Chapter 11. Ground Transportation

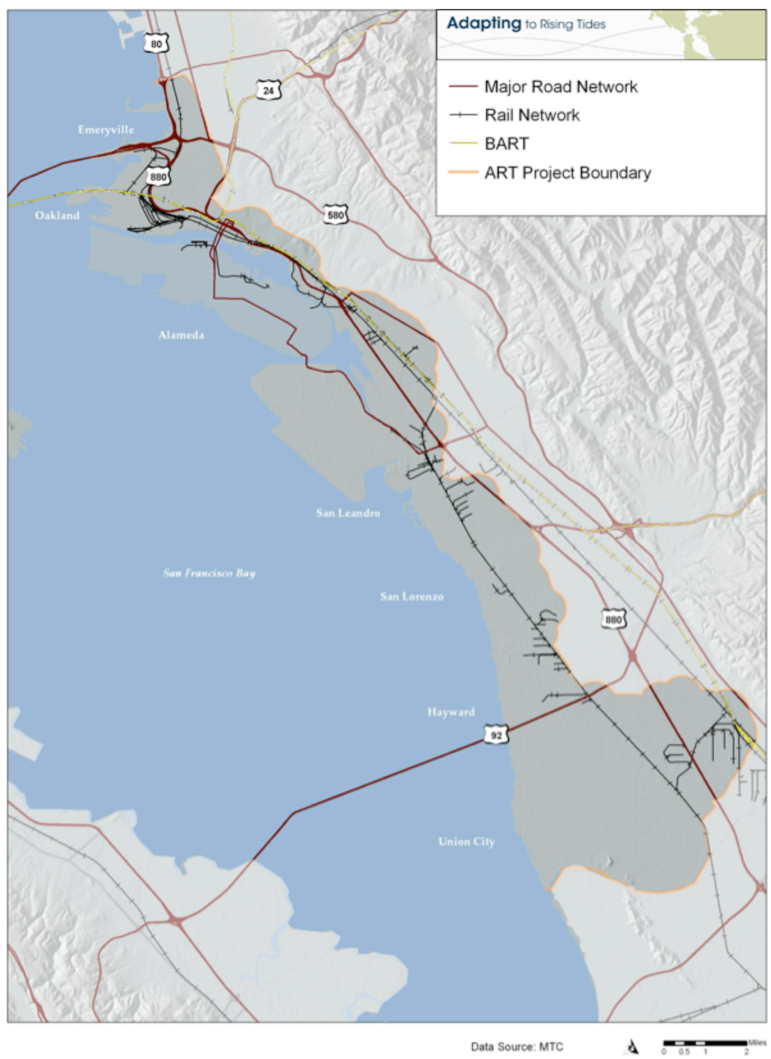
The ART project area is home to a number of critical transportation modes that are part of a system that connects and serves the greater Bay Area. These include Interstate highways and local roads, Bay Area Rapid Transit (BART) passenger rail system, commuter and freight rail, and the trans-bay ferry network. All of these modes could be affected by the prospect of a changing climate, whether due to daily tidal inundation, storm event flooding, or elevated groundwater. Each transport mode is different in both form and function, and consequently will respond differently to sea level rise and other climate impacts.

This chapter presents an overview of these transportation categories and examines their ability to adapt to sea level rise under forecasted scenarios. The information is drawn from an analysis conducted by AECOM and Arcadis for the Adapting to Rising Tides: Transportation Vulnerability and Risk Assessment Pilot Project (AECOM, 2011), including data on use levels of various transportation assets (unless otherwise cited).

Roadways

Three major interstates and several highways are located within the ART project area (Figure 1), connecting it to the employment centers in San Francisco and the Peninsula and to the Oakland International Airport and the Port of Oakland's seaport. These are: Interstate 80/580 (Eastshore Freeway), Interstate 880, Interstate 980, California State Highway 92 (CA-92), and California State Highway 61. Interstate 80/580 and Interstate 880 serve as primary connections to the San Francisco-Oakland Bay Bridge (Bay Bridge), the only bridge that crosses directly into the City and County of San Francisco from the East Bay. More than 212,000 vehicles use Interstate 880 to travel throughout the East Bay on an average day. Interstates 80 and 580 connect to other highway and interstate systems that serve both the county and the region. Interstate 80 links San Francisco to the national network of Interstate highways, while Interstate 880 provides a regional connector for the movement of people and goods between Oakland International Airport, the Port of Oakland, and CA-92. CA-92 runs the length of the San Mateo-Hayward Bridge and is used by 86,000 vehicles every day. The San Mateo-Hayward Bridge (San Mateo Bridge) provides commuters a connection between the East Bay and the Peninsula, a significant employment center in

Figure 1. Overview of ground transportation assets in the ART project area



the Bay Area and home to Silicon Valley. The San Mateo Bridge also provides an alternative bridge route in the event of Bay Bridge closures. During the recent closures for the Bay Bridge seismic retrofit, for example, the San Mateo Bridge served as a primary alternative for East Bay commuters to travel into San Francisco.

Three major roads serve Oakland International Airport (one of three international airports in the Bay Area and the only one in the East Bay) and connect it to Interstate 880: Hegenberger Road; 98th Avenue, and California Highway-61. All of the major access roads meet up to form Airport Drive, the major road in and out of the airport's passenger terminals.

There are several primary routes serving the Port of Oakland's seaport, including Interstate 880, Interstate 80/580, Interstate 580 East, Interstate 80 East, and Interstate 980. The Port of Oakland is the primary seaport in the region, exporting agricultural goods and importing machinery, electronics, and apparel.

Interstate 80/580 serves and passes through the City of Emeryville, and Interstate 880 serves and passes through the cities and communities of Oakland, San Leandro, San Lorenzo, Hayward, and Union City. Interstates 880 and 980 provide access to the City of Alameda, which is an island west of the City of Oakland. The island is connected to downtown Oakland through a set of two one-way tunnels (Webster and Posey Tubes), while three bridges (Park Street, Fruitvale Avenue, and High Street) connect the city to other parts of Oakland. Bay Farm Island, a mainland residential area within the City of Alameda, connects to the island portion of Alameda via a parallel pair of a pedestrian/bicycle and vehicular bridges.

Buses

The majority of bus routes in the ART project area are operated by AC Transit, an Oakland-based public transit agency serving the western portions of Alameda and Contra Costa Counties. With a few exceptions, most of AC Transit's bus routes share identical rights-of-way with private automobiles. As of August 2011, AC Transit's 364 square mile service area consists of a total of 116 bus lines: 71 of these are local lines within the East Bay; 34 are Transbay lines that cross the Bay Bridge and provide service to San Francisco, as well as one line that crosses the San Mateo Bridge to the Peninsula; and 6 are All-Nighter lines that provide a viable means of regional transportