component of the system disrupts the entire system.
- The functionality of the **railroad tracks** depends upon the functionality of the signal system; impacts of disruptions to the signal system range from train delays to entire shutdown of the route, depending on the number of disruptions to the signal system at one time.
- Some **Capitol Corridor stations** are physically vulnerable to sea level rise due to their geographic location, and all are functionally vulnerable because of their reliance upon external power.
- The **Oakland Maintenance Facility** is a crucial asset to the Capitol Corridor, and it is especially vulnerable to rising sea levels and liquefaction due to its location and its sensitive below-grade components.
- The complex ownership and management structure for Capitol Corridor assets will likely complicate planning processes for future adaptation or resilience projects.
- There is a significant lack of detailed, easily accessible, and well-coordinated public information about railroad infrastructure (tracks, signal system, and bridges) owned by

Union Pacific, and there is currently no formal information sharing agreement between Union Pacific and CCJPA.

Focus Area Vulnerabilities

The extent of the Capitol Corridor route from Suisun/Fairfield (SUI) station to Santa Clara/Great America (GAC) station was considered for this study. Tracks and stations outside of that general extent were not considered because of their inland location, where sea level rise is not a significant climate change concern. Within the larger project area, six specific areas were chosen to better illustrate the details of vulnerabilities and risks of different rail assets to sea level rise and storm events: Suisun/Fairfield Station, Martinez Station, Point Pinole, Oakland, Oakland Coliseum Station, and Santa Clara/Great America Station. The array of focus areas characterize the impact of sea level rise on assets in different geographic and land use settings and serve as an overview of the range of the vulnerabilities and risks faced by the Capitol Corridor passenger train system in the future. In these focus areas, the risks of permanent inundation, temporary flooding, and shoreline erosion comes from nearby sources or bodies of water, which includes wetlands, the Bay, and streams. Another factor that can cause physical damage to railroad assets is liquefaction[1]. Saturated soils that are loose or sandy will exhibit the characteristics of a liquid when shaken long and hard enough, which could cause structures built on top of the soil to distort and collapse. As the groundwater levels rise due to sea level rise, liquefaction zones are expected to increase in overall extent[2].

Next Steps for CCJPA

Recommended adaptation responses and next steps for CCJPA focus generally on addressing governance and information vulnerabilities, since CCJPA does not own any assets and therefore has no direct control over physical assets. Working with existing stakeholders and community partners to address vulnerabilities and plan for future adaptation projects will be crucial for the resiliency of the Capitol Corridor system.

CCJPA Internal Organizational Actions

- Expand upon this assessment with new sea level rise research and GIS modeling of normalized shorelines along the entire San Francisco Bay coastline.
- Develop internal CCJPA database of key asset information.

[1] Liquefaction may result in ground sinking or pulling apart, ground displacement, or ground failure such as lateral spreads and sand boils, or sand "volcanoes." Liquefaction is a significant threat not only to railroads, but to underground pipelines, airport runways, and road or highway surfaces, as it causes buckling of these features due to ground shifting. Liquefaction may also cause building damage due to foundation movement or cracking when the underlying soils shift, or when there is a loss of bearing capacity for foundation elements, and can cause levee damage and failure, increasing the risk of flooding in low-lying areas.

[2] http://quake.abag.ca.gov/earthquakes/#liquefaction

- Develop operational plans for frequent temporary service gaps (e.g. bus bridges) to maintain passenger service where possible, including plans for train movement and storage.
- Incorporate sea level rise into existing and future operational and capital planning.

Working with Partners

- Develop closer partnership with and adopt a formal data sharing agreement with Union Pacific to fill in information gaps in railroad assets (tracks, signal system, bridges). Information gaps include existing conditions and maintenance records. Knowledge of Union Pacific's asset management system and plans would also be helpful in understanding the vulnerabilities of railroad assets.
- Develop multi-agency agreements with Caltrain and San Joaquin Joint Powers Authority (SJJPC) to establish shared climate change and sea level rise adaptation objectives. Cost-sharing responsibilities for future adaptation projects can also be discussed.
- Work with adjacent communities and businesses as part of a larger regional adaptation planning process to develop and jointly implement adaptation strategies for climate change and sea level rise impacts. Access to stations and protection of railroad, community, and business assets are key points for joint adaptation strategies.
- Work with communities, Amtrak, and Union Pacific to monitor groundwater and salinity levels near vulnerable assets and increase inspection and maintenance of vulnerable assets.
- Convey to Amtrak and Union Pacific the importance of following existing or developing new standards requiring new construction or repairs of existing assets to use waterproof and corrosion-resistant materials and the need for reliable and adequate backup power to minimize disruptions to critical assets such as the railroad signal system, maintenance facility, and electronic systems at stations.
- Explore adaptation strategies with Amtrak and the State of California for the Oakland Maintenance Facility.

Project Background

Global sea level is expected to rise as a result of climate change, and the rise is inexorable even if the world takes drastic measures to mitigate global greenhouse gas emissions now. Accompanied by storms, high winds, and waves, even a small extent of sea level rise has the potential to cause flooding in vulnerable areas. The Capitol Corridor Joint Powers Authority (CCJPA) Sea Level Rise Vulnerability Assessment attempts to identify various types of vulnerabilities (physical, functional, governance, and information) for different assets in six focus areas along the Capitol Corridor route through a process of Geographic Information Systems (GIS) analysis and consulting with various asset managers. The project initially stemmed from the San Francisco Bay Conservation Development Commission's (BCDC) Adapting to Rising Tides (ART) project. The assessment methodology follows the ART assessment process model, which is shown below (Figure 1). The results of the assessment will help CCJPA planners and asset managers make informed decisions about future climate resilience and adaptation options for the passenger rail system.

Adapting to Rising Tides Project

The ART Project is a federally-funded project aimed to "increase the Bay Area's preparedness and resilience to sea level rise and storm events while protecting critical ecosystem and community services."[3] BCDC, despite traditionally being a regulatory agency, took on the role of organizer for the project and convened a diverse range of stakeholders to discuss shared Bay Area climate change impacts in the same room. CCJPA has been a participant since the beginning of the ART Project. Other stakeholders include the Port of Oakland, San Francisco International Airport, East Bay Regional Park District, East Bay Municipal Utilities District (EBMUD), PG&E, BART, and others. With the active input and participation of the stakeholders, the ART Project team produced a Vulnerability and Risk Assessment Report for the San Francisco Bay Area.

The Vulnerability and Risk Assessment identified key vulnerabilities for 12 different asset categories, one of which is ground transportation. Key transportation findings of the ART Vulnerability and Risk Assessment are:

- Transportation assets rely on services provided by others – uninterrupted power, rights-of-ways and easements, shoreline protection – to ensure system and network function.
- Transportation agencies cannot address sea level rise and storm events on their own, and addressing regulatory and financial challenges with others will be crucial.
- Transportation vulnerabilities are often the first functional vulnerability for other assets, such as airports, seaports, residential areas and other critical facilities.
- A lack of accessible, geo-referenced data makes it difficult to assess vulnerability and develop responses.
- Before sea level rise and permanent inundation becomes a problem for transportation networks, widespread disruptions will likely be caused by storm surge and flooding.

[3] www.adaptingtorisingtides.org

- Multi-agency and multi-jurisdictional vulnerability assessments that provide understanding of how physical vulnerabilities are linked to functional vulnerabilities can help the affected partners to come up with cost-effective responses that address multiple issues.

The findings of the CCJPA Sea Level Rise Vulnerability Assessment echo and reinforce the results of the ART Vulnerability and Risk Assessment. The fact that CCJPA does not own any of the assets it relies upon to operate the passenger train service leads to information and governance vulnerabilities. CCJPA currently has no easy access to critical asset maintenance and operations data, especially for the railroad network. CCJPA also does not have direct control over the physical and functional aspects of the assets, which complicates and lengthens any future adaptation and resilience planning processes. Working with external partners, neighbors, and stakeholders will be crucial for the Capitol Corridor intercity passenger train service to adapt to a future of sea level rise and extreme storm events.

Multi-agency, multi-jurisdictional partnership is a key recommendation for all of the asset categories in the ART Project, but that also points to a critical need for leaders and conveners of these partnerships. BCDC acted as the organizer for the ART Project, but it may not be the appropriate body for other, more sector-specific, efforts. CCJPA can be the convener for Union Pacific Railroad, Amtrak, and municipalities, but a separate, perhaps regional, leader will be needed to facilitate and conduct multi-sector adaptation planning. The question of who should take on the responsibilities of convener is yet to be answered. Governance, jurisdiction, and regulatory vulnerabilities apply for all asset categories in the ART Project, and conveners to facilitate multi-sector adaptation planning and implementation are critically needed to move regional adaptation efforts forward.

Assessment Process

The vulnerability assessment method used for this project was modeled after BCDC's Adapting to Rising Tides Planning Process (Figure 1). The assessment starts at the Scope & Organize stage and proceeds to the Plan stage with suggestions for adaptation responses. A literature review of papers and reports on climate change and sea level science and predictions, especially those that focus on California or the rail system, was done prior to the assessment.

FIGURE 1: BCDC ADAPTING TO RISING TIDES PLANNING PROCESS

Literature Review

Climate Change and Sea Level Rise in the SF Bay Area

Ekstrom and Moser's 2012 California Energy Commission paper[4] synthesizes SF Bay Area-focused findings from research conducted in 2010-2012. In the SF Bay Area, the impacts of climate change will mainly manifest in flooding along the Bay shoreline from more frequent extreme storms in the winter and higher Bay water levels. Historical trends show consistent sea level rise and more frequent extreme tides in the Bay. Sea level rise in the Bay has occurred at a rate of approximately one inch per decade since the 1930s, and the frequency of extreme tides has increased 20-fold since 1915. By 2050, sea levels could rise approximately 5-24 inches above 2000 levels, and by 2100 could reach between 17 to 66 inches. The current 100-year (1% annual chance) flood elevation would become an annual event by the end of the century. The projections could be much higher if the western Antarctic ice sheet melts at an accelerated rate. The scenario could already be happening, as new satellite images from the European Space Agency's CryoSat taken between 2010 and 2013 show that the Antarctic ice sheet is retreating at twice the speed compared to when it was surveyed in the previous decade. In addition, two groups of scientists reported in May 2014 that a large section of the West Antarctic ice sheet has begun breaking apart and its continued melting appears to be unstoppable[5]. This event could eventually lead to sea level rise of 10 feet or more in the next centuries.

Table 1: Range of sea level rise projections for California South of Cape Mendocino, Using 2000 as a baseline[6]

	Sea Level Rise (inches)		
Year	**NRC 2012 Projection** (mean ± the standard deviation for the A1B Scenario[7])	**Low** (mean of the B1 scenario)	**High** (mean of the A1F1 scenario)
2030	**5.6** (±1.9)	2	12
2050	**11.0** (±3.6)	5	24
2100	**36.1** (±10)	17	66

[4] Ekstrom, Julia and Moser, Susanne. 2012. *Climate Change Impacts, Vulnerabilities, and Adaptation in the SF Bay Area: A Synthesis of PIER Program Reports and Other Relevant Research*. CEC-500-2012-071. http://www.energy.ca.gov/2012publications/CEC-500-2012-071/CEC-500-2012-071.pdf

[5] http://www.nytimes.com/2014/05/13/science/earth/collapse-of-parts-of-west-antarctica-ice-sheet-has-begun-scientists-say.html?_r=0

[6] National Research Council of the National Academies. 2012. *Sea-Level Rise for the Coasts of California, Oregon, and Washington.*

[7] The A1 scenario family assumes high economic growth, low population growth that peaks mid century, and the rapid introduction of more efficient technologies (A1B is balanced and A1FI is fossil fuel intensive). The B1 scenario family assumes the same low population growth as the A1 scenarios, but a shift toward a lower-emission service and information economy and cleaner technologies.

Climate Adaptation for Transportation Systems and Railroads

A 2008 Transportation Research Board Special Report by the National Research Council[8] provided some background knowledge on how the U.S. railroad system is organized and how investment and operating decisions are made in the transportation sector. Most U.S railroads are privately owned and operated (e.g. Union Pacific Railroad) and the federal government has regulatory oversight over safety. Railroad tracks are usually designed for up to 50 years of use, which means there are fewer opportunities for adaptation, as major rehabilitation and retrofits are performed at longer intervals. Because right-of-ways are enormously expensive to acquire, especially in urban areas, relocation of railroad tracks is usually not the most viable adaptation options for railroads.

One of the challenges of climate change adaptation within the transportation sector is the differences in planning horizons. Many transportation planners perceive that impacts of climate change will be experienced well beyond the time frame of their longest-term plans without realizing that the impacts are occurring and that investment decisions made today will affect how well the infrastructure accommodates these and future changes. The uncertainly that is inherent within climate change predictions also makes planning and designing difficult for transportation planners, who are more used to focusing on “knowns” or the “best available” forecasts. Another challenge for climate change adaptation for transportation is the poor alignment between climate change impacts, which are widespread across physical distance and functional modes, and the current transportation organizational arrangements, which is often decentralized and modally focused.

Examples of climate adaptation and resilience projects in the rail transportation sector can be found in the New York and New Jersey rail transit systems as a result of Hurricane Sandy. Both Metropolitan Transit Authority (MTA) and New Jersey Transit (NJ Transit) experienced significant impacts from the storm in their rail systems, but MTA was able to recover faster than NJ Transit because they had already implemented resiliency projects across their system and had an emergency plan ready. MTA’s 2008 Adaptations paper[9] documents the risk-based framework that MTA used to identify vulnerabilities and develop adaptation responses. In 2012, NJ Transit funded a climate resilience study to review potential risks of its assets to climate impacts and to identify specific resilience strategies for critical assets. While the governance and operational contexts for MTA and NJ Transit rail systems are quite different from that of Capitol Corridor (e.g. MTA and NJ Transit own and operate their assets and their service area is geographically smaller than Capitol Corridor), the vulnerability frameworks and assessment processes utilized by the two studies are good references for CCJPA’s vulnerability assessment.

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[8] National Research Council of the National Academies. 2008. *Potential Impacts of Climate Change on U.S. Transportation: Transportation Research Board Special Report 290.* http://onlinepubs.trb.org/onlinepubs/sr/sr290.pdf

[9] Metropolitan Transportation Authority. 2008. *MTA Adaptations to Climate Change: A Categorical Imperative.* http://www.mta.info/sustainability/pdf/Jacob_et%20al_MTA_Adaptation_Final_0309.pdf

Sea Level Rise Inundation Scenarios

Sea level rise risk analysis in most assessments has been limited to using inundation extents and depths to understand risk. However, water levels associated with sea level rise can occur due to a variety of hydrodynamic conditions by combining different levels of sea level rise and either daily or extreme high tide/storm surge[10]. Extreme tide levels can be interpreted as high tides (influenced by the alignment of the Sun, Moon, and Earth) or as storm surge (influenced by storm conditions). For example, a 12 inch water level above MHHW[11] could occur as a result of either a daily high tide with 12 inches of sea level rise or a 1-year extreme tide[12] with no sea level rise (or existing conditions). Table 2 is a useful matrix to use when considering the different ranges of high water level scenarios. The 1-year, 2-year, etc. labels for Extreme Tide Level (Storm Surge) represents the statistical probability of that kind of extreme tide level or storm surge to occur: A 1-year extreme tide level or storm surge has a 100% chance of occurring each year, and a 100-year extreme tide level or storm surge has a 1% chance of occurring each year. The different colors in the matrix highlight scenarios with the same water levels.

The matrix helps planners to think about sea level rise risk in the near term by expressing inundation or flooding risk in terms of how frequently that may occur in existing conditions or with just a small amount of sea level rise. The range of scenarios presented by the matrix is used throughout this CCJPA Sea Level Rise Vulnerability Assessment to express different levels of risk for assets and focus areas.

Table 2: Matrix of Water Levels Associated with Sea Level Rise and Extreme Tide Scenarios

		Extreme Tide Level (Storm Surge)						
Sea Level Rise	**Water Level above MHHW**	**1-yr**	**2-yr**	**5-yr**	**10-yr**	**25-yr**	**50-yr**	**100-yr**
+0	0	12	18	24	30	36	42	48
+6	6	18	24	30	36	42	48	54
+12	12	24	30	36	42	48	54	60
+18	18	30	36	42	48	54	60	66
+24	24	36	42	48	54	60	66	72
+30	30	42	48	54	60	66	72	78
+36	36	48	54	60	66	72	78	84
+42	42	54	60	66	72	78	84	90
+48	48	60	66	72	78	84	90	96
+54	54	66	72	78	84	90	96	102
+60	60	72	78	84	90	96	102	108

10 BCDC Alameda County Sea Level Rise Enhanced Shoreline Exposure Analysis Memo, AECOM, March 18, 2014.
11 Mean higher high water (MHHW) is calculated as the average of the higher of the two daily high tides over a 19 year tidal epoch.
12 1-year extreme tides occur annually and are known as "king tides".

In a partnership between the Adapting to Rising Tides (ART) program and the Alameda County Flood Control and Water Conservation District (ACFCWCD), the shoreline of Alameda County was delineated and analyzed using a normalized shoreline methodology to inform an understanding of where along the Alameda County shoreline Bay waters are likely to cause inland flooding as sea level rises. The normalized shoreline analysis compares the height of the existing shoreline to the MHHW, or high tide, of that area of the Bay. For example, a shoreline segment with a low normalized value has a likelier chance of being overtopped during storm events when Bay water levels are elevated. The shoreline analysis identifies any shoreline or flood protection structures such as levees, natural shorelines such as beaches and wetlands, roadways, and other high points that are the first line of defense against inland flooding. Together, the normalized shoreline analysis and sea level rise inundation maps help reveal specific weak spots where water could overtop the shoreline causing flooding or inundation of adjacent low-lying inland areas. Further analysis can then be conducted to identify the hydrologic pathways that would carry flood water from the shoreline to these locations further inland.

Figure 2 shows an example of what the normalized shoreline analysis outputs looks like. The location shown in the map is the Bay Bridge touchdown peninsula. The pink and red portions of shoreline have lower normalized values and the green and blue portions have higher normalized values. The map shows water entering inland through the portions of shoreline with low normalized values, and a hydrologic pathway can be inferred by tracing the flow of water from the shoreline to further inland.

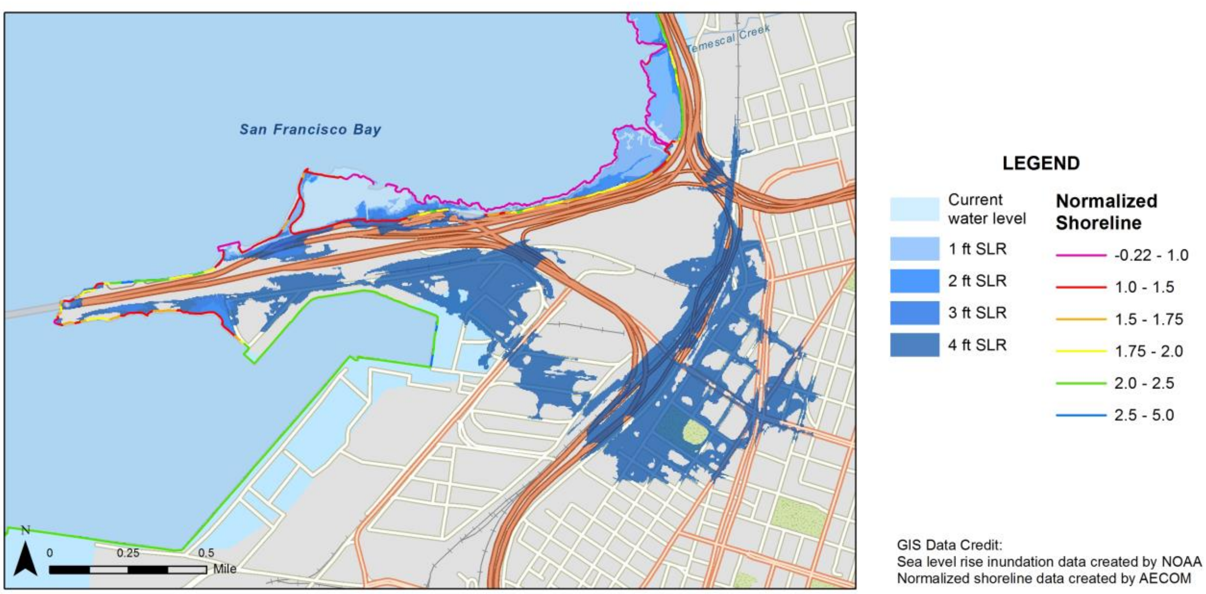


FIGURE 2: NORMALIZED SHORELINE EXAMPLE

The normalized shoreline analysis was only completed for Alameda County, so this type of detailed information is only available for the Alameda County focus areas in this Capitol Corridor Sea Level Rise Assessment. However, there are currently tentative plans to extend the shoreline modeling to all of Bay Area, which will provide more information for asset managers and planners thinking about future adaptation or resilience projects.

For a full list of literature and studies reviewed and consulted during the process of this assessment, please refer to Appendix A: Annotated Bibliography.

Project Focus Areas

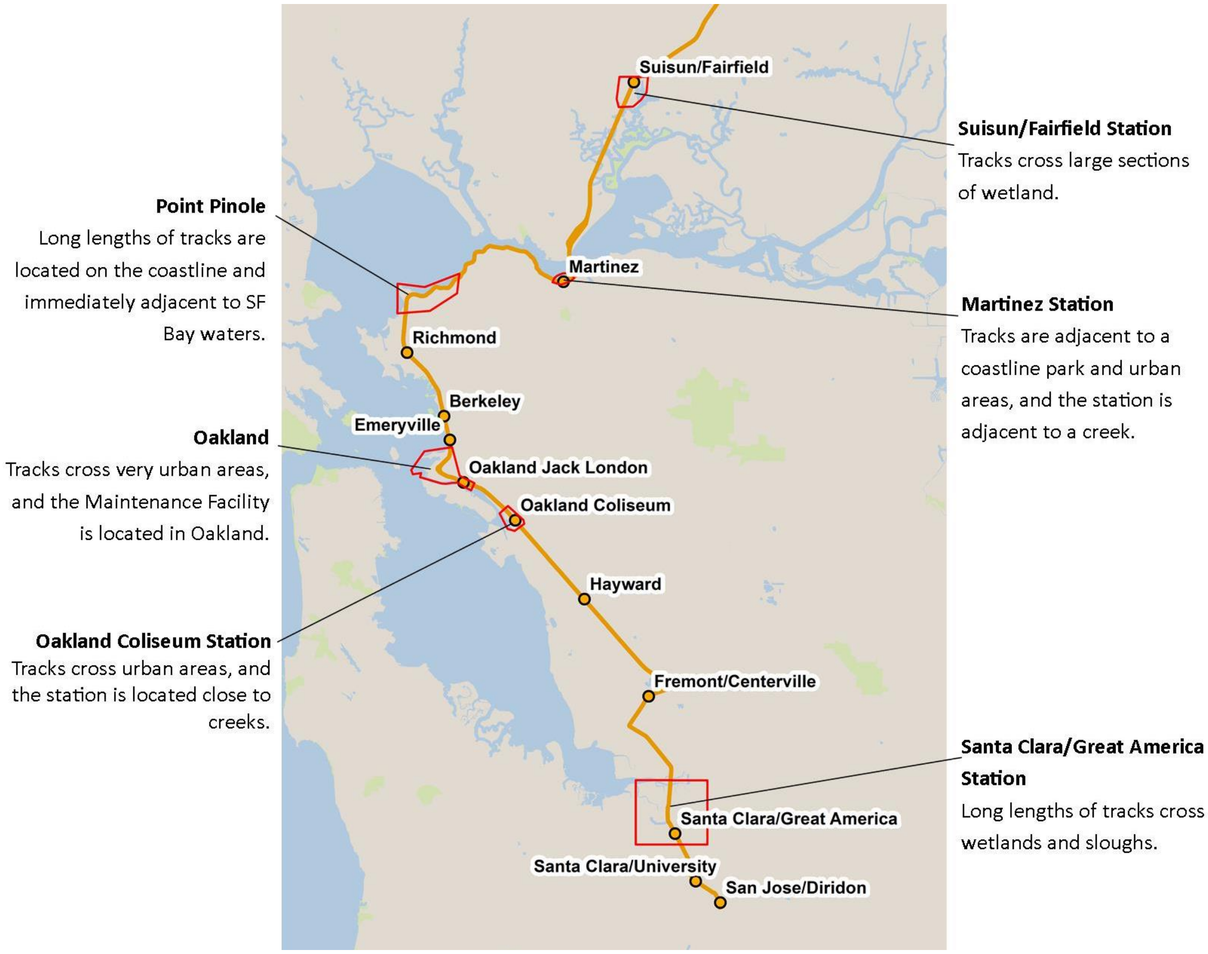


FIGURE 3: ASSESSMENT FOCUS AREAS WITH BRIEF DESCRIPTIONS

The extent of the Capitol Corridor route from Suisun/Fairfield (SUI) station to Santa Clara/Great America (GAC) station was considered for this study. Tracks and stations outside of that general extent were not considered because of their inland location, where sea level rise is not a significant climate change concern. Within the larger project area, six specific areas were chosen to better illustrate the details of vulnerabilities and risks of different rail assets to sea level rise. The areas selected for detailed assessment are outlined in Figure 3.

The array of focus areas characterize the impact of sea level rise on rail tracks and stations in different geographic and land use settings and serve as an overview of the range of sea level rise vulnerabilities and risks faced by the Capitol Corridor passenger train system in the future. Different focus areas have different physical climate impact risks. In some areas, the Capitol Corridor route passes through natural areas and open space (e.g. in the Suisun marsh), whereas in other areas (e.g. Martinez, Oakland, etc.), the route is surrounded by developed land uses. Therefore, adaptation responses will likely differ among focus areas, and, in many instances, will require the coordination of multiple stakeholders who will be impacted along with Capitol Corridor.

Adaptation and Resilience Response Goals

The following are possible goals that CCJPA may hope to accomplish as a result of future adaptation or resilience strategies based on the mission of CCJPA and the findings of this Assessment. These goals lead to criteria by which proposed adaptation or resilience strategies should be evaluated.

1. Ensure continual, safe, and reliable (on-time) train service for all passengers by minimizing service interruptions.
2. Maintain functional passenger rail service by preserving access to crucial Capitol Corridor stations and to other transit connections for passengers.
3. Build organizational capacity among CCJPA partners (Union Pacific, Amtrak, etc.) and others, such as those with assets within the rail track ROW (e.g. Kinder Morgan), to approach future sea level rise resilience projects collaboratively.
4. Develop partnerships and/or positive relationships with neighboring stakeholders to approach future sea level rise resilience projects collaboratively.
5. Act as a responsible neighbor to private and public entities and communities along the rail service route.
6. Comply with all applicable federal and state laws concerning the protection of endangered species and wildlife habitats as well as quality natural areas during the operations of train service, maintenance, and planning of Capitol Corridor projects.
7. Support the restoration or enhancement efforts of natural systems near the Capitol Corridor route.
8. Work with the host railroad to support and preserve railroad function and maintenance access including planning, design, and safe function and operations.

Climate Scenarios & Impacts

In the San Francisco Bay Area, the two major climate change-related stressors are storm events and sea level rise. These two stressors will lead to more frequent and longer flooding events, shoreline erosion and overtopping of levees, and higher groundwater levels. These impacts affect all types of rail assets and various aspects of the Capitol Corridor train operation, from maintenance to passenger service.

Sea level rise inundation maps for six water levels scenarios were used in this assessment to analyze the risk to assets and focus areas (see Figure 3). The inundation GIS data was provided by the National Oceanic and Atmospheric Administration (NOAA) Coastal Services Center[13]. The water level scenarios were developed by adding different amounts of sea level rise, from zero to six feet, onto the elevation of the existing conditions daily high tide level (Mean Higher High Water, or MHHW). Because five to six feet of sea level rise is not expected to occur within this century, these two scenarios are only used to evaluate temporary extreme flood events that may occur during storm surge with lesser amounts of sea level rise (refer to Table 2).

[13] http://csc.noaa.gov/digitalcoast/tools/slrviewer

Climate change stressor	*Impacts associated with climate change stressor*	*Potential effects of sea level rise and storm event impacts on rail assets and operations*
STORM EVENTS	More frequent extreme high sea level events cause **more frequent flooding events** in flood-prone areas	• Overwhelmed flood protection channels, culverts, and storm drains increase flooding in low-lying areas, which could result in increased inundation of certain portions of track and parts of stations • Disruption to rail service if severe flooding affects integrity of rail tracks, bridge structures, or operational assets such as the signal system • Decreased access to stations for riders and to tracks for maintenance purposes
	With longer duration extreme high sea level events, **flooding lasts longer**	• Increased costs of repair and maintenance during and after flood events, including the need to pump flooded areas and clean up and dispose of debris • Loss of access to stations and disruption of train service • Changes to sediment transport and deposition affect capacity of tidal wetlands to keep up with sea level rise
SEA LEVEL RISE	Higher high tides, shifts in tidal range, and increases in depth and duration of tidal inundation cause **frequent flooding or permanent inundation** of areas that are not currently in the daily tidal range	• Inundation of certain rail tracks and parts of stations that reduces ability to provide high quality, consistent passenger service • Structures, including shoreline track and bridge structures that are not adequately protected, elevated or flood-proofed are destroyed or damaged, and require replacement, repair and/or more frequent maintenance • Increased scour of bridges and shoreline protection structures potentially leading to damage or failure • Decreased access to stations for riders and to tracks for maintenance purposes • Tidal habitats that cannot keep up or migrate inland will drown, potentially reducing flood reduction benefits of tidal marsh and mudflats to inland assets and communities
	Higher Bay water level causes changes in wave activity in the Bay leading to **increased shoreline erosion and waves over-topping shoreline protection**	
	Higher Bay water level leads to **elevated groundwater levels and salinity**	• Increased liquefaction potential during seismic events • Damage to track bed and ballast materials potentially causing failures, reducing asset lifespans, and increasing maintenance needs

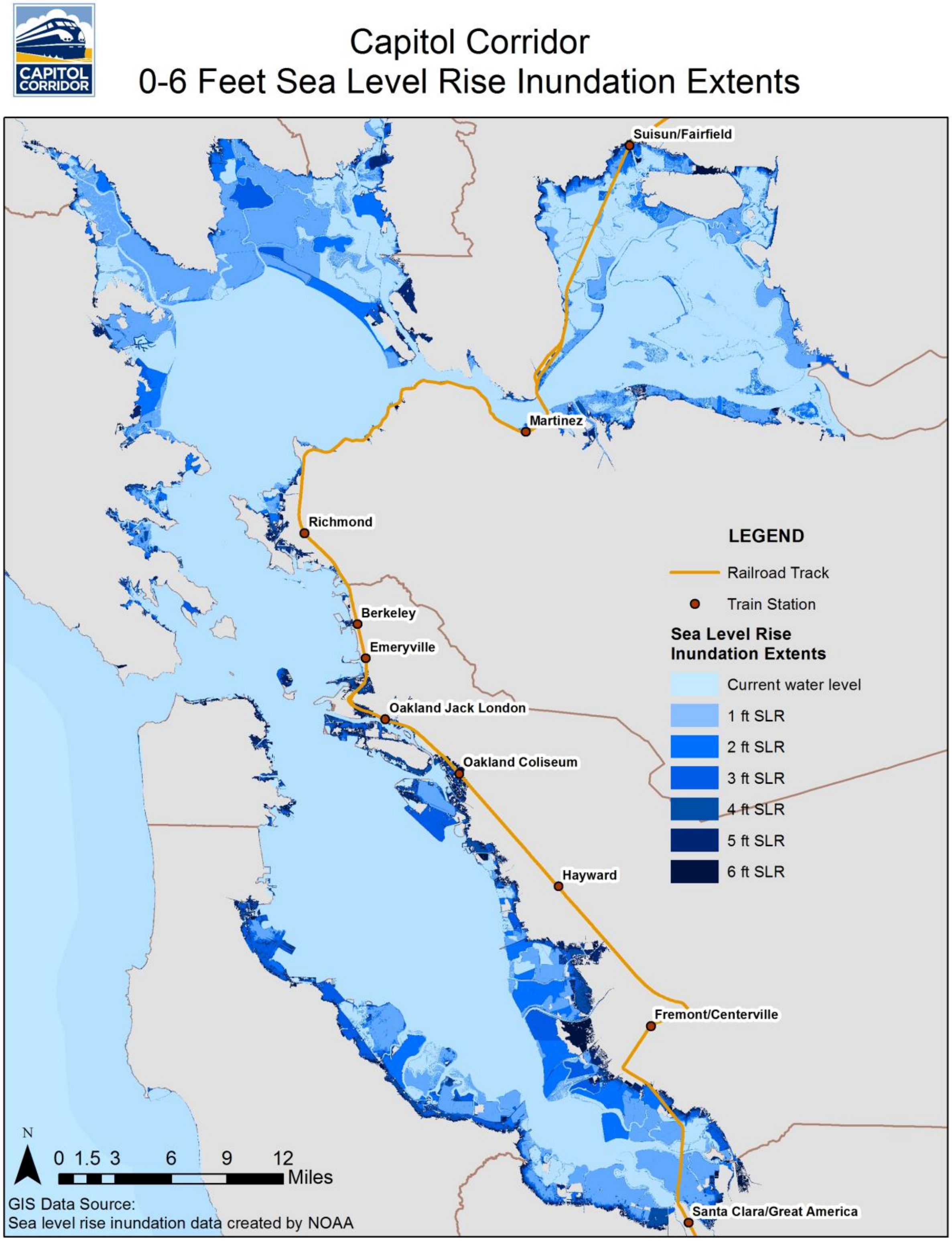
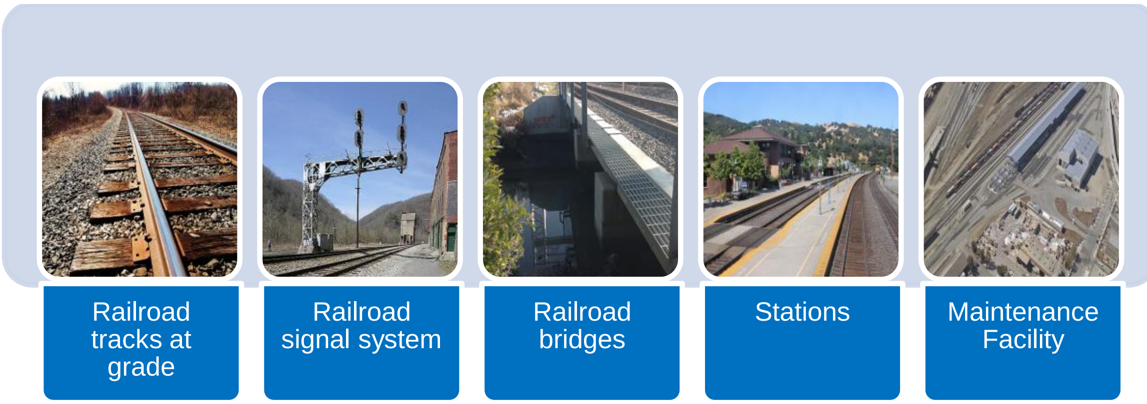


Figure 4: Capitol Corridor 0-6 ft Sea Level Rise Inundation Extent

Assets

Various Capitol Corridor rail assets necessary for train operations were categorized based on their functionalities.



Vulnerability Metrics

A list of questions regarding existing conditions and different types of vulnerabilities (physical, functional, governance, information) were presented to asset managers, who answered the questions to the best of their knowledge. The metrics were developed by the BCDC Adapting to Rising Tides staff and address how assets respond to different risks such as saltwater inundation, power outages and liquefaction. Though not directly related to climate change, liquefaction was also considered as an asset risk in the assessment, as earthquakes are a significant hazard for the Bay Area. As groundwater level rise due to sea level rise, the risk of liquefaction may also increase as areas with susceptible soil conditions become wetter. Below are descriptions of the vulnerability categories and some examples of the metrics questions:

- **PHYSICAL** vulnerability metrics help determine whether an asset or asset category has vulnerabilities due to how an asset is designed or built.
  - Are any components of the asset at-grade or below-grade (e.g., pipes, tubes, tunnels, ventilation grates)? If so, are they sensitive to water or saltwater (e.g., electrical components)? Are they waterproof, corrosion-resistant, or otherwise protected from water and saltwater?
  - Is the asset co-located with other assets that require coordination for access or repairs, or where coordinated access would be beneficial?

- **FUNCTIONAL** vulnerability metrics help determine whether an asset or asset category is vulnerable due to its functions and relationships with other assets and asset categories.
  - Is the asset connected to other assets, such that failure in one part of the system could disrupt the entire system?
  - Describe any redundancy in the system that would allow the system to continue to function if one asset is disrupted.

- **GOVERNANCE** vulnerability metrics help determine whether an asset or asset category is vulnerable due to challenges with management, regulation, or funding.
    - What performance and / or safety regulations is the asset currently subject to?
    - What is the ownership status of the asset?

- **INFORMATION** vulnerability metrics help determine whether there are any ways in which an asset or asset category is vulnerable due to lacking, incomplete, or poorly coordinated information.
    - What types of information sources necessary to conduct a vulnerability and risk assessment are publicly available?
    - What types of mechanisms exist to share information between owners of interconnecting or interdependent transportation infrastructure?

The entire list of asset vulnerability metrics questions can be found in Appendix B: Asset Vulnerability Metrics.

Asset Vulnerabilities and Risks

After collecting the vulnerability metrics data, the metrics data was analyzed and specific vulnerabilities in each of the four categories (physical, functional, governance, and information) were organized and summarized in profile sheets. Assets in the same asset category have common vulnerabilities even in different focus areas, so vulnerabilities were organized by asset categories to highlight themes.

Asset Vulnerabilities Key Takeaways

- The linear character of the **railroad system** inherently lacks redundancy, and any disruption to one section of the system disrupts the entire system.
- The functionality of the **railroad tracks** depends upon the functionality of the signal system; impacts of disruptions to the signal system range from train delays to entire shutdown of the route, depending on the number of disruptions to the signal system at one time.
- Some **Capitol Corridor stations** are physically vulnerable to sea level rise due to their geographic location, and all are functionally vulnerable because of their reliance upon external power.
- The **Oakland Maintenance Facility** is a crucial asset to the Capitol Corridor, and it is especially vulnerable to rising sea levels and liquefaction due to its location and its sensitive below-grade components.
- The complex ownership and management structure for Capitol Corridor assets will likely complicate planning processes for future adaptation or resilience projects.
- There is a significant lack of detailed, easily accessible, and well-coordinated public information about railroad infrastructure (tracks, signal system, and bridges) owned by Union Pacific, and there is currently no formal information sharing agreement between Union Pacific and CCJPA.

Note: The difference between the terms *inundation* and *flooding* must be distinguished when reading the vulnerability profile sheets. Permanent *inundation* occurs when an area is exposed to regular daily tidal inundation. An area under permanent inundation cannot be used in the same way as an inland area due to the frequency of exposure to sea water. On the other hand, *flooding* occurs when an area is exposed to short episodes of extreme tide events (or storm surge). Inland areas that experience flooding may maintain a portion of their functionality once floodwaters recede. Therefore, flooding, as used in this assessment, refers to temporary inundation conditions as a result of a storm event rather than the permanent inundation due to daily high tides.

Note: Inundation levels, permanent or temporary, can occur through several scenarios of different combinations of sea level rise and extreme high tides/storm surge. Refer to Table 2 for full range of possible scenarios.

Vulnerability Profile Sheets by Asset Category

Each profile sheet includes a description of the asset, a key issue statement summarizing the vulnerabilities and risks for the asset, a vulnerabilities and risks statements section detailing the different types of vulnerabilities, and a consequences section describing the potential impacts of physical or functional disruptions to the existing railroad and passenger trail system.

Railroad Tracks at Grade

Asset Description: Railroad tracks are the structures on which trains travels. Aside from the steel rails (superstructure), there are also understructure components to a typical railroad track, including ballast, embankment and roadbed (see Figure 5).

Ballast is the strata of granular materials that are installed for the purpose of 1) permitting drainage within the track substructure, 2) anchorage of the track superstructure, 3) distribution of loads and transfer of the track superstructure loads to the underlying roadbed, 4) facilitating fine adjustment of track superstructure alignment, grade and cross level without system reconstruction, and 5) shielding the materials of the embankment and roadbed from climatic forces.

Embankment (labeled subgrade in Figure 5) is the earth material directly beneath the ballast. The embankment further elevates the rails above the ground to isolate the ballast and rail from water elements. In areas where there is no water near the tracks, embankment may not be present.

The roadbed (not shown in Figure 5) is the portion of the track structure beneath the embankment. The performance of the roadbed is greatly influenced by the presence of excess moisture in the roadbed and the site specific drainage characteristics of the roadbed and ballast/embankment sections.

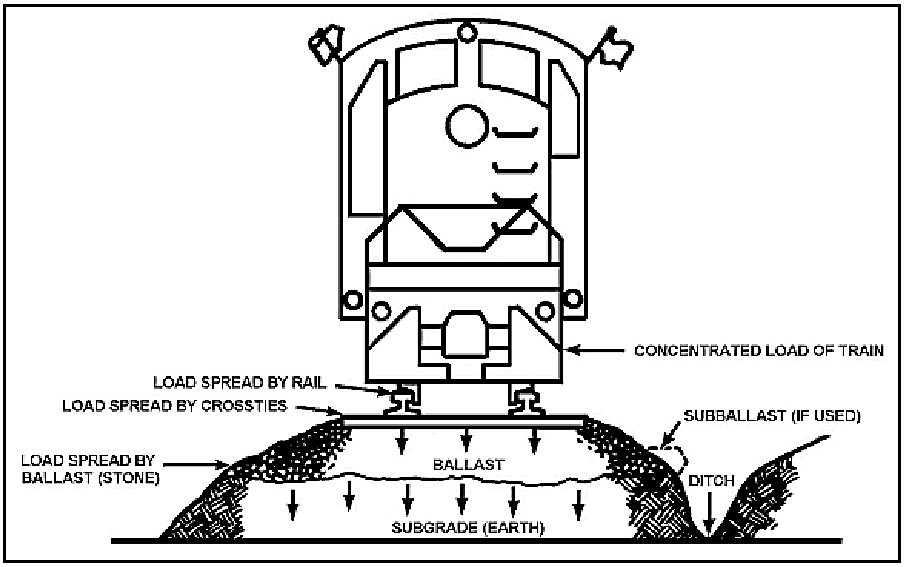


FIGURE 5: RAILROAD TRACK STRUCTURE COMPONENTS

Key Issue Statement: Portions of the railroad tracks are physically vulnerable to sea level rise and liquefaction due to their geographic location in wetlands and on soft sandy soils. The ballast and earth embankment are susceptible to washout in cases of strong wave action and high water. In the event of railroad tracks being submerged in water, trains are not permitted to pass due to the design of railroad equipment and safety reasons. The tracks are functionally vulnerable to disruptions of external electricity sources, which powers the signal system, and train service on the entire track system are impacted if one section of track is out-of-service. There is a significant lack of public information available to conduct a full vulnerability and risk assessment, and the willing participation of Union Pacific as a project partner is crucial in the planning and implementation of future resilience or adaptation projects.

Vulnerability and Risk Statements

PHYSICAL VULNERABILITIES

PHYS1: Major portions of the railroad tracks are located in the current FEMA 1% annual-chance floodplain, which makes these sections very vulnerable to the flooding caused by extreme storm events and sea level rise.

PHYS2: Many portions of the railroad tracks in the focus areas are at risk for liquefaction due to their geographic location and their structural characteristics. Liquefaction susceptibility increases when the geologic material underneath the railroad track infrastructure is composed of loosely packed sandy or silty materials that are saturated with water. The tracks that cross wetlands are built upon that exact type of material and therefore are extremely susceptible to liquefaction. The geographic areas around Suisun/Fairfield station, Martinez station, Oakland Jack London station, Oakland Coliseum station, Fremont station, and Alviso are also highly susceptible to liquefaction.

PHYS3: The ballast and earth embankment under the steel railroad tracks are sensitive to wave action and easily eroded during extreme storm events with strong wave action.

PHYS4: Increases in the water table due to sea level rise, increased flooding, or other causes will increase the extent to which the subsurface (including roadbed) soils beneath railroad embankments are saturated. This will have the effect of reducing the effective strength of the subsurface soils, which will destabilize the embankments and affect the railroad track structural integrity.

FUNCTIONAL VULNERABILITIES

FUNC1. Operation of train service on the tracks would be affected by a disruption to commercial power supplies, as the signal system is critical to the safe operation of the railroad service. Although the signal system has battery backups that can last a few hours, and then there are protocols in place for manual signaling by railroad staff, these are only short-term solutions.

FUNC2. Due to the linear connectivity of railroad track, a disruption to any railroad segment within the Capitol Corridor would impact passenger and freight train service. In sections that are double-tracked, the two railroad tracks are close in proximity to each other, so it is highly likely that both will be impacted or damaged at the same time. If both tracks are impacted or damaged, temporary bus bridges can be set up for passenger train service and freight trains will need to be rerouted within the greater geographic area at potentially great economic cost. Manual signaling is possible in the short-term, but will result in service slow-down and high labor cost.

FUNC3. There are no alternative railroad transit options providing intercity service from San Jose to Sacramento, and the state highway I-880 that could provide an alternative route for car or bus service is vulnerable to the same sea level rise and storm event impacts as this segment of railroad track.

GOVERNANCE VULNERABILITIES

GOV1: The details and status of Union Pacific's maintenance plans or capital improvement plans relating to the tracks are unknown. The best case would be that Union Pacific has an asset management plan with a georeferenced database that compiles asset operations, maintenance, and capital improvement information.

GOV2. Some sections of railroad tracks components may be protected from flooding by levees owned by adjacent landowners. Union Pacific and adjacent landowners generally do not coordinate and share information or make decisions together.

GOV3. Minor and major maintenance to the tracks requires specialized crew, materials, and, at times, custom-built components and repairs may not be possible immediately after damages/disruption.

GOV4. The co-location of petroleum pipelines and fiber optic cables (located below-grade, generally at the edge of the Union Pacific right-of-way) with certain sections of railroad tracks will require joint decision-making and coordination when performing major maintenance projects.

INFORMATION VULNERABILITIES

INFO1: There is a lack of detailed, easily accessible, and well-coordinated information about the railroad tracks, which are owned and managed by Union Pacific Railroad, a private corporation. For example, updated and accurate information about the detailed location, condition and elevation of the signal system components are not publicly available. The information may be accessed by request by Capitol Corridor, but this type of request has not been attempted yet.

INFO2: There is no formal information sharing agreement between Capitol Corridor Joint Powers Authority and Union Pacific (information is requested on a case-by-case scenario), so acquiring the necessary information for a detailed vulnerability assessment will not be possible without Union Pacific as an active participant.

Consequences

SOCIETY, COMMUNITY, EQUITY

Petroleum is currently being transferred in pipelines belonging to Kinder Morgan (the pipelines located within the embankment in the Union Pacific right-of-way), and, if spilled, could cause human health problems. Destabilization of the railroad embankment could cause distortion and rupture of the pipelines. Relocation and repair of the railroad infrastructure must take into account the presence of the pipelines and other underground utilities, potentially requiring relocation of the lines within the right-of-way. Increasing the height of the railroad embankment can cause additional forces on the underground pipelines, which could lead to rupture. Petroleum has high mobilization potential in floodwater.

Creosote (a wood preservative used on railroad ties) is used as a fungicide, insecticide, miticide, and sporicide to protect railroad ties. EPA has classified creosote as a probable carcinogen. Creosote has medium mobilization potential in floodwater.

Air quality would decrease due to increased exhaust from cars during road congestion, which is expected to occur if Capitol Corridor or San Joaquin (which uses the same tracks as Capitol Corridor from Oakland to Martinez) trains experience major disruptions and potential passengers are forced to drive rather than take the train.

ENVIRONMENT

Petroleum is currently being transferred in pipelines belonging to Kinder Morgan, and, if spilled, could cause ecological damage to wildlife and fish. Petroleum has high mobilization potential in floodwater.

There is phosphorus and other unidentified chemicals buried underneath the ROW near the intersection of Chadbourne Slough and the railroad tracks in Grizzly Bay from a railroad accident in the 1960s. Phosphorus has high mobilization potential in floodwater.

Economy

Loss of the Capitol Corridor intercity passenger railroad service would affect travelers that use the service to access jobs, goods or services in the cities and metro areas of the Bay Area and Sacramento regions.

Disruption of the railroad track would not only significantly affect passenger service, it would also disrupt freight operations and affect goods movement as there are not alterative railroad alignments in this geographic region. Disruption of goods movement would have significant regional economic impacts.

Railroad Signal System

Asset Description: The railroad signal system controls railway traffic safety through a system of color light signals mounted on masts located adjacent to railroad tracks or on overhead fixtures above the railroad tracks. The signals are controlled by switches located inside signal cabinets located alongside the tracks at different intervals. The signal cabinets are usually metal sheds build on concrete platforms. Electrical currents are mainly transmitted through electrical wires located underneath the track infrastructure, but small currents are also transmitted through the steel railroad tracks.

Key Issue Statement: Physical vulnerabilities of the signal system are intimately linked with the physical vulnerabilities of the railroad track system; where the tracks are vulnerable, the signal system there is also vulnerable, as the two systems are located in the same place and are mutually reliant. The signal system is extremely sensitive to moisture in the railroad track subgrade, where a small amount of moisture could short out the current flowing in the rails. The signal system is functionally highly vulnerable to disruptions in external power sources. There is a significant lack of public information available to conduct a full vulnerability and risk assessment, and the willing participation of Union Pacific as a project partner is crucial in the planning and implementation of future resilience or adaptation projects.

Vulnerability Statements

PHYSICAL VULNERABILITIES

PHYS1: Major portions of the railroad tracks and the associated signal system are located in the current FEMA 100-year flood zone, which makes these sections very vulnerable to the flooding caused by extreme storm events and sea level rise.

PHYS2: Many portions of the railroad tracks and the associated signal system in the focus areas are at risk for liquefaction due to their geographic location and their structural characteristics. Liquefaction susceptibility increases when the geologic material underneath the railroad track infrastructure is composed of loosely packed sandy or silty materials that are saturated with water. The tracks that cross wetlands are built upon that exact type of material and therefore are extremely susceptible to liquefaction. The geographic areas around Suisun/Fairfield station, Martinez station, Oakland Jack London station, Oakland Coliseum station, Fremont station, and Alviso are also highly susceptible to liquefaction.

PHYS3: The railroad signal system is extremely sensitive to excessive moisture in the railroad track subgrade; excessive moisture could short out the small current flowing in the track rails even if the track is not submerged. The signal system stops operating if the current stops flowing. In the short term the railroad could institute manual signaling, but this would only be a short term solution and would result in significant delays to freight and passenger trains.

PHYS4: Some railroad signal system components are neither waterproof nor corrosion-resistant and therefore cannot be exposed to any duration of flooding. Other components, for example masts and power cabinets, are waterproof but not completely corrosion-resistant and therefore cannot be exposed to salt water. Some components, such as below-grade electric wires are designed to be waterproof and corrosion-resistant.

PHYS5: The ballast and earth embankment under the steel railroad tracks and associated signal system components are sensitive to wave action and easily eroded during extreme storm events with strong waves.

FUNCTIONAL VULNERABILITIES

FUNC1. The signal system is critical to safe railroad operation, and therefore any disruption to commercial power supplies could affect train service. Although the signal system has battery backups that can last a few hours, and there are protocols in place for manual signaling by railroad staff, these are only short-term solutions.

FUNC2. Due to the linear connectivity of railroad track, a disruption to any railroad segment within the Capitol Corridor would impact passenger and freight train service. In sections that are double-tracked, the two railroad tracks are close in proximity to each other, so it is highly likely that both will be impacted or damaged at the same time. If both tracks are impacted or damaged, temporary bus services can be set up for train passengers and freight trains will need to be rerouted within the greater geographic area at potentially great economic cost. Manual signaling is possible in the short-term, but will result in service slow-down and high labor cost.

FUNC3. There are no alternative railroad transit options providing intercity service from San Jose to Sacramento, and the state highway I-880 that could provide an alternative route for car or bus service is vulnerable to the same sea level rise and storm event impacts as this segment of railroad track.

GOVERNANCE VULNERABILITIES

GOV1: The details and status of Union Pacific's maintenance plans or capital improvement plans relating to the signal system are unknown. The best case would be that Union Pacific has an asset management plan with a georeferenced database that compiles asset operations, maintenance, and capital improvement information.

GOV2. Some sections of railroad tracks and associated signal system components may be protected from flooding by levees owned by adjacent landowners. Union Pacific and adjacent landowners generally do not coordinate and share information or make decisions together.

GOV3. Minor and major maintenance to the signal system require specialized crew, materials, and, at times, custom-built components and repairs may not be possible immediately after damages/disruption. Extensive testing of the repairs is required which can incur high labor costs.

INFORMATION VULNERABILITIES

INFO1: There is a lack of detailed, easily accessible, and well-coordinated information about the railroad signal system, which is owned and managed by Union Pacific Railroad, a private corporation. For example, updated and accurate information about the detailed location, condition and elevation of the signal system components are not publicly available. The information may be accessed by request by Capitol Corridor, but this type of request has not been attempted yet.

INFO2: There is no formal information sharing agreement between Capitol Corridor Joint Powers Authority and Union Pacific (information is requested on a case-by-case scenario), so acquiring the necessary information for a detailed vulnerability assessment will not be possible without Union Pacific as an active participant.

Consequences

SOCIETY, COMMUNITY, EQUITY

Air quality would decrease due to increased exhaust from cars during road congestion, which is expected to occur if Capitol Corridor or San Joaquin (which uses the same tracks as Capitol Corridor from Oakland to Martinez) trains experience major disruptions and would-be passengers are forced to drive rather than take the train.

ENVIRONMENT

In the event of a train service disruption, greenhouse gas emissions will increase if people are forced to drive instead of taking the train or need to drive further to get to an in-service station instead of one nearby.

ECONOMY

Loss of the Capitol Corridor intercity passenger railroad service would affect travellers that use the service to access jobs, goods or services in the cities and metro areas of the Bay Area and Sacramento regions.

Disruption of the railroad track due to signal system issues would not only significantly affect passenger service, it would also disrupt freight operations and affect goods movement as there are not alterative railroad alignments in this geographic region. Disruption of goods movement would have significant regional economic impacts.

Railroad Bridges

Asset Description: Railroad bridges are structures with railroad tracks that cross bodies of water. There are many types of railroad bridges, and the type is usually dependent upon the size of the water body and the age of the bridge. Bridge types include steel beam span, prestressed concrete box, reinforced concrete slab, and timber stringers.

Key Issue Statement: Almost all of the railroad bridges in the focus areas are in the FEMA 100-year flood zone, and all of them cross tidal creeks, which makes them very vulnerable to extreme storm events and in particular those with heavy rainfall and wind. Bridge support structures are susceptible to washout by strong waves, and high water levels in the creeks may inundate the rail tracks on the bridge. Raising the elevation of a railroad bridge requires the simultaneous elevation of the connected railroad tracks to maintain grade continuity. There is a lack of detailed, easily accessible, and well-coordinated information about the railroad bridges in the focus areas, which are owned and managed by Union Pacific Railroad.

Vulnerability and Risk Statements

PHYSICAL VULNERABILITIES

PHYS1: Almost all of the bridges in the focus areas are in the FEMA 100-year flood zone and all of them cross tidal creeks, which makes them very vulnerable to extreme storm events that cause high creek flow and potential overbank flooding. Scour at bridge footings is also expected to occur as tidal energy and wave heights increase with sea level rise.

PHYS2: The bridges in the focus areas from Oakland to Santa Clara are at risk for liquefaction due to their geographic location. Bridges are structurally vulnerable to liquefaction during an earthquake because damage to support structures (piers, concrete boxes, etc.) could cause collapse of the bridge.

FUNCTIONAL VULNERABILITIES

FUNC1: Due to the linear connectivity of railroad tracks, a disruption to any segment along the Capitol Corridor route would impact passenger and freight train service. If a railroad bridge is flooded or damaged to the extent that normal train service cannot be operated over it safely, the functionality of the railroad bridge and of the adjacent railroad tracks is impacted. In the event of a track disruption, temporary bus services can be set up for train passengers, and freight trains will need to be rerouted within the greater geographic area at potentially great economic cost.

GOVERNANCE VULNERABILITIES

GOV1: Some bridges are protected by flooding from levees and other structures owned and managed by entities other than Union Pacific. Any past collaboration in flood protection planning is unknown.

GOV2: Railroad bridges are subject to performance and safety standards of multiple entities (Union Pacific railroad bridge standards, CA PUC standards, FRA standards) and require multiple permits (SF BCDC, USACE, etc.) for changes to be made, which could lengthen and complicate future resilience or adaptation projects.

INFORMATION VULNERABILITIES

INFO1: There is a lack of detailed, easily accessible, and well-coordinated information about the railroad bridges in the focus areas, which are owned and managed by Union Pacific Railroad. For example, updated and accurate information about the detailed components, condition and elevation of the bridges are not publicly available. The information may be accessed by request by Capitol Corridor, but this type of request has not been attempted yet.

Consequences

SOCIETY, COMMUNITY, EQUITY

Air quality would decrease due to increased exhaust from cars during road congestion, which is expected to occur if Capitol Corridor or San Joaquin (which uses the same tracks as Capitol Corridor from Oakland to Martinez) trains experience major disruptions and would-be passengers are forced to drive rather than take the train.

ENVIRONMENT

Some bridges are near wetlands, parks, or other protected natural resources, and the chemicals from rail materials (creosote from rail ties, for example) may mobilize in water if exposed for extended periods of time.

ECONOMY

Loss of the Capitol Corridor intercity passenger rail service would affect commuters that use the service to access jobs, goods or services in the cities and metro areas of the Bay Area and Sacramento regions.

Disruption of any of the bridges would not only significantly affect passenger service, it would also disrupt freight operations and affect goods movement as there are not alterative rail alignments in this geographic region. Disruption of goods movement would have significant regional economic impacts.

Stations

Asset Description: Train stations are where passengers board and exit Capitol Corridor trains. Every train station has one or multiple boarding platforms where passengers have direct access to train doors. Only two stations within the study area are staffed and have station buildings (Martinez and Oakland Jack London) while the others are not staffed and only have Quik-Trak machines for ticketing purposes. Oakland Coliseum Station and Santa Clara/Great America Station have canopied concrete platforms with video surveillance systems. Suisun/Fairfield Station has an open concrete platform and no video surveillance system. All of the stations have parking (very limited at some stations) nearby and are accessed via city roads by pedestrians, bikes, and automobiles.

Key Issue Statement: Most of the stations in the focus areas are somewhat vulnerable to flooding under current conditions, and will become more vulnerable to flooding as climate change increases the frequency and severity of flood events. Reliance on power provided by external entities and access to stations from roads managed by others are two of the main functional vulnerabilities for stations. All of the stations and their components are owned and managed by various entities, including Union Pacific, Amtrak, Capitol Corridor Joint Powers Authority, and various cities and municipalities; this complex governance structure could complicate future planning and implementation processes for possible station adaptation projects.

Vulnerability and Risk Statements

PHYSICAL VULNERABILITIES

PHYS1: Most of the stations in the focus areas are somewhat vulnerable to flooding under current conditions, and will become more vulnerable to flooding as climate change increases chances and severity of flood events. Four of the five stations assessed are either in or near the FEMA 500-year (0.2% annual chance) flood zone. Mechanical and electrical equipment (e.g. ticketing machines, lighting, electronic notification system) that are essential to the safe operation of the station will be damaged by exposure to water and/or salinity.

PHYS2: Some of the stations in the focus areas are at risk for liquefaction due to their geographic location. Oakland Jack London, Oakland Coliseum, and Santa Clara/Great America are at risk of liquefaction according to ABAG's earthquake hazards map.

PHYS3: The safe operation of the stations relies on utilities that are below-grade. Electrical and mechanical equipment are generally not waterproof or corrosion resistant, even if located below-grade, and rising groundwater or overland flooding could disrupt these components. Electrical lines are encased in plastic conduit, which are waterproof and corrosion-resistant, but water could enter the conduit from various connection or junction points.

FUNCTIONAL VULNERABILITIES

FUNC1: Stations are functionally vulnerable because they are connected to the main line rail tracks for full service. The stations will lose functionality long-term if train service is not available to the station. Temporary bus service can be set up between stations but are not long-term solutions in the event of permanent sea level rise.

FUNC2: Stations have no alternative power supply other than commercial power, making them vulnerable to power outages. Without power, electric signage will be unavailable, and safety and security components (e.g. lights, security cameras) will also be out of service. Generators can be brought in to supply electricity temporarily, but need to be supervised and require fuel.

FUNC3: Stations are often only accessible to passengers via a limited number of access roads. If those roads are flooded or become inaccessible, cars, bikers, and pedestrians will not be able to get to the station easily or safely.

GOVERNANCE VULNERABILITIES

GOV1: Multiple agencies and entities are involved in the ownership status of different parts of each station, complicating decision-making for issues that involve the entire station. Union Pacific owns the railroad tracks, right-of-way, and sometimes boarding platforms; cities or other entities own the station building and sometimes the boarding platform. Amtrak is responsible for maintaining the platform.

GOV 2: CCJPA does not have control over the surrounding land, road, or transit that provides access to the station or control over services that provide flood protection.

Ensuring that access to the station remains viable and that current levels of flood protection are maintained will require cooperation between CCJPA, adjacent landowners, various cities, and related water control district(s).

INFORMATION VULNERABILITIES

INFO1: Many types of information sources necessary to conduct a thorough vulnerability and risk assessment are not publicly available, which makes the assessment process more time-consuming and the results not as comprehensive.

INFO2: There is no formal information sharing agreement between the different entities that own and manage the stations (information is requested on a case-by-case scenario), making it difficult for any one entity to plan and implement resiliency or adaptation projects by themselves at the stations.

Consequences

SOCIETY, COMMUNITY, EQUITY

The two stations in Oakland have closed or inactive remediation sites nearby. The mobilization potentials in floodwater of the chemicals or materials at the sites are unknown.

Air quality would decrease due to increased exhaust from cars during road congestion, which is expected to occur if Capitol Corridor or San Joaquin (which uses the same tracks as Capitol Corridor from Oakland to Martinez) trains experience major disruptions and would-be passengers are forced to drive rather than take the train.

ENVIRONMENT

In the event of a station taken out of service, greenhouse gas emissions will increase if people are forced to drive instead of taking the train or need to drive further to get to a in-service station instead of one nearby.

Economy

Loss of the Capitol Corridor intercity passenger rail service would affect travellers that use the service to access jobs, goods or services in the cities and metro areas of the Bay Area and Sacramento regions.

Loss of functionality of any one station would not interrupt Capitol Corridor rail service, however disruption of this station would affect passengers that use this station for work and leisure purposes.

Oakland Maintenance Facility

Asset Description: The Oakland Maintenance Facility is located on 3rd Street, in the corner of Interstate 880 and Adeline Street. The facility provides small and large rolling stock maintenance and restocks dining car food items. It services Capitol Corridor, San Joaquin, and a few other Amtrak train routes. The facility was built by a collaboration of Amtrak and Caltrans in 2004, but Amtrak owns the property and manages the facility operations.

Key Issue Statement: The Oakland Maintenance Facility is physically vulnerable to flooding due to the large number of below-grade components, and it is vulnerable to liquefaction during an earthquake due to its geographic location. It is functionally vulnerable to disruptions in the external power supply, and any disruption to the service provided by the maintenance facility will directly impact the passenger train service of the Capitol Corridor route. Any possible resilience or adaptation projects will need multiple permits from various agencies, which could lengthen and complicate the planning and implementation process. The adaptation projects will also be very expensive, as changing one component will necessitate the change of other interconnected components. Increasing resilience of the maintenance facility will likely require a complete overhaul of the entire facility.

Vulnerability Statements

PHYSICAL VULNERABILITIES

PHYS1: The maintenance facility is at risk for liquefaction in an earthquake due to its geographic location. Liquefaction susceptibility increases when the geologic material underneath the railroad track infrastructure is composed of loosely packed sandy or silty materials that are saturated with water. The maintenance facility has significant below-grade asset components in addition to at-grade components, so the magnitude of damage in the event of liquefaction is likely severe.

PHYS2: Many components of the maintenance facility are below-grade and are sensitive to water. The electrical main switch gear is at grade and is very vulnerable to salinity. Electrical equipment (e.g. the wheel truing machine, the Whiting drop table) and fluid storage tanks have no protection against water if underground areas are flooded. There are no existing equipment that can pump water out of the below-grade sunk pits in the event of flooding; the existing sunk pit pumps are not intended to de-water the facility but are used to send industrial water from operational activities (e.g. washing locomotives) to the water treatment system before the water is sent to the sanitary sewer. If water levels in the Bay rises, storm drains would back up since they drain by gravity toward the Bay. Drainage problems may be aggravated by higher groundwater levels as a result of sea level rise. Groundwater levels are expected to rise as Bay water level rise, but the specifics of expected impacts are not yet known due to lack of scientific research on the subject in the Bay Area.

FUNCTIONAL VULNERABILITIES

FUNC1: Operation of the maintenance facility would be affected by a disruption to commercial power supplies, as the equipment and machinery rely upon external power to function. There are no existing alternative power supplies that are available; however, there is currently a request for $1.2 million to build a backup power supply (funding not yet approved).

FUNC2: Any disruption in the ability of the maintenance facility to service trains will have impacts on the overall train service because the maintenance facility is crucial to Capitol Corridor operations. The Oakland maintenance facility services all the Capitol Corridor rolling stock to ensure that they run at optimum performance. The maintenance facility also restocks dining cars with food items. Though there are options to reroute rolling stock to maintenance facilities in other cities, the railroad capacity to transport rolling stock to other locations is limited and may be a challenging issue to resolve. Also, the capacity to service additional trains at the other maintenance facilities is limited.

GOVERNANCE VULNERABILITIES

GOV1: The maintenance facility is subject to multiple performance and/or safety regulations and permits which will likely increase the time and complexity of making changes to the stations. Agencies involved include the Fire Department, Food and Drug Administration, Federal Rail Administration, American Rail Association, California Public Utilities Commission, Amtrak, and the Regional Water Quality Control Board.

GOV2: The maintenance facility is separated from the Bay by the Port of Oakland facilities, which could serve as a barrier to flooding. However, Amtrak and the Port have minimal contact on an operational basis. The only existing relationship involves real estate (Oakland Jack London station and maintenance facility office spaces).

GOV3: Repairs and changes to the maintenance facility require specialized crew, materials, and, at times, custom-built components, thus repairs may not be possible immediately after damages/disruption.

INFORMATION VULNERABILITIES

INFO1: There is no formal information sharing agreement between CCJPA and Amtrak (information is requested on a case-by-case scenario), so acquiring the necessary information for a detailed vulnerability assessment will likely be complicated without Amtrak's active participation.

Consequences

SOCIETY, COMMUNITY, EQUITY

There is vinyl chloride contamination underground near South Prescott Park, which is north of the Oakland maintenance facility. The contamination was partially cleaned up but a large volume still remains. Vinyl chloride is highly mobile in water.

If the maintenance facility is closed for a period of time due to physical damages or recovery work, the income of the workers employed by the facility will decrease. The sensitivity of these workers to decreases in income will need to be investigated.

Air quality would decrease due to increased exhaust from cars during road congestion, which is expected to occur if Capitol Corridor or San Joaquin (which uses the same tracks as Capitol Corridor from Oakland to Martinez) trains experience major disruptions and would-be passengers are forced to drive rather than take the train.

ENVIRONMENT

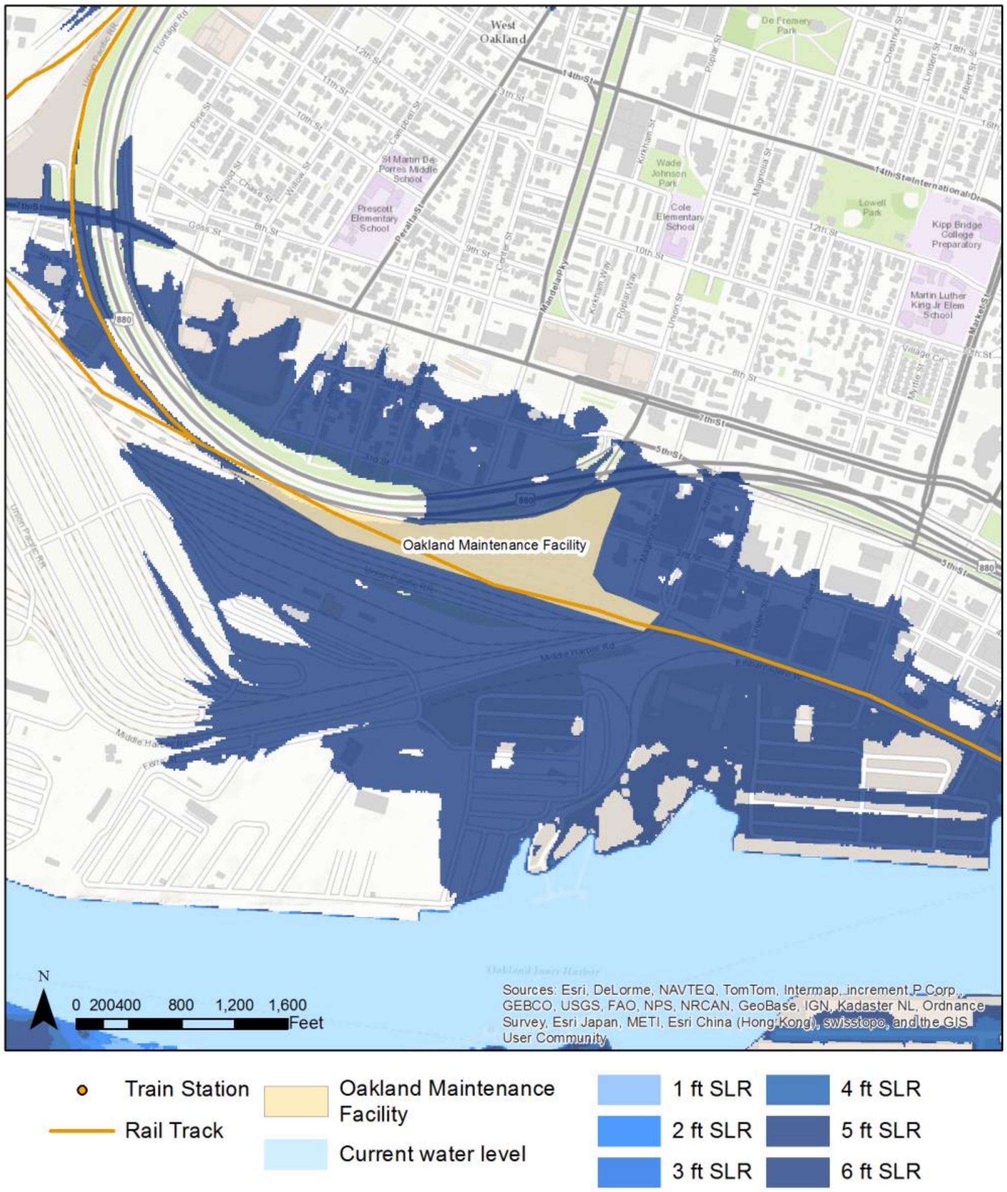
Chemicals used at the maintenance facility may mobilize in floodwaters. Specific chemicals are currently unknown.

ECONOMY

Train delays or cancellations of the Capitol Corridor intercity passenger rail service would affect travellers that use the service to access jobs, goods or services in the cities and metro areas of the Bay Area and Sacramento regions.

Disruption of service of the Oakland maintenance facility would not only affect Capitol Corridor trains, but would also affect San Joaquin trains and other Amtrak trains that are also serviced at the maintenance facility. The San Joaquin route serves a wide geographic area, connecting Sacramento, the Bay Area, and the Central Valley. The Oakland maintenance facility is an important asset to multiple passenger rail services, and any service disruptions to the facility will have wide-ranging impacts on the entire passenger rail system in Northern and Central California.

Oakland Maintenance Facility
0-6 ft Sea Level Rise Inundation Extents



Focus Area Vulnerabilities and Risks

Vulnerabilities and risks were analyzed and presented from the lens of focus areas as well. The different geographic, land use, and property ownership contexts among the focus areas result in different vulnerabilities, different possible resilience and adaptation strategies, and different resilience/adaptation challenges.

Note: The difference between the terms *inundation* and *flooding* must be noted when reading the vulnerability profile sheets. Permanent *inundation* occurs when an area is exposed to regular daily tidal inundation. An area under permanent inundation cannot be used in the same way as an inland area due to the frequency of exposure to sea water. On the other hand, *flooding* occurs when an area is exposed to short episodes of extreme tide events (or storm surge). Inland areas that experience flooding may maintain a portion of their functionality once floodwaters recede. Therefore, flooding, as used in this assessment, refers to temporary inundation conditions as a result of a storm event rather than the permanent inundation due to daily high tides.

Note: Inundation levels, permanent or temporary, can occur through several scenarios of different combinations of sea level rise and extreme high tides/storm surge. Refer to Table 2 for full range of possible scenarios.

Suisun/Fairfield Station

Focus Area Description:

This focus area is located in the northern extents of Grizzly Bay. A major portion of the rail tracks is in existing wetland. The majority of the area is open and natural; however, there are some wildlife hunting clubs scattered among the wetlands. There are also a few private properties with residences adjacent to the tracks in the wetlands. Overall, there is minimal human activity surrounding the tracks in the wetlands.

As the rail tracks approach north toward Suisun/Fairfield station, land use becomes commercial. Office buildings and businesses are located on the east side of the tracks in Suisun City, and the station is accessed by various roads from the north, east, and south.

Key Issue Statement:

The major vulnerability in this focus area comes from the tracks crossing wetlands, which are very likely to be impacted by the effects of sea level rise. Soil subsidence in the wetlands is already a concern and is the cause for much of the current railroad track maintenance. Permanent inundation of the tracks is likely to occur with as little as two feet of sea level rise, and temporary flooding of the tracks may occur with a 5-year extreme storm tide level. The station will be vulnerable to disruption if road access from Suisun City is flooded. Many of the key access roads are expected to be impacted by sea level rise starting at two feet.

Assets in Focus Area:

- Railroad tracks at grade
- Railroad signal system
- Suisun/Fairfield station

Asset Vulnerabilities and Risk:

A major portion of the **railroad tracks** in this focus area lay in existing wetland. The soil in the wetlands is soft and saturated with water; it is not a stable material to build on and creates an existing problems of continual subsidence to the tracks. Union Pacific currently performs frequent maintenance on the embankment and ballast in this wetland area to maintain a level surface for the tracks. The tracks in the wetland are extremely vulnerable to increases in water level, scour and washout during extreme storm events with strong waves and to liquefaction during an earthquake.

The physical vulnerabilities of the **railroad signal system** are directly related to those of the rail tracks, since signal masts and power cabinets are built on the earthen embankment. Some signal system components, such as belowground electric wires are designed to be waterproof and corrosion-resistant. Other components, for example masts and power cabinets, are waterproof but not completely corrosion-resistant and therefore cannot be exposed to salt water.

Some components are neither waterproof nor corrosion-resistant and therefore cannot be exposed to any duration of flooding. Excessive moisture in the subgrade and embankment can cause shortage of the small electrical current running through the track rails, which will cause the signal system to stop operating in that section. In the short term the railroad could institute manual signaling, but this would only be a short term solution and would result in significant delays to freight and passenger trains.

The **Suisun/Fairfield station** is not situated near any bodies of water, but is near the FEMA 1% annual chance flood zone. Road access to the station will be one of the earlier concerns in the progression of sea level rise. Starting at 3 feet of sea level rise, roads needed to access the Suisun/Fairfield station become permanently inundated, and at 5 feet of sea level rise, the station is almost entirely surrounded by water. Temporary flooding of 3 feet can occur with a 25-year extreme storm tide level, and temporary flooding of 5 feet can occur with a 100-year extreme storm tide level on top of a 1 foot sea level rise.

Consequences:

Society, Community, Equity
Petroleum is currently being transferred in pipelines belonging to Kinder Morgan (the pipelines located within the embankment in the Union Pacific right-of-way in the focus area), and, if spilled, could cause human health problems. Destabilization of the railroad embankment could cause distortion and rupture of the pipelines. Relocation and repair of the railroad infrastructure must take into account the presence of the pipelines and other underground utilities, potentially requiring relocation of the lines within the right-of-way. Increasing the height of the railroad embankment can cause additional forces on the underground pipelines, which could lead to rupture. Petroleum has high mobilization potential in floodwater.

Creosote (a wood preservative used on railroad ties) is used as a fungicide, insecticide, miticide, and sporicide to protect railroad ties. EPA has classified creosote as a probable carcinogen. Creosote has medium mobilization potential in floodwater if exposed for an extended period of time.

Air quality would decrease due to increased exhaust from cars during road congestion, which is expected to occur if Capitol Corridor trains experience major disruptions and potential passengers are forced to drive rather than take the train.

Environment
Petroleum is currently being transferred in pipelines belonging to Kinder Morgan, and, if spilled, could cause ecological damage to wildlife and fish. Destabilization of the railroad embankment could cause distortion and rupture of the pipelines. Relocation and repair of the railroad infrastructure must take into account the presence of the pipelines and other underground utilities, potentially requiring relocation of the lines within the right-of-way. Increasing the height of the railroad embankment can cause additional forces on the underground pipelines, which could lead to rupture. Petroleum has high mobilization potential in floodwater.

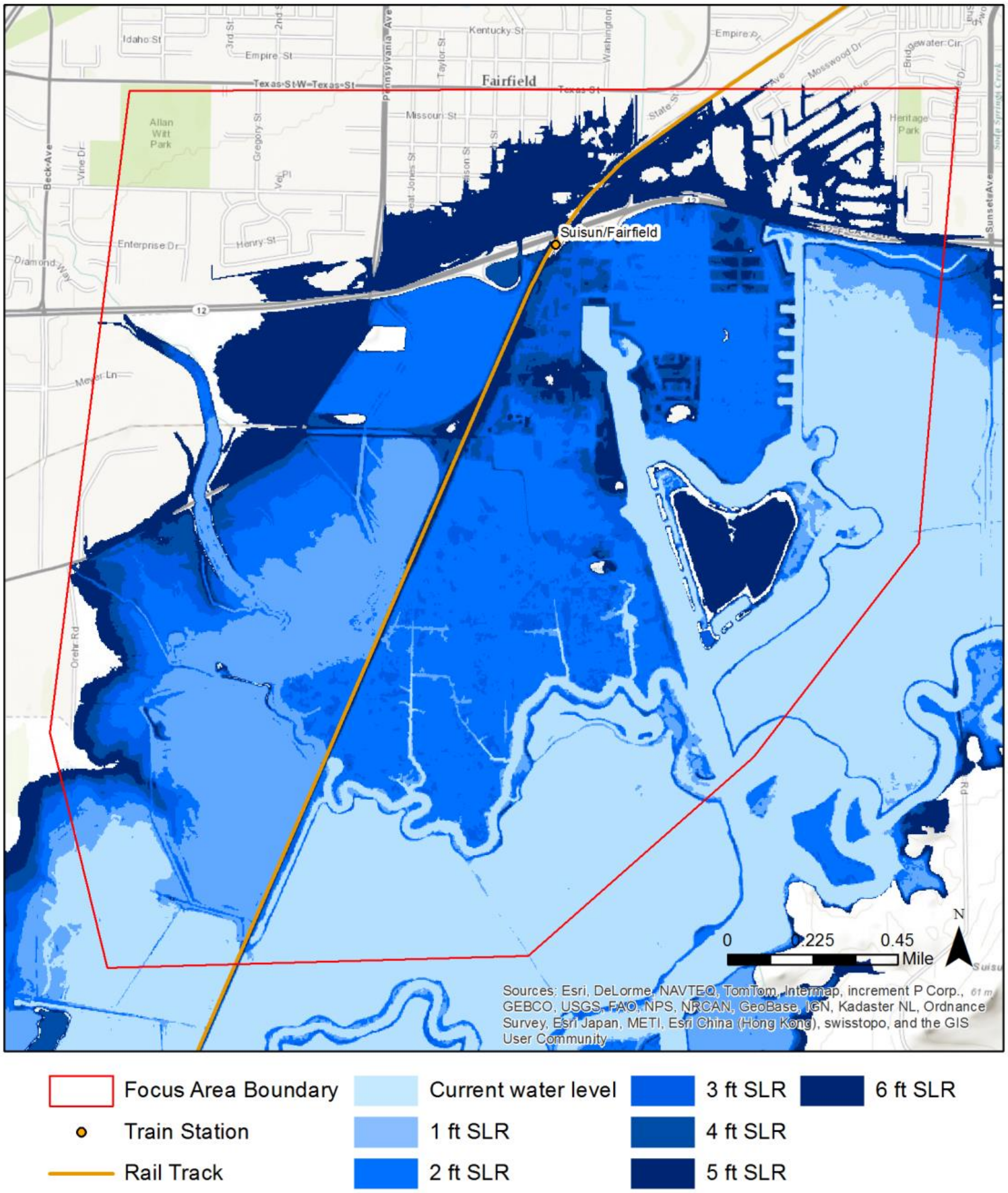
There is phosphorus and other unidentified chemicals buried underneath the ROW near the intersection of Chadbourne Slough and the railroad tracks in Grizzly Bay from a railroad accident in the 1960s. Phosphorus has high mobilization potential in floodwater.

Economy

Loss of the Capitol Corridor intercity passenger railroad service would affect travelers that use the service to access jobs, goods or services in the cities and metro areas of the Bay Area and Sacramento regions.

Disruption of the railroad track in this focus area would not only significantly affect passenger service, it would also disrupt freight operations and affect goods movement as there are not alterative railroad alignments in this geographic region. Disruption of goods movement would have significant negative regional economic impacts.

Suisun/Fairfield Station Focus Area
0-6 ft Sea Level Rise Inundation Extents



Martinez Station

Focus Area Description:

This focus area is centered around the Martinez Amtrak station. The city of Martinez is located on the south edge of Carquinez Strait, and the Martinez station is directly south of the Martinez Regional Shoreline Park, which is mostly marsh. The focus area has a mix of land uses, from industrial and commercial to natural areas. The city of Martinez is southeast of the train station, and regional shoreline parks are to the north and west of the station. From east to west, the rail tracks cross a Shell refinery plant, extend between the Martinez Regional Shoreline and downtown Martinez near the station, and run along the Bay coast with the Carquinez Strait Regional Shoreline Park immediately adjacent inland.

Key Issue Statement:

Permanent inundation becomes a serious risk for the station and the tracks in Martinez starting at 4 feet, or 48 inches, of sea level rise. Temporary flooding of 4 feet of water above MHHW is expected to occur with a 100-year extreme storm tide level with no sea level rise and could also occur with a 50-year extreme storm tide level with 6 inches of sea level rise. The rail bridge crossing Alhambra Creek is vulnerable to flooding either due to permanent sea level rise or storm surge during a strong storm. Many Capitol Corridor passengers board and depart from Martinez (it is the 4th busiest station in the Capitol Corridor system) and, therefore, any impact to the station will cause greater-than-average disruptions to the passenger train service.

Assets in Focus Area:

- Railroad tracks at grade
- Railroad signal system
- Railroad bridge
    - Alhambra Creek
- Martinez station

Asset Vulnerabilities and Risk:

The **railroad tracks** immediately west of the Martinez Station are very vulnerable to sea level rise flooding and liquefaction during an earthquake. Water will approach the tracks via Alhambra Creek and from the direction of the Martinez Regional Shoreline Park from the north.

The physical vulnerabilities of the **railroad signal system** are directly related to those of the rail tracks, since signal masts and power cabinets are built on the earthen embankment. Some signal system components, such as belowground electric wires are designed to be waterproof and corrosion-resistant. Other components, for example masts and power cabinets, are waterproof but not completely corrosion-resistant and therefore cannot be exposed to salt water. Some components are neither waterproof nor corrosion-resistant and therefore cannot be exposed to any duration of flooding. Excessive moisture in the subgrade and embankment can cause shortage of the small electrical current running through the track rails, which will cause the signal system to stop operating in that section. In the short term the railroad could institute manual signaling, but this would only be a short term solution and would result in significant delays to freight and passenger trains.

A **railroad bridge** crosses Alhambra Creek, which runs adjacent to the Martinez Station on the west. The inundation risk of the rail bridge depends on the height of the bridge above the current high tide level (e.g. MHHW) and the flow capacity of the creek, which are currently not known. The bridge is vulnerable to collapse if liquefaction occurs during an earthquake.

The vicinity around **Martinez Station** is very vulnerable to flooding due to its proximity to the marsh. Starting at 5 feet, or 60 inches, of water level above MHHW (equivalent to 5 feet of permanent inundation due to sea level rise, or temporary flooding as a result of a 100-year extreme storm tide level with 1 foot of sea level rise), the parking lot areas of the station as well as the access roads to the station will be inundated, which will impact the functionality of the station, as riders will not be able to safely access the station. The Martinez Station is also very susceptible to liquefaction in the event of an earthquake due to the loose sandy soil underneath the building area.

Consequences:

Society, Community, Equity

Petroleum is currently being transferred in pipelines belonging to Kinder Morgan (the pipelines located within the embankment in the Union Pacific right-of-way in the focus area), and, if spilled, could cause human health problems. Destabilization of the railroad embankment could cause distortion and rupture of the pipelines. Relocation and repair of the railroad infrastructure must take into account the presence of the pipelines and other underground utilities, potentially requiring relocation of the lines within the right-of-way. Increasing the height of the railroad embankment can cause additional forces on the underground pipelines, which could lead to rupture. Petroleum has high mobilization potential in floodwater.

Creosote (a wood preservative used on railroad ties) is used as a fungicide, insecticide, miticide, and sporicide to protect railroad ties. EPA has classified creosote as a probable carcinogen. Creosote has medium mobilization potential in floodwater.

Air quality would decrease due to increased exhaust from cars during road congestion, which is expected to occur if Capitol Corridor or San Joaquin (which uses the same tracks as Capitol Corridor from Oakland to Martinez) trains experience major disruptions and potential passengers are forced to drive rather than take the train.

Environment

Petroleum is currently being transferred in pipelines belonging to Kinder Morgan, and, if spilled, could cause ecological damage to wildlife and fish. Petroleum has high mobilization potential in floodwater.

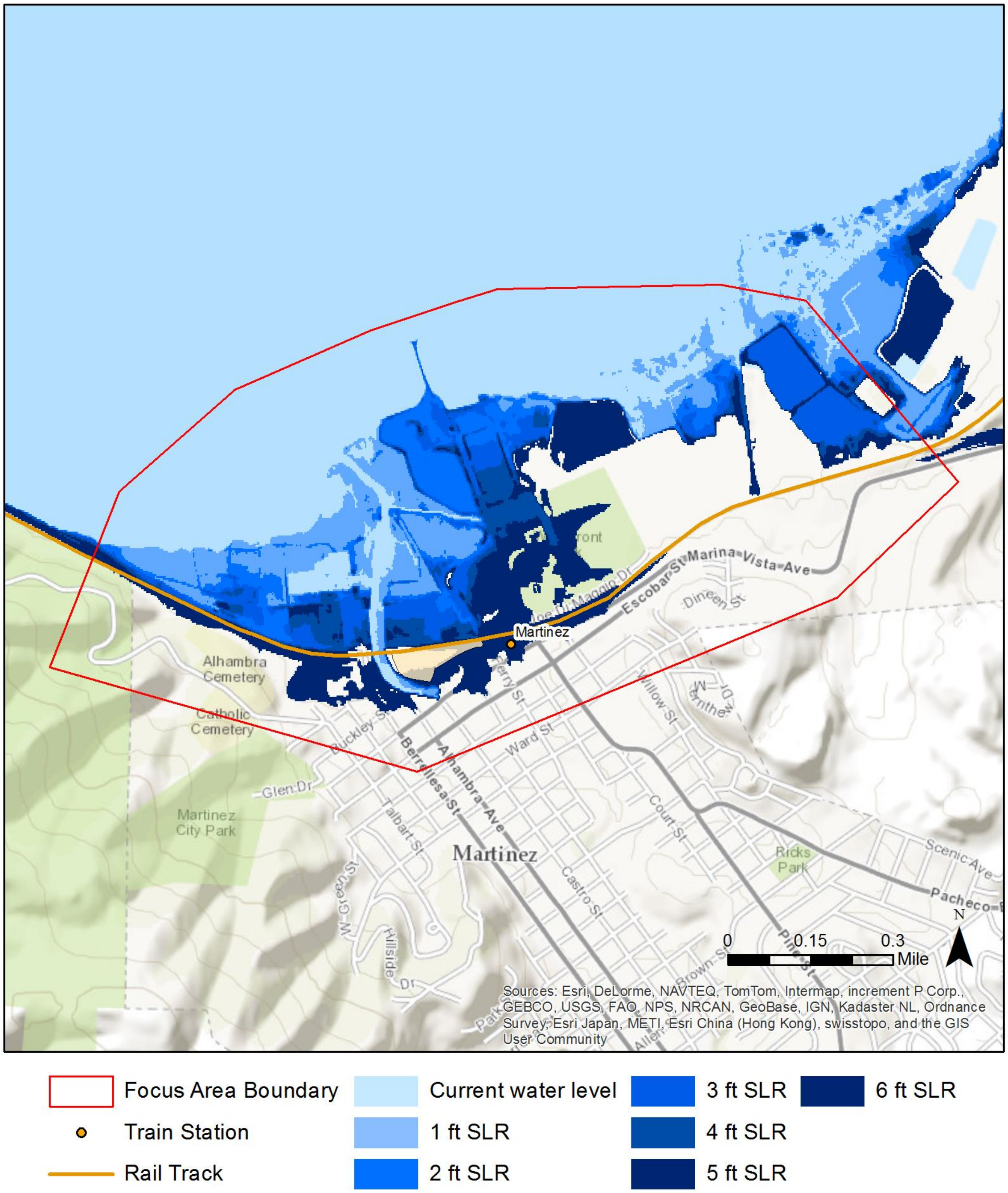
Economy

Loss of functionality of the Martinez Station would not interrupt Capitol Corridor rail service, however disruption of this station would affect passengers that use this station for work and leisure purposes.

Loss of the Capitol Corridor intercity passenger railroad service would affect travelers that use the service to access jobs, goods or services in the cities and metro areas of the Bay Area and Sacramento regions.

Disruption of the railroad track in this focus area would not only significantly affect passenger service, it would also disrupt freight operations and affect goods movement as there are not alterative railroad alignments in this geographic region. Disruption of goods movement would have significant regional economic impacts.

Martinez Station Focus Area
0-6 ft Sea Level Rise Inundation Extents



Point Pinole

Focus Area Description:

The focus area is located in the northwest area of the East Bay, with Point Pinole Regional Shoreline as a major landmark near the western edge and the city of Hercules near the eastern edge. The land use in this focus area is mostly a mix of urban residential and open parks, with a few commercial and industrial sites along the rail track route.

Key Issue Statement:

The key physical vulnerability for the tracks in this focus area is the proximity of the Union Pacific right-of-way to the Bay. During storm events, higher high tides and strong waves due to sea level rise could cause washout of the embankment and water intrusion into the ballast, both of which are major concerns. There are also three rail bridges that may be vulnerable to flooding in the focus area.

Assets in Focus Area:

- Railroad tracks at grade
- Railroad signal system
- Railroad bridges
    - Refugio Creek
    - Pinole Creek
    - Garrity Creek

Asset Vulnerabilities and Risk:

A significant length of **railroad tracks** in this focus area is located on the immediate coastline, with stone riprap as the only shoreline protection. Wave energy can cause washout of track ballast and embankment, and the occurrence of large waves is expected to increase as sea level rises and extreme storms become stronger and more frequent. Accompanied by sea level rise, waves may reach higher elevations than have occurred before, temporarily inundating the railroad tracks. Portions of tracks in the focus area are highly susceptible to liquefaction during an earthquake due to the soft sandy soil that the tracks are built upon.

The physical vulnerabilities of the **railroad signal system** are directly related to those of the rail tracks, since signal masts and power cabinets are built on the earthen embankment. Some signal system components, such as belowground electric wires are designed to be waterproof and corrosion-resistant. Other components, for example masts and power cabinets, are waterproof but not completely corrosion-resistant and therefore cannot be exposed to salt water. Some components are neither waterproof nor corrosion-resistant and therefore cannot be exposed to any duration of flooding. Excessive moisture in the subgrade and embankment can cause shortage of the small electrical current running through the track rails, which will cause the signal system to stop operating in that section. In the short term the railroad could institute manual signaling, but this would only be a short term solution and would result in significant delays to freight and passenger trains.

Three **railroad bridges** exist in the Point Pinole focus area, crossing Garrity Creek, Pinole Creek, and Refugio Creek. The inundation risk of the rail bridge depends on the height of the bridges relative to the current high tide (e.g. MHHW) water level and the flow capacity of the creeks, which are not known yet. The creeks are FEMA-designated floodways, so any proposed plans to alter the bridge or adjacent areas within the floodway will have added regulatory challenges and restrictions.

Consequences:

Society, Community, Equity

Petroleum is currently being transferred in pipelines belonging to Kinder Morgan (the pipelines located within the embankment in the Union Pacific right-of-way in the focus area), and, if spilled, could cause human health problems. Destabilization of the railroad embankment could cause distortion and rupture of the pipelines. Relocation and repair of the railroad infrastructure must take into account the presence of the pipelines and other underground utilities, potentially requiring relocation of the lines within the right-of-way. Increasing the height of the railroad embankment can cause additional forces on the underground pipelines, which could lead to rupture. Petroleum has high mobilization potential in floodwater.

Creosote (a wood preservative used on railroad ties) is used as a fungicide, insecticide, miticide, and sporicide to protect railroad ties. EPA has classified creosote as a probable carcinogen. Creosote has medium mobilization potential in floodwater.

Air quality would decrease due to increased exhaust from cars during road congestion, which is expected to occur if Capitol Corridor or San Joaquin (which uses the same tracks as Capitol Corridor from Oakland to Martinez) trains experience major disruptions and potential passengers are forced to drive rather than take the train.

Environment

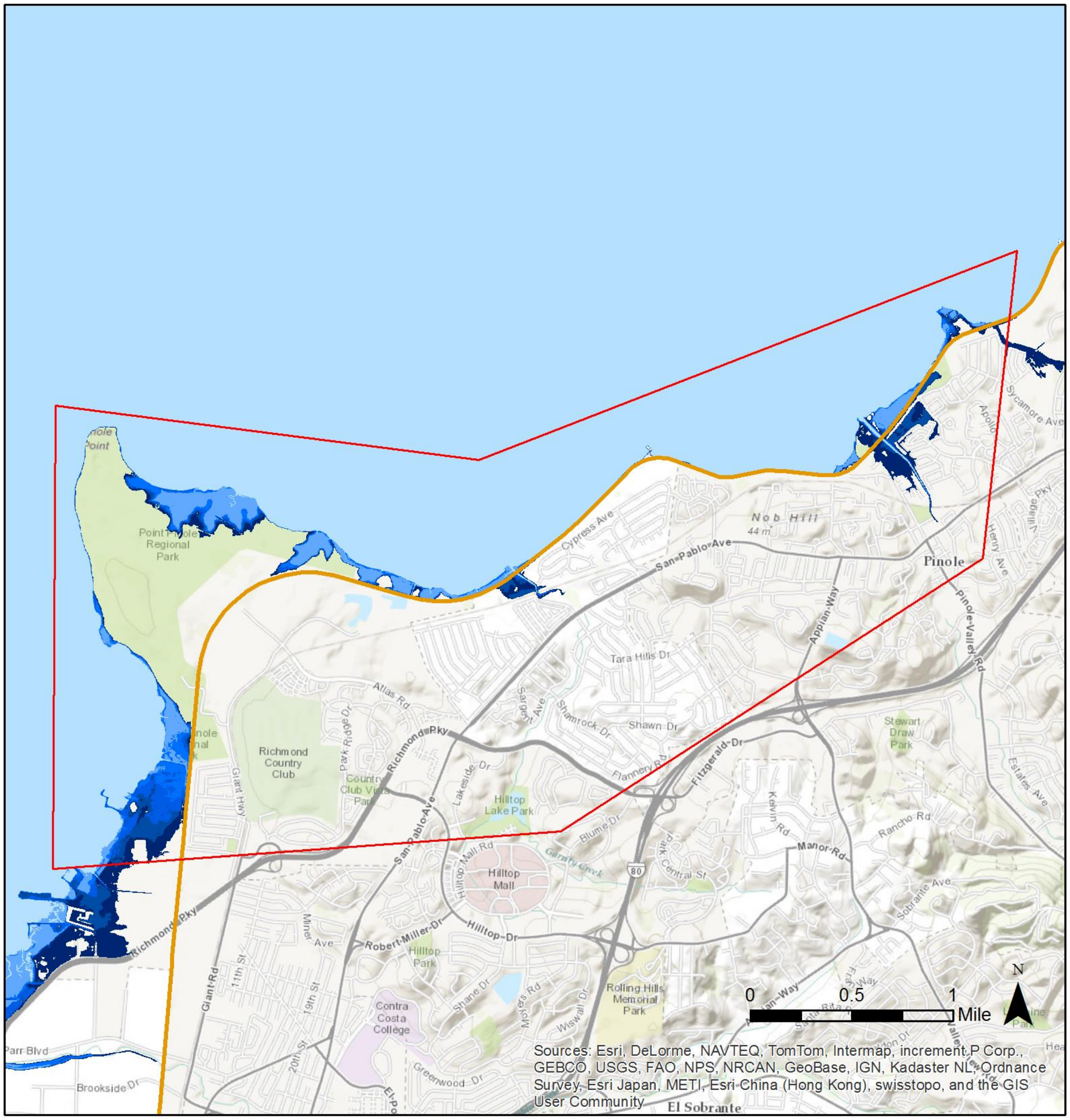
Petroleum is currently being transferred in pipelines belonging to Kinder Morgan, and, if spilled, could cause ecological damage to wildlife and fish. Petroleum has high mobilization potential in floodwater.

Economy

Loss of the Capitol Corridor intercity passenger railroad service would affect travelers that use the service to access jobs, goods or services in the cities and metro areas of the Bay Area and Sacramento regions.

Disruption of the railroad track in this focus area would not only significantly affect passenger service, it would also disrupt freight operations and affect goods movement as there are not alterative railroad alignments in this geographic region. Disruption of goods movement would have significant regional economic impacts.

Point Pinole Focus Area
0-6 ft Sea Level Rise Inundation Extents



Focus Area Boundary
Train Station
Rail Track
Current water level
1 ft SLR
2 ft SLR
3 ft SLR
4 ft SLR
5 ft SLR
6 ft SLR

Oakland

Focus Area Description:

This focus area is centered in a very urbanized area and includes several important assets to the Capitol Corridor passenger train system, such as the Oakland Maintenance Facility. Land use in the focus area is mostly urban commercial and residential, with industrial activities clustered to the west (Port of Oakland).

Key Issue Statement:

Permanent and temporary inundation is a major concern for the tracks in West Oakland and for the section from the Maintenance Facility to Lake Merritt Channel. Rising waters are expected to approach from the Bay Bridge touchdown peninsula and from the Oakland Inner Harbor. Permanent inundation of the tracks near Lake Merritt Channel can occur with 3 feet of sea level rise, and temporary inundation of those tracks can occur with a 25-year extreme storm tide level. Permanent inundation of tracks in West Oakland can occur with 4 feet of sea level rise, and temporary inundation of those tracks can occur with a 100-year extreme storm tide level. The Oakland Maintenance Facility is vulnerable to permanent inundation from a 5 feet sea level rise and to temporary flooding from a 100-year extreme storm tide level with a 1 foot sea level rise. Almost all of the tracks in the focus area are highly susceptible to liquefaction during an earthquake due to the soft sandy soil that the track structure is built upon. The Oakland maintenance facility is also highly susceptible to liquefaction, and the consequences are especially high for the maintenance facility due to the large number of below-grade components.

Assets in Focus Area:

- Rail tracks at grade
- Rail signal system
- Rail bridge
    - Lake Merritt Channel
- Oakland Jack London Station
- Oakland Maintenance Facility

Asset Vulnerability and Risk:

The entire length of **railroad tracks** in the focus area crosses urbanized areas, and some sections are vulnerable to permanent inundation from 4 feet of sea level rise. Temporary flooding of the tracks could occur with a 100-year extreme storm tide level. Almost all of the tracks in the focus area are highly susceptible to liquefaction during an earthquake due to the soft sandy soil that the track structure is built upon.

The physical vulnerabilities of the **railroad signal system** are directly related to those of the rail tracks, since signal masts and power cabinets are built on the earthen embankment. Some signal system components, such as belowground electric wires are designed to be waterproof and corrosion-resistant. Other components, for example masts and power cabinets, are waterproof but not completely corrosion-resistant and therefore cannot be exposed to salt water. Some components are neither waterproof nor corrosion-resistant and therefore cannot be exposed to any duration of flooding. Excessive moisture in the subgrade and embankment can cause shortage of the small electrical current running through the track rails, which will cause the signal system to stop operating in that section. In the short term the railroad could institute manual signaling, but this would only be a short term solution and would result in significant delays to freight and passenger trains.

A **railroad bridge** crosses the Lake Merritt Channel near the southern edge of the focus area. The inundation risk of the rail bridge depends on the height of the bridge relative to the current high tide (e.g., MHHW) water level and the flow capacity of the channel, which are not yet known.

Oakland Jack London station is an important station in the Capitol Corridor route that serves many passengers. The station building and platform are very vulnerable to liquefaction during a seismic event and is vulnerable to permanent inundation with 5 feet of sea level rise. The station building and platform are vulnerable to temporary flooding with a 100-year extreme storm high tide level on top of a 1 foot sea level rise.

The **Oakland Maintenance Facility** is functionally very vulnerable to temporary and permanent inundation because there are many sensitive equipment below-grade, such as the wheel truing machine and the Whiting drop table. The electrical main switch gear, which is at grade, is also very vulnerable to saltwater intrusion. There is no existing equipment that can pump water out of the below-grade pits in the event of flooding, and existing storm drains will likely back up if water levels rise in the Bay, since the drains operate by gravity toward the Bay. The Maintenance Facility is also situated on top of soft and silty soil, which makes it extremely vulnerable to liquefaction. Uneven ground can already be observed today in certain parts of the facility.

Consequences:

Society, Community

Creosote (a wood preservative used on railroad ties) is used as a fungicide, insecticide, miticide, and sporicide to protect railroad ties. EPA has classified creosote as a probable carcinogen. Creosote has medium mobilization potential in floodwater.

Air quality would decrease due to increased exhaust from cars during road congestion, which is expected to occur if Capitol Corridor or San Joaquin (which uses the same tracks as Capitol Corridor from Oakland to Martinez) trains experience major disruptions and potential passengers are forced to drive rather than take the train.

Environment

Oakland Jack London Station has closed and open remediation sites nearby. The mobilization potentials in floodwater of the chemicals or materials at the sites are unknown.

Economy
Loss of functionality of Oakland Jack London Station would not interrupt Capitol Corridor rail service, however disruption of this station would affect passengers that use the station for work and leisure purposes.

Disruption of the Capitol Corridor intercity passenger railroad service would affect travelers that use the service to access jobs, goods or services in the cities and metro areas of the Bay Area and Sacramento regions.

Disruption of the railroad track in this focus area would not only significantly affect passenger service, it would also disrupt freight operations and affect goods movement as there are not alterative railroad alignments in this geographic region. Disruption of goods movement would have significant regional economic impacts.

Oakland Coliseum Station

Focus Area Description:

This focus area is centered around the Oakland Coliseum Station, which is located between the Oakland Coliseum BART station and the O.Co Coliseum. The majority of properties adjacent to the rail tracks and station are commercial and industrial. The four creeks (East Creek Slough, Lion Creek, 73rd Ave Creek, and San Leandro Creek) in the focus area are hydrologically connected to the Bay: two are near the station, and the other two near the outer edge of the area.

Key Issue Statement:

Most of the focus area is very vulnerable to sea level rise due to low elevation and the four creeks that connect to the Bay. Some portions of track are extremely vulnerable to liquefaction as well. The bridges that cross creeks in the focus area would be vulnerable to rising water levels and to strong waves. Inundation of tracks in certain sections may occur with three feet of sea level rise or with a 25-year extreme storm tide level.

Assets in Focus Area:

- Railroad tracks at grade
- Railroad signal system
- Railroad bridges
  - East Creek Slough
  - Lion Creek
  - 73rd Avenue Creek
  - San Leandro Creek
- Oakland Coliseum Station

Asset Vulnerabilities and Risk:

The entire length of **railroad tracks** in the focus area crosses urbanized areas, and almost the entire length is vulnerable to sea level rise inundation and storm event flooding. Some sections are vulnerable to permanent inundation starting at three feet of sea level rise and to temporary flooding with a 25-year extreme storm tide level. The tracks from Lion Creek to 73rd Ave Creek are extremely susceptible to liquefaction.

The physical vulnerabilities of the **railroad signal system** are directly related to those of the rail tracks, since signal masts and power cabinets are built on the earthen embankment. Some signal system components, such as belowground electric wires are designed to be waterproof and corrosion-resistant. Other components, for example masts and power cabinets, are waterproof but not completely corrosion-resistant and therefore cannot be exposed to salt water. Some components are neither waterproof nor corrosion-resistant and therefore cannot be exposed to any duration of flooding. Excessive moisture in the subgrade and embankment can cause shortage of the small electrical current running through the track rails, which will cause the signal system to stop operating in that section. In the short term the railroad could institute manual signaling, but this would only be a short term solution and would result in significant delays to freight and passenger trains.

Open deck timber stringer **railroad bridges** cross Lion Creek, 73rd Ave Creek, and San Leandro Creek. The inundation risk of the rail bridge depends on the height of the bridge relative to the water level at high tide (e.g., MHHW) and on the flow capacity of the creeks, which are not yet known.

Oakland Coliseum station is vulnerable to permanent flooding starting at five feet of sea level rise and is extremely susceptible to liquefaction. Aside from normal commuter passenger service, the station provides a connection to the BART system and serves passengers that attend events at the O.co Coliseum and Oracle Arena.

Consequences:

Society, Community, Equity
Oakland Coliseum Station has closed and open inactive remediation sites nearby. The mobilization potentials in floodwater of the chemicals or materials at the sites are unknown.

Creosote (a wood preservative used on railroad ties) is used as a fungicide, insecticide, miticide, and sporicide to protect railroad ties. EPA has classified creosote as a probable carcinogen. Creosote has medium mobilization potential in floodwater.

Air quality would decrease due to increased exhaust from cars during road congestion, which is expected to occur if Capitol Corridor or San Joaquin (which uses the same tracks as Capitol Corridor from Oakland to Martinez) trains experience major disruptions and potential passengers are forced to drive rather than take the train.

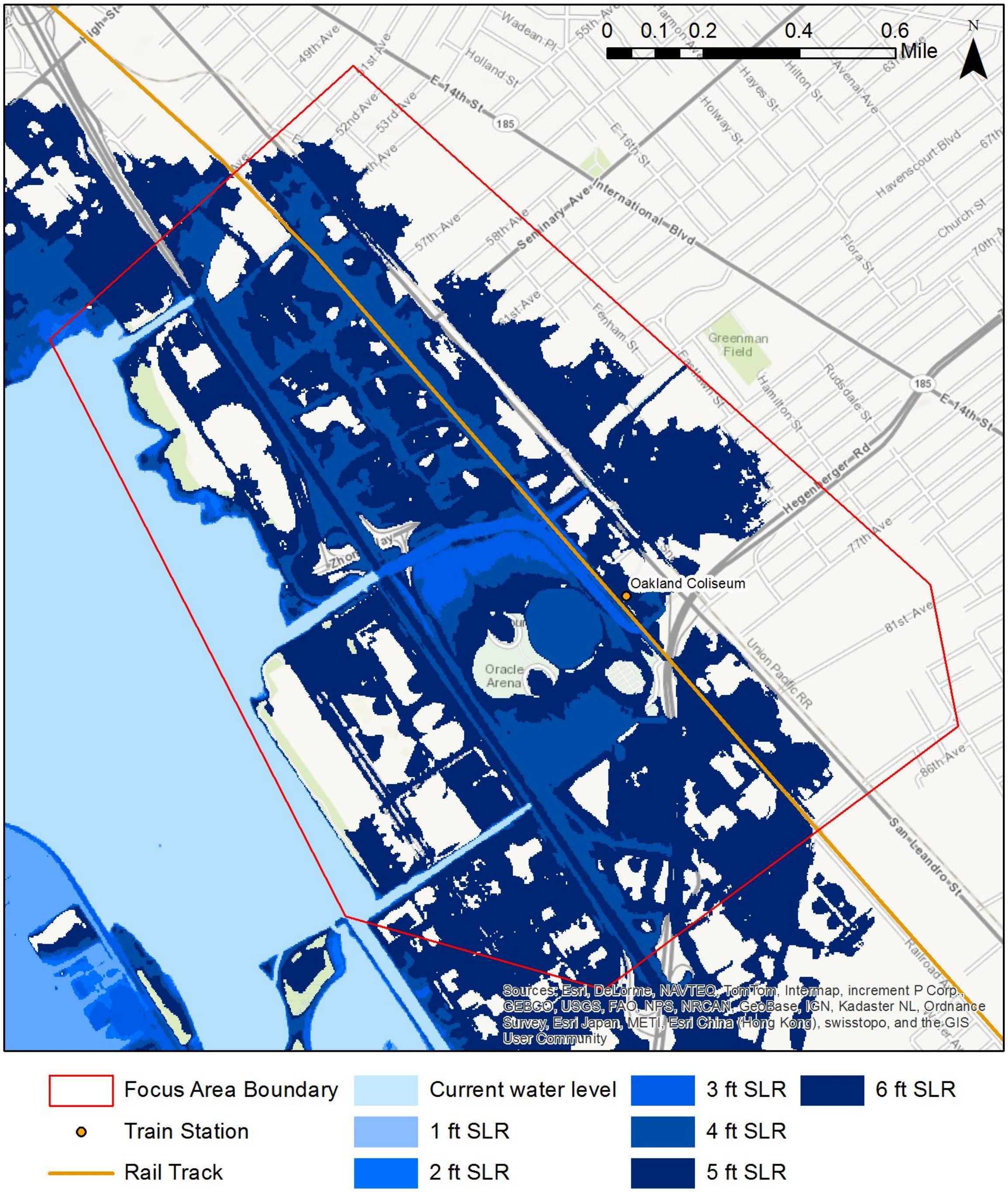
Environment
Oakland Coliseum Station has closed and open inactive remediation sites nearby. The mobilization potentials in floodwater of the chemicals or materials at the sites are unknown.

Economy
Loss of functionality of Oakland Coliseum Station would not interrupt Capitol Corridor rail service, however disruption of this station would affect passengers that use the station for work and leisure purposes.

Disruption of the Capitol Corridor intercity passenger railroad service would affect travelers that use the service to access jobs, goods or services in the cities and metro areas of the Bay Area and Sacramento regions. Disruption of train service to the Oakland Coliseum station specifically will result in loss of revenue to Capitol Corridor JPA, the Athletics, Oakland Coliseum Stadium, and any associated Coliseum Stadium services from decrease in game attendees who access the Coliseum Stadium via Capitol Corridor.

Disruption of the railroad track in this focus area would not only significantly affect passenger service, it would also disrupt freight operations and affect goods movement as there are not alterative railroad alignments in this geographic region. Disruption of goods movement would have significant regional economic impacts.

Oakland Coliseum Station Focus Area
0-6 ft Sea Level Rise Inundation Extents



Alviso/Santa Clara Great America Station

Focus Area Description:

The focus area is located in the South Bay, with the community of Alviso situated in the center of the area. The northern portion of the focus area is dominated by sloughs, which are areas of soft, muddy ground often inundated with water. The sloughs are sectioned into numerous derelict salt ponds. The raised earthen barriers between the ponds keep the water levels in the ponds relatively stable and lessen the effects of strong waves in the inner sloughs.

Key Issue Statement:

The entire focus area is currently vulnerable to flooding, as the area is either in the FEMA 1% or 0.2% annual chance flooding zone. Assets in the slough and in Alviso are vulnerable to permanent inundation starting at 2 feet, or 24 inches, of sea level rise; temporary flooding of 24 inches could occur as a result of a 5-year extreme storm tide level with no sea level rise or as a result of a 1-year extreme storm tide level with 12 inches of sea level rise.

Assets in Focus Area:

- Railroad tracks at grade
- Railroad signal system
- Railroad bridges
    - Mud Slough
    - Coyote Creek
    - Guadalupe River
- Santa Clara/Great America Station

Asset Vulnerabilities and Risk:

A significant length of **railroad tracks** in the focus area cross sloughs, and are extremely vulnerable to sea level rise. Almost all of the tracks in the focus area are moderately susceptible to liquefaction during an earthquake, and the tracks in Alviso are extremely susceptible to liquefaction due to the soft soil underneath.

Three **railroad bridges** are located in the slough area. These bridges are very vulnerable to flooding due to their close proximity to large bodies of water. The inundation risks of the bridges depend on the elevations of these bridges above the current high tide (e.g. MHHW) water level and the flow capacity of the creeks and the channels they cross, which are currently not known.

The **Santa Clara/Great America station** is located under the Tasman Drive overpass in Santa Clara and can be accessed by pedestrians via Bill Walsh Drive and Lafayette Street. The proximity of the station to the new 49er's Levi's Stadium is expected to increase ridership for the station in the near future. The station platform is currently vulnerable to flooding, as it is within the FEMA 0.2% annual-chance flood map zone, and future sea level rise will only increase the frequency and potential extent and depth of flooding that could occur. The station is moderately susceptible to liquefaction.

Consequences:

Society, Community, Equity
Creosote (a wood preservative used on railroad ties) is used as a fungicide, insecticide, miticide, and sporicide to protect railroad ties. EPA has classified creosote as a probable carcinogen. Creosote has medium mobilization potential in floodwater.

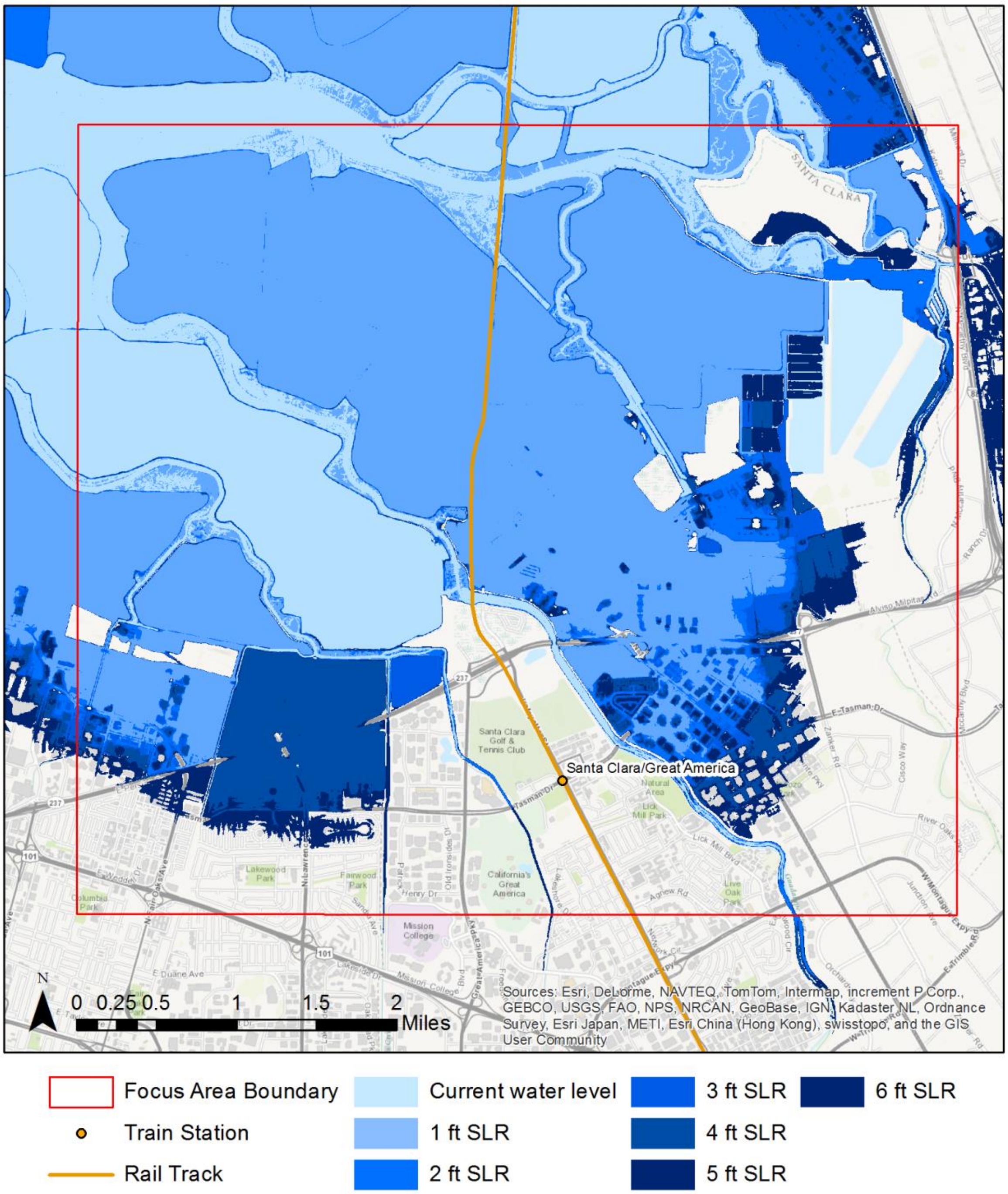
Air quality would decrease due to increased exhaust from cars during road congestion, which is expected to occur if Capitol Corridor or San Joaquin (which uses the same tracks as Capitol Corridor from Oakland to Martinez) trains experience major disruptions and potential passengers are forced to drive rather than take the train.

Environment
None

Economy
Disruption of the Capitol Corridor intercity passenger railroad service would affect travelers that use the service to access jobs, goods or services in the cities and metro areas of the Bay Area and Sacramento regions. Disruption of train service to the Santa Clara/Great America station specifically will result in loss of revenue to Capitol Corridor JPA, the 49ers, Levi’s Stadium, and any associated Levi’s Stadium services from decrease in game attendees who access Levi’s Stadium via Capitol Corridor.

Disruption of the railroad track in this focus area would not only significantly affect passenger service, it would also disrupt freight operations and affect goods movement as there are not alterative railroad alignments in this geographic region. Disruption of goods movement would have significant regional economic impacts.

Santa Clara/Great America Station Focus Area
0-6 ft Sea Level Rise Inundation Extents



Next Steps for CCJPA

Recommended adaptation responses and next steps for CCJPA focus generally on addressing governance and information vulnerabilities, since CCJPA does not own any assets and therefore have no direct control over physical assets. Working with existing stakeholders, communities, and neighbors along the route will be essential for maximizing cost-efficiency and increasing regional climate resilience with future adaptation projects. Coordinated adaptation responses by community and regional stakeholders will be more likely to protect a wider geographic scope of inland assets and ensure that local and regional assets can continue to function as the Bay water levels rise.

CCJPA Internal Organizational Actions

- Expand upon this assessment with future sea level rise research and GIS modeling of normalized shorelines along the entire San Francisco Bay coastline.
    - Our Coast, Our Future (OCOF) is expected to release a new online GIS mapping tool for sea level rise and storms *inside* San Francisco Bay (the NOAA GIS data used in this assessment was for the entire California coast and does not directly include flooding due to storms) in late August or early September 2014. This level of specificity will increase the level of detail for future Capitol Corridor adaptation planning.
    - The AECOM team that created the normalized shoreline data for the Alameda County shoreline has plans to expand the data for the entire San Francisco Bay shoreline given adequate funding. Further details about this project are currently unknown.
- Develop internal CCJPA database of key asset information.
- Develop operational plans for frequent temporary service gaps (e.g. bus bridges) to maintain passenger service where possible, including plans for train
- Set aside future CCJPA funding to assist in sea level rise adaptation projects headed by partner agencies and adjacent communities. These could include maintenance, repair, and retrofit of railroad assets or of shoreline protection infrastructure, which can be hard-engineered (e.g. levees) or soft-engineered (e.g. wetland/estuary restoration).

Working with Partners

- Develop close partnership and adopt a formal data sharing agreement with Union Pacific to fill in information gaps in railroad assets (tracks, signal system, bridges). Information gaps include existing conditions and maintenance records. Knowledge of Union Pacific's asset management system and plans would also be helpful in understanding the vulnerabilities of various railroad assets.
- Develop multi-agency agreements with Caltrain and San Joaquin Joint Powers Authority (SJJPC) to establish shared climate change and sea level rise adaptation objectives. Cost-sharing responsibilities for future adaptation projects can also be discussed.

- Work with adjacent communities and businesses as part of a larger regional adaptation planning process to develop and jointly implement adaptation strategies for climate change and sea level rise impacts. Access to stations and protection of railroad, community, and business assets are key points for joint adaptation strategies.
- Work with communities, Amtrak, and Union Pacific to monitor groundwater and salinity levels near vulnerable assets and increase inspection and maintenance of vulnerable assets.
- Convey to Amtrak and Union Pacific the importance of following existing or developing new standards requiring new construction or repairs of existing assets to use waterproof and corrosion-resistant materials and the need for reliable and adequate backup power to minimize disruptions to critical assets such as the railroad signal system, maintenance facility, and electronic systems at stations.
- Explore adaptation strategies with Amtrak and the State of California for the Oakland Maintenance Facility.

About the Author

Shirley Qian is a Climate Corps Bay Area Fellow whose 10-month fellowship at Capitol Corridor Joint Powers Authority started in October of last year. Her main project at CCJPA is the Sea Level Rise Vulnerability Assessment, and she has worked on the project with the help of the Adapting to Rising Tides team at BCDC and Jim Allison, Manager of Planning at CCJPA.

Shirley is a recent graduate of Cornell University in Ithaca, New York, where she studied environmental science and urban and regional studies.

Appendix A: Annotated Bibliography

Author/Institution	BCDC, MTC, Caltrans
Date	November 2011
Study Name	**Adapting to Rising Tides: Transportation Vulnerability and Risk Assessment Pilot Project**
URL	http://www.mtc.ca.gov/planning/climate/RisingTides-TechnicalReport.pdf
Abstract	This technical report documents the full project process. It is accompanied by a briefing book that summarizes key elements of the project for a more general reader. The remainder of the report is structured as follows, with lessons learned and recommendations for the FHWA on the pilot model integrated into relevant chapters: • Chapter 2, "Asset Inventory Development and Asset Selection," describes the process of developing an asset inventory and collecting relevant data on transportation and shoreline assets, as well as the process of selecting assets for future analysis. • Chapter 3, "Seismic Vulnerability Assessment," describes the seismic vulnerabilities and risk for transportation facilities in the project area from ground shaking and liquefaction of unconsolidated soils and the effect that SLR will have on this seismic risk. • Chapter 4, "Climate Science and Climate Impacts," describes the climate science and climate impacts for the sub-region, as well as the detailed inundation mapping and overtopping analysis carried out for the shoreline assets. • Chapter 5, "Vulnerability and Risk Assessment," describes the vulnerability assessment and risk assessment of the assets identified in Chapter 2. This chapter also includes risk profiles of the selected assets, summarizing the vulnerability and risk-related information gathered. • Chapter 6, "Sea Level Rise Maps," contains the detailed inundation and overtopping maps created especially for the project (as a potential separate pullout). • Chapter 7, "Potential Adaptation Approach," describes a suggested methodology on how to use the information from the risk profiles to determine what type of adaptation measures can be used to address the vulnerability of transportation assets. It includes, as an example,

	descriptions of the methodology used to assess impacts, potential adaptation measures, and nonphysical aspects of climate adaptation for two selected transportation assets. The appendix contains more detailed technical information, including the results of the data inventory, lists of transportation assets, and a description of the mapping methodology.
Key Words	Sea level rise, seismic, transportation, FHWA, vulnerability and risk assessment, adaptation

Research Notes	• Methodology
	  ○ Asset inventory
	  ○ Shoreline asset categorization
	  ○ Inundation mapping/sea level rise maps
	    ▪ Inundation – depth and extent
	      • High tides – Mean Higher High Water (MHHW)
	      • 100-year extreme water levels – Still Water Elevations (100-yr SWEL)
	      • 100-year extreme water levels with wind waves (100-yr SWEL + wind waves)
	    ▪ Overtopping potential
	  ○ Vulnerability and risk assessment
	    ▪ Exposure
	    ▪ Sensitivity
	    ▪ Adaptive capacity

Author/Institution	Federal Highway Administration
Date	December 2012
Study Name	**Climate Change & Extreme Weather Vulnerability Assessment Framework**
URL	http://www.fhwa.dot.gov/environment/climate_change/adaptation/resources_and_publications/vulnerability_assessment_framework/fhwahep13005.pdf
Abstract	The ***Framework*** is a guide for transportation agencies interested in assessing their vulnerability to climate change and extreme weather events. It gives an overview of key steps in conducting vulnerability assessments and uses in-practice examples to demonstrate a variety of ways to gather and process information. The framework is comprised of three key steps: defining study objectives and scope; assessing vulnerability; and incorporating results into decision making.
Key Words	Vulnerability assessment, climate change
Research Notes	Methodology (improved from regional pilots) ○ Asset inventory ○ Identify key climate variables to study ○ Climate inputs for vulnerability assessment Sources for sensitivity and threshold information ○ Design standards or guidelines ○ Performance experience in the past during extreme weather

Author/Institution	California Energy Commission; Greg S. Biging, John D. Radke, Jun Hak Lee
Date	July 2012
Study Name	**Impacts of Predicted Sea-Level Rise and Extreme Storm Events on the Transportation Infrastructure in the San Francisco Bay Region**
URL	http://www.energy.ca.gov/2012publications/CEC-500-2012-040/CEC-500-2012-040.pdf
Abstract	Literature concerning the potential effect of climate change (sea-level rise inundation and 100- year storm events) on the San Francisco Bay region's transportation infrastructure is reviewed. Currently available geographical information system data is employed, and a review of how those datasets have been used in previous studies is reported. The second part of this paper presents methods. They include a higher-resolution digital elevation model for the Bay Area; a new approach using a digital surface model is introduced to improve the surface elevations of features and better calculate the risk of over-topping by sea level shifts and storm surges. A metric to assess change in the transportation infrastructure is introduced that calculates accessibility of first responders to the population at large. Sea level rise is incremented to the expected 1.4 meters in tandem with a 100-year flood to analyze the extent to which transportation assets are at risk of inundation. The increased travel time from first responder locations to all neighborhoods in the region is measured for each iteration of the model. Local accessibility analysis for the entire San Francisco Bay region is performed to provide a synoptic view. Two localities are chosen to view in detail the impact on first-responder accessibility caused by sea level rise and a 100-year storm event. Next, the regional vulnerability of the transportation network to these events is assessed. This is accomplished by creating nodes that are the intersections of the major regional highways that surround the Bay. The loss of accessibility is measured by calculating the changes in travel time between these major nodes through iterations of our inundation model. Finally, the accessibility impacts to the hinterland from the major highway intersections for each peak water level iteration is determined, calculating the first and last 20 minutes of an origin-destination journey.

Key Words	climate change, sea level rise, flooding, inundation, extreme storms, peak water levels, transportation infrastructure vulnerability, ports, airports, roads, accessibility, first responder accessibility, travel time changes, digital elevation model, DEM, digital surface model, DSM, LiDAR, location-allocation
Research Notes	Methodology of potential inundation analyses – water depth and water paths. Estimates of the length of rails at risk to a 100-year flood event combined with different sea level rise scenarios. • PWL(1.4) : 155.7 miles • PWL (0) : 36.3 miles For details, see Table 7. Miles of Rails at Risk to a 100-year Extreme Storm Event by County using Water Depth and Water Paths Analysis

Author/Institution	California Energy Commission; Julia Ekstrom and Susanne Moser
Date	December 2012
Study Name	**Climate Change Impacts, Vulnerabilities, and Adaptation in the SF Bay Area** A Synthesis of PIER Program Reports and Other Relevant Research
URL	http://www.energy.ca.gov/2012publications/CEC-500-2012-071/CEC-500-2012-071.pdf
Abstract	This paper synthesizes San Francisco Bay Area-focused findings from research conducted in 2010–2012 as part of the state's Vulnerability and Adaptation study sponsored by the California Energy Commission's Public Interest Energy Research (PIER) Program. Historical observations of changes already evident are summarized, as well as projections of future changes in climate based on modeling studies using various plausible scenarios of how emissions of heat-trapping gases in the atmosphere may change. Studies synthesized here show how these climate changes increase risks to society and natural ecosystems in a number of ways. Sectors for which impacts, vulnerabilities, and adaptation options are presented include water, agriculture, energy supply and demand, transportation, ecosystems, public health, wildfire, and coastal resources. Results show that depending on the vulnerability of human and natural communities, and their abilities to respond to these growing risks through adaptive changes, the San Francisco Bay Area could experience either significant impacts or maintain its resilience in the face of a rapidly changing environment.
Key Words	San Francisco Bay Area, climate change, adaptation, vulnerability, impacts
Research Notes	• Geography of the area ○ Dry season in the summer and fall and wet winters ○ Variety of geographic features → distinct climatic zones ○ Coastal areas are typically cooler than inland areas, and the northern counties tend to receive more rain than the southern counties. ○ Winter time flooding can occur along the open coast and Bay shoreline during coastal storms and in local watersheds under extended wet conditions when the ground becomes saturated (more common in the North and the South Bay).

	○ The Sacramento-San Joaquin Delta supplies water for agriculture and consumptive uses and supports a high diversity of species and habitat, including tidal marsh ○ Sea level rise ▪ Historical trends • ~0.9 inches (2.2cm) per decade since the 1930s, consistent with global average • Since 1915, the frequency of extreme tides has increased 20-fold ▪ Projections • By 2050, sea level could rise approx. 11-19in over 2000 levels, and by 2100 reach between 30 to 55 in. • Combined with storms, high winds, and waves • 100-year flood would become an annual event by the end of the century

Author/Institution	Caltrans
Date	April 2013
Study Name	**Caltrans Activities to Address Climate Change**
URL	http://www.dot.ca.gov/hq/tpp/offices/orip/climate_change/documents/Caltrans_ClimateChangeRprt-Final_April_2013.pdf#zoom=75
Abstract	This report provides a comprehensive overview of activities undertaken by the California Department of Transportation (Caltrans) to reduce greenhouse gas (GHG) emissions and adapt the state's transportation system to prepare for the impacts of climate change. It also identifies opportunities for additional reductions in GHG emissions and climate adaptation activities that Caltrans may wish to consider in the future.
Key Words	GHG emissions, sea level rise adaptation, State Highway System
Research Notes	EO S-13-08 directs state agencies planning construction projects in areas vulnerable to future sea level rise to consider a range of sea level rise scenarios for the years 2050 and 2100. The order specifically requires Caltrans to collaborate with other state agencies in assessing the vulnerability of transportation systems to sea level rise and identifying ways to maintain the State Highway System in vulnerable areas. The Caltrans Climate Change Branch manages and coordinate's the Department's efforts to reduce GHG emissions and to identify and adapt to climate change impacts. Current projects that relate to sea level rise adaptation include: • Sea Level Rise Hot Spot Map: Map identifies locations along the State Highway System that are likely to vulnerable to sea level rise projections for 2100. • Guidance on Incorporating Sea Level Rise in Project Initiation Documents: First formal guidance provided to Caltrans staff working in coastal areas and describes how to address seal level rise in the early stages of project planning. Currently working on guidance documents for implementation, later phases of project planning and delivery process.

	Possible strategies for railway flooding due to sea level rise: • Design: increase base elevation; strengthen, heighten, and construct new seawalls and dikes; hard engineering and soft engineering measures to protect coastal infrastructure; relocate sections of tracks • Operations/Maintenance: increase monitoring of infrastructure conditions; ensure that drainage systems are adequate for flood conditions; ensure that bridge openings/culverts are clear for appropriate flood management

Author/Institution	Federal Transit Authority (FTA)
Date	August 2011
Study Name	**Flooded Bus Barns and Buckled Rails: Public Transportation and Climate Change Adaptation**
URL	http://www.fta.dot.gov/documents/FTA_0001_-_Flooded_Bus_Barns_and_Buckled_Rails.pdf
Abstract	The objective of this project is to provide transit professionals with information and analysis relevant to adapting U.S. public transportation assets and services to climate change impacts. Climate impacts such as heat waves and flooding will hinder agencies' ability to achieve goals such as attaining a state of good repair and providing reliability and safety. The report examines anticipated climate impacts on U.S. transit and current climate change adaptation efforts by domestic and foreign transit agencies. It further examines the availability of vulnerability assessment, risk management, and adaptation planning tools as well as their applicability to public transportation agencies. The report provides examples of adaptation strategies and discusses how transit agencies might incorporate climate change adaptation into their organizational structures and existing activities such as asset management systems, planning, and emergency response. By focusing specifically on public transportation, and the unique assets, circumstances, and operations of that mode, the report supplements transportation sector wide studies whose scopes did not allow for more in-depth treatment of transit.
Key Words	Public transit, climate change, risk assessment
Research Notes	Report focuses on the impacts of four climate change variables on public transit systems, which usually consists of various assets such as buses and rails. Multiple case studies of transit systems around the country are presented, highlighting the possible impacts that may be experienced as climate change effects increase in the future. *Section 3: Climate Risk Assessments* provides an overview of public transportation related elements of various climate risk assessment frameworks used by governmental agencies. The

	frameworks share a general approach: develop or gather climate projections, establish how those climate changes will impact assets, determine the severity of the impacts, and develop measures to address the high-risk impacts. A list of Adaptation Assessment Guidebooks is provided.

Author/Institution	Metropolitan Transportation Authority (MTA); Klaus Jacob, Cynthia Rosenzweig, Radley Horton, David Major and Vivien Gornitz
Date	October 2008
Study Name	**MTA Adaptations to Climate Change: A Categorical Imperative**
URL	http://www.mta.info/sustainability/pdf/Jacob_et%20al_MTA_Adaptation_Final_0309.pdf
Abstract	The document provides a risk-based framework for adaptations to climate change of the MTA system. The document addresses different climate change impact scenarios and the potential impacts on MTA infrastructure, operations, and policies. Vulnerabilities and challenges faced by different agencies are explored, and short-term and long-term solutions are proposed.
Key Words	Climate change, adaptation assessment, vulnerability assessment, MTA, New York
Research Notes	Steps in adaptation assessment: • Identify MTA facilities and programs subject to climate risk • Identify main climate change impacts to MTA facilities and programs • Apply future climate change scenarios by time slice • Characterize adaptation options: management and operations adaptations, infrastructure investments, and policy change • Conduct initial feasibility screening • Link to capital replacement and rehabilitation cycles • Evaluate options: benefit/cost analysis, environmental impacts • Develop implementation plans, including timeframes for implementation • Monitor and reassess adaptation strategies according to unfolding of climate change and developments in climate science The report includes a cursory listing of the key vulnerabilities of MTA's facilities and operations; input was provided on an ad hoc basis (without the normally required engineering vigor) by the various MTA agencies and affiliates. Thorough engineering and management assessments of the

	asset vulnerabilities will need to be performed in the future. Most relevant MTA asset to Capitol Corridor sea level rise adaptation study is the Metro North Railroad (MNR) and Long Island Rail Road (LIRR). MNR and LIRR staff mostly focuses on maintaining and improving day-to-day operations and can devote little time to projecting future climate hazards to design future strategic plans. The staff is not generally familiar with future climate trends, tides, flood probabilities, and related adaptation options and do not have the engineering expertise to provide the specialized analysis needed for a climate change adaptation analysis. However, the staff can provide data on past operational experiences during extreme weather events. Climate change adaptation policies and performance standards should be mandated by the MTA central management is the sentiment shared by most of the MTA operating agencies, including MNR and LIRR.

Author/Institution	National Research Council of the National Academies; Committee on Sea Level Rise in California, Oregon, and Washington, Board on Earth Sciences and Resources and Ocean Studies Board, Division on Earth and Life Studies
Date	2012
Study Name	**Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future**
URL	http://www.nap.edu/catalog.php?record_id=13389
Abstract	This report evaluates changes in sea level in the global oceans and along the coasts of California, Oregon, and Washington for 2030, 2050, and 2100. Chapter 2 describes methods for measuring sea level and presents recent estimates of global sea-level rise. Chapter 3 updates the IPCC (2007) estimates of the major components of global sea-level change— thermal expansion of ocean water, melting of glaciers and ice sheets, and transfers of water between land reservoirs and the oceans. Chapter 4 assesses the factors that influence sea-level change along the U.S. west coast, including regional changes in ocean circulation, climate-induced changes in storms, gravitational and deformational effects of land ice change, and vertical land motions. Chapter 5 summarizes recent projections of global and regional sea-level rise and presents the committee's projections for 2030, 2050, and 2100. Chapter 6 summarizes the literature on natural shoreline responses to and protection from sea-level change.
Key Words	Climate change, sea level rise, California, Oregon, Washington, coastline
Research Notes	Of special interest to the Capitol Corridor SLR Adaptation Project are responses of the natural shoreline, especially coastal cliffs and bluffs and estuaries and tidal marshes, to SLR. Coastal cliffs and bluffs: the rate of coastal cliffs and bluffs retreat is controlled by the properties of the rock materials and the physical forces acting on the cliffs. Granitic or volcanic rock is less susceptible to weathering than sedimentary rocks or unconsolidated materials. The physical forces driving erosion include marine processes (wave energy and impact, tidal range or sea-level variations) and terrestrial processes (rainfall and runoff, groundwater seepage, landslides, rockfalls,

	etc.). Estuaries and tidal marshes: The San Francisco Bay-Delta is a large estuary and numerous tidal marshes (herbaceous wetlands frequently or continually inundated with fresh, brackish, or saline water) are found along the estuarine embayments. Estuaries are comprised of three ranges: subtidal (permanently flooded) areas, intertidal flats (unvegetated area regularly exposed by falling tides), and vegetated marshes. The transition between these ranges depends on the interaction of tides with the local topography. Sea level rise may change the tidal dynamics within the estuary, including tidal range. The response of flats and marshes to sea level rise depends on the balance between submergence, erosive forces, and sediment supply, and is mediated by climatic influences on biotic processes. Tidal flats will be more resistant against erosion with increased vegetation and other biota (e.g. clams). The Case Study on the California Bay-Delta on page 130 is a worthy read. The committee's projected sea level rise for the SF Bay Delta is 93 cm by 2100; highest projections are 1.6m by 2100.

Author/Institution	National Research Council of the National Academies; Committee on Climate Change and U.S. Transportation, Transportation Research Board, Division on Earth and Life Studies
Date	2008
Study Name	**Potential Impacts of Climate Change on U.S. Transportation:** Transportation Research Board Special Report 290
URL	http://onlinepubs.trb.org/onlinepubs/sr/sr290.pdf
Abstract	The primary focus of this report is on the consequences of climate change for the infrastructure and operations of U.S. transportation. The report provides transportation professionals with an overview of the scientific consensus on those current and future climate changes of particular relevance to U.S. transportation, including the limitations of present scientific understanding as to their precise timing, magnitude, and geographic location; identifies potential impacts on U.S. transportation and adaptation options; and offers recommendations for both research and actions that can be taken to prepare for climate change. The report also summarizes previous work on strategies for reducing transportation-related emissions of carbon dioxide (CO_2)—the primary GHG—that contribute to climate change, a relatively well-researched area.
Key Words	Climate change, sea level rise, transportation, adaptation responses, adaptation strategies
Research Notes	*Chapter 4: Challenges to Response* is a good background reading for how the U.S. transportation system is organized and how investment and operating decisions are made. Railroads are privately owned and operated and the federal government has regulatory oversight over safety. Rail tracks are designed for up to 50 years of use. Opportunities for adaptation are fewer for longer-lived assets, which are rehabilitated or retrofitted at longer intervals. The most important design decision is where to locate an asset initially; relocating the right-of-way (ROW) would be enormously expensive. One of the challenges of climate change adaptation within the transportation sector is the differences in planning horizons in view of climate change timelines. Many transportation planners perceive that impacts of climate change will be experienced well beyond the time frame of their longest-term plans without realizing that the impacts are occurring and that investment

	decisions made today will affect how well the infrastructure accommodates these and future changes. The uncertainly that is inherent within climate change predictions also makes planning and designing difficult for transportation planners, who are more used to focusing on “knowns”, or the “best available” forecasts. Another challenge for climate change adaptation for transportation is the poor alignment between climate change impacts, which are widespread across physical distance and functional modes, and the current transportation organizational arrangements, which is often decentralized and modally focused. The report introduces a decision framework for addressing climate change for transportation planners. The decision framework performs assessments of the hazards, assets, and consequences (related to susceptibility and risk). California’s seismic retrofit program for bridges is presented as a case study of a decision framework to assess which bridges are to be retrofitted and to what extent of risk they are to be retrofitted for. Concepts such as acceptable performance standard or level of risk are introduced. *Chapter 5: Adaptation Responses* provides an overview of various adaptation strategies. Operational responses are the most rapid time-wise and involve changes in transportation operating and maintenance practices.

Author/Institution	U.S. Climate Change Science Program; Michael J. Savonis (FHWA), Virginia R. Burkett (US Geological Survey), Joanne R. Potter (Cambridge Systematics)
Date	March 2008
Study Name	**Impacts of Climate Change and Variability on Transportation Systems and Infrastructure: Gulf Coast Study, Phase I**
URL	N/A
Abstract	This study has investigated the questions of what risks the U.S. transportation network system faces from climate change and possible adaptation and resilience plans planners and policymakers can adopt through a case study of a segment of the U.S. central Gulf Coast. The research, sponsored by the U.S. Department of Transportation (DOT) in partnership with the U.S. Geological Survey (USGS), has been conducted under the auspices of the U.S. Climate Change Science Program (CCSP). The study is 1 of 21 "synthesis and assessment" products planned and sponsored by CCSP. The interdisciplinary research team included experts in climate and meteorology; hydrology and natural systems; transportation; and decision support.
Key Words	Climate change, sea level rise, transportation, adaptation responses, adaptation strategies, Gulf Coast, Houston, New Orleans, Mobile, AL
Research Notes	The Gulf Coast study area, extending eastward from the Greater Houston-Galveston area to Mobile, Al, is an important hub for the transport of goods with an extensive system of rail and pipeline network. Most of the rail activity is freight; passenger rail service is very light. Of the Amtrak rail lines, the Sunset Limited routes between Mobile and New Orleans on the CSX-owned track and between New Orleans and Houston on the UP-owned track are at risk from sea level rise. Hurricane Katrina and the associated storm surge caused damage to all of the major railroads in the study area. The Hurricane Katrina and Rita case studies are interesting to read and offer a glimpse of potential storm damage due to strong precipitation and wind events.

Author/Institution	Federal Highway Administration (FHWA); ICF International
Date	June 13, 2011
Study Name	**Assessing Criticality in Transportation Adaptation Planning**
URL	N/A
Abstract	This memorandum discusses the common challenges associated with assessing criticality, options for defining criticality and identifying scope, and applying criteria and ranking assets.
Key Words	Criticality, adaptation planning, transportation
Research Notes	To understand criticality, the purpose and intended audience of the criticality assessment need to be defined and understood first. What are the assets of concern? What is the study area? What is considered a significant loss? Defining the scope of the project involves determining how many critical assets to identify and how to draw the spatial, temporal, modal, ownership, and other parameters of the study. The criticality of an asset depends both on its physical characteristics and on its function in multiple systems. Criticality may also include important auxiliary systems such as electricity transmission and distribution systems and communication systems. Three approaches to criticality assessment: • Desk review: emphasizes objectivity and quantitative information based upon readily available data sources; require little local knowledge to apply in asset ranking • Stakeholder elicitation: elicit criticality input from a group of stakeholders with expert knowledge of specific interests; results highly subjective; outcome dependent on quality of workshop facilitation, composition of workshop attendees, and participation of key experts; early buy-in from stakeholders. • Hybrid approach: begins with desk review and then use results to inform and structure feedback from stakeholders and local experts.

Author/Institution	Federal Highway Administration (FHWA); ICF International
Date	May 31, 2011
Study Name	**Assessing the Sensitivity of Transportation Assets to Climate Change in Mobile, AL** Impacts of Climate Change and Variability on Transportation Systems and Infrastructure: The Gulf Coast Study, Phase 2
URL	N/A
Abstract	The purpose of this stage of the Gulf Coast Project, Phase 2 was to review transportation assets in Mobile, Alabama and to qualitatively assess their sensitivity to changes in climate. To address these objectives we created two products: (i) a ***Sensitivity Matrix*** that identifies relationships, thresholds, and indicators of sensitivity for transportation assets, and (ii) a ***Sensitivity Screen*** that planners and decision makers can use to quickly assess whether transportation assets are sensitive to certain climate stressors. This final report describes these two products, presents the methodology for their development, and provides key conclusions derived from them.
Key Words	Sensitivity, transportation, Gulf Coast Project, Mobile AL, sensitivity matrix, sensitivity screen, climate change adaptation
Research Notes	Sensitivity is difficult to define and assess because it is locally-defined and depends on contexts and relationships that are difficult to generalize. The *Sensitivity Matrix* is organized according to climate variable groupings and have four columns each: important impact-asset relationships, threshold, Mobile-specific detail, and potential indicators of sensitivity. The Important Impact-Asset Relationship column qualitatively describes stressors between the climate variable and the sub-mode. The Threshold column includes any specific information about the exposure level at which damage to the sub-mode may begin increasing. Historical context relevant to Mobile is placed in the Mobile-Specific Detail column, and the Potential Indicators of Sensitivity column contains a list of indicators that have been associated with increased sensitivity to that climate stressor in the past. Methodology of the development of the

	Sensitivity Matrix is included in the report. Expert consultants, design standards and guidelines, and historical data/analogues were sources of information in filling out the matrices. The *Sensitivity Screen* is a complementary tool developed from the *Matrix* and shows layers of information: • A grid listing the climate variables in columns, and the transportation modes and sub-modes in rows • A color-coded mapping of the sub-modes that were found to exhibit sensitivity to specific climate stressors in the *Matrix* • A layer of quantitative information on climate variable thresholds above which impacts may be more severe The *Screen* allows planners and decision-makers to screen out sub-modes that were not found to exhibit sensitivity to certain climate stressors in the *Matrix* and layer climate projections onto the screen to identify where future climate variables are likely to exceed current thresholds. *Railroad and auxiliary assets: electrical equipment (gates, flashers, and signal bungalows), railroad ties, railroad tracks (steel and wooden), services, and operations.

Author/Institution	Federal Highway Administration (FHWA); ICF International
Date	September 1, 2011
Study Name	**Assessing Infrastructure for Criticality in Mobile, AL** Impacts of Climate Change and Variability on Transportation Systems and Infrastructure: The Gulf Coast Study, Phase 2
URL	N/A
Abstract	This report summarizes the methodology and findings of Task 1 of Phase 2 of the Gulf Coast Study. Task 1 was to identify the transportation infrastructure components that are critical to the Mobile, AL region. While Phase 1 took a broad look at the entire Central Gulf Coast region between Houston/Galveston and Mobile with an overview of the climate-related challenges facing infrastructure, Phase 2 focuses on Mobile, AL. The study area includes Mobile County (including Dauphin Island) and the crossings of Mobile Bay to the east to landfall in Baldwin County.
Key Words	Criticality, transportation, Gulf Coast Project, Mobile AL
Research Notes	“Critical” infrastructure was defined by this study as infrastructure that serves to keep the mobility and accessibility functions of the transportation network viable as they enable the economic and social activities in the study area. The framework for assessing criticality was based on three criteria: socioeconomic (e.g. community livability and viability, economic viability), use and operational characteristics (e.g. Average Daily Traffic, tonnage, and ridership), and health and safety (e.g. access to health facilities, evacuation routes). Criteria for evaluating the criticality of assets within each mode were developed with input from transportation specialists. Socioeconomic criteria: • component of national/international commerce system • important multi-modal linkage • functions as community connection • lack of system redundancy

	• serves area economic centers Use/Operational criteria for transit: • Ridership • Customer facilities/Stations • Intermodal connectivity • Garage and maintenance facilities

Author/Institution	National Research Council of the National Academies; Committee on Understanding and Monitoring Abrupt Climate Change and its Impacts, Board on Atmospheric Studies and Climate, Division on Earth and Life Studes
Date	December 2013
Study Name	**Abrupt Impacts of Climate Change: Anticipating Surprises**
URL	http://www.nap.edu/catalog.php?record_id=18373
Abstract	The current rate of carbon emissions is changing the climate system at an accelerating pace, making the chance of crossing tipping points all the more likely. The question is now whether the surprises can be anticipated, and the element of surprise reduced. The report addresses both abrupt climate changes in the physical climate system, and abrupt climate impacts that occur in human and natural systems from a steadily changing climate.
Key Words	Climate change, tipping point
Research Notes	Abrupt climate changes already underway: disappearance of late-summer arctic sea ice and increases in extinction rates of marine and terrestrial species. Abrupt changes of unknown probability: destabilization of the West Antarctic Ice Sheet. Abrupt changes unlikely to occur this century: disruption to the Atlantic Meridional Overturning Circulation (AMOC) and potential abrupt changes due to high-latitude methane. Overall, sea level rise from different factors (ocean thermal expansion, destabilization of WAIS ice sheets and other ice sheets) is not expected to experience abrupt change within this century. Ocean thermal expansion and ice loss from land is expected to increase sea level gradually. However, deep uncertainty persists about the likelihood of a rapid ice-sheet “collapse” contributing to a major acceleration of SLR; for the coming century, the probability of such an event is generally considered to be low but not zero.

Appendix B: Asset Vulnerability Metrics

Existing conditions metrics describe the asset and highlight any conditions or stressors that could affect the asset's vulnerability to sea level rise and storm events or ground shaking or liquefaction from seismic activity.		
Questions	**Responses**	**Data Source(s)**
1. Where is the asset located?		
2. Briefly describe the asset and its functions. *If asset is made up of several elements (e.g., ballast, culverts, etc.) make a note of them and their functions.*		
3. Who owns and who manages the asset? *Make a note if the asset has different owners and managers.*		
4. How old is the asset and what is its remaining service life? *If different components of the asset have a different remaining service life, include that information.*		
5. What is the general condition of the asset? *Is it maintained routinely? Is it currently affected by flooding during high tides or storms? Are there problems with erosion, groundwater, or saltwater intrusion? Has the asset been seismically retrofitted at any point in its life? If so, when, and what was done?*		

Physical characteristics vulnerability metrics help determine whether an asset or asset category has vulnerabilities due to how an asset is designed or built.		
Questions	**Responses**	**Data Source(s)**
1. Is asset in current 100-year floodplain? (answers may vary with focus area)		
2. Is the asset or a component of the asset in an area of fill, loose or sandy soils, or a high water table that is at risk for liquefaction in an earthquake?		
3. Is the asset or a component of the asset located in any State-mandated "Zone of Required Investigation" such as an earthquake fault zone, liquefaction seismic hazard zone, or earthquake-induced landslide zone?		
4. Does the asset cross tidal creeks or the Bay?		
5. Are any components of the asset at-grade or below-grade (e.g., pipes, tubes, tunnels, ventilation grates)? If so, are they sensitive to water or saltwater (e.g., electrical components)? Are they waterproof, corrosion-resistant, or otherwise protected from water and saltwater?		
6. Are any elements of the asset that are at-grade or below-grade (e.g., tubes, tunnels, ventilation grates, switchgears, electrical or mechanical components) sensitive to wave action or easily eroded?		
8. How accessible are asset components for monitoring, maintenance, mitigation, or		

replacement? *For example, are components underground, such as tunnels?*		
9. Is the asset co-located with other assets that require coordination for access or repairs, or where coordinated access would be beneficial? *For example, roadways and rights-of-way co-located with buried pipelines, transmission lines or data cables.*		
10. Are there opportunities for reengineering the asset to make it more resilient or would it require replacement?		
11. Is the asset currently under consideration or planned for improvement, or is it in an area that is planned for future development / redevelopment?		

Functional characteristics vulnerability metrics help determine whether an asset or asset category is vulnerable due to its functions and relationships with other assets and asset categories.		
Questions	**Responses**	**Data Source(s)**
1. What is the current level of use? *For example, train frequencies, ridership, etc.*		
2. What is the projected future level of use?		
3. Is the asset a critical access route? *For example, does it provide access to an airport, seaport, or other critical regional asset?*		
4. Is the asset an emergency or lifeline route?		
5. Is the asset a sole or limited access route? *For example, is it the only way to or from a neighborhood?*		
6. What is the peak period traffic volume, direction, use, and ridership? When and how often does that peak traffic occur?		
7. Describe any redundancy in the system that would allow the system to continue to function if one asset is disrupted. *For example, alternative routes, bus bridges, etc.*		
48 For assets that rely on power to function (e.g., signaling system), are there resilient or alternative power supplies? If so, how long will alternative power supplies last? *For example, a generator with sufficient fuel*		

that is protected from flooding/storm event impacts.		
9. How has the asset performed historically during floods or seismic events?		
10. Is the asset connected to other assets, such that failure in one part of the system could disrupt the entire system? *For example, long, linear assets such as rail.*		

Governance vulnerability metrics help determine whether an asset or asset category is vulnerable due to challenges with management, regulation, or funding.		
Questions	**Responses**	**Data Source(s)**
1. Describe any plans that are relevant to asset management or improvement and their status. *For example, Master Plan, Capital Improvement Plan, etc.; when was the last update? How frequently is it updated?*		
2. Describe any systems that are in place that help the organization manage its assets, and their status. *For example, infrastructure database that tracks build and upgrade dates, O&M tracking and reporting system, etc.; how frequently are they reviewed or updated?*		
3. Describe if and how management plans and asset management systems are integrated. *For example, are planning documents up-to-date and used to guide O&M, financing, reporting, etc.?*		
4. Has any seismic assessment of other hazard assessment been conducted for the asset? If so, how does this inform future maintenance, improvements, or capital planning?		
5. What performance and / or safety regulations is the asset currently subject to?		

6. What types of permits are necessary to make changes to the asset? Which agencies would need to be involved?		
7. What is the ownership status of the asset? *Does the asset owner own the property where the asset is located? If not, what is the relationship between the asset owner and the property owner? Is there a right-of-way, access easement, or other agreement?*		
8. Is the asset part of an interconnected system that is owned by another entity? If so, what is the nature of the interconnection? What is the relationship between the asset owner/manager and the owner/manger of interconnected infrastructure? *For example, roadways that have utility corridors or rights-of-way, stormwater easements, etc.*		
9. Is the asset protected from flooding by land or assets owned by other entities? If so, what is the relationship between the asset owner and the other entities? Do they coordinate and share information and decision-making? *For example, a rail segment owned by Union Pacific, protected by a levee owned by a park district.*		
10. What funding sources currently exist that can be used to assess asset vulnerability and / or to adapt (retrofit or replace) assets? What funding restrictions exist that could limit managers' capacity to plan for climate change		

or seismic events?		
11. What resources (aside from funding) does the asset require for repair? *For example, would it require specialized or large amounts of materials, a large crew, specialized expertise?*		
12. Is the asset currently under consideration for improvement, or is it in an area that is planned for future development / redevelopment?		
13. What are the ongoing operations and maintenance costs for the asset or asset system?		
14. What are the average annual capital improvement costs for the asset or asset system?		
15. If the asset has suffered a service disruption in the past, what were the costs (due to disruptions of services, not to repair the asset)?		
16. If the asset has been damaged or has lost function in the past, what were the costs to repair it?		
17. What would it cost to retrofit, replace, or rebuild the asset or asset system?		
18. If the asset were damaged, what would the cost be to rebuild in place to current codes and standards?		

Information vulnerability metrics help determine whether there are any ways in which an asset or asset category is vulnerable due to lacking, incomplete, or poorly coordinated information. Any challenges you encountered in gathering data for the above sections may inform your answers to the questions below.		
Questions	**Responses**	**Data Source(s)**
1. What types of information sources necessary to conduct a vulnerability and risk assessment are publicly available? *Examples: databases with asset owner and manager, location, and condition of assets such as roads, rail, paths, and public transit infrastructure; geo-referenced (GIS) data, etc.*		
2. What types of mechanisms exist to share information between owners of interconnecting or interdependent transportation infrastructure? *Examples: information sharing agreement*		
3. What is the quality of available information? *For example: is it up-to-date? Has it been quality checked? Is it at the planning level or the site or project level? Is it sufficiently reliable to use for decision-making?*		
4. Where information sources are not publicly available, is it available to asset owners and relevant regulatory agencies?		

Consequences metrics help understand the potential consequences of a climate change impact.		
Questions	**Responses**	**Data Source(s)**
Society, community, equity		
1. What kinds of services does the asset provide to the surrounding community?		
2. Does the asset serve vulnerable communities or critical facilities? *For example, community members who are low-income, disadvantage, transit-dependent; facilities such as hospitals, transportation, fire stations, etc.*		
3. Is the asset part of emergency response / management?		
4. Are there any hazardous materials at the asset site that could pose a risk to public health? What is their mobilization potential in floodwater? How close are they to sensitive receptors such as schools, elderly housing, or hospitals?		
Environment		
1. Is the asset near wetlands, parks, or other protected natural resources?		
2. Are there any hazardous materials at the asset site that could pose a risk to the environment?		
Economic		
1. What is the value of the asset to the local economy?		

For example, does it contribute to major economic activity or employment centers, generate revenue, provide jobs, etc.?		
2. Are there sunk costs in the asset? Have recent investments been made in the asset that would be lost if rebuilding or relocating were necessary?		
3. What is the scale of economic costs if the asset were to experience service disruptions or damage? Would they be local, regional, state, or national?		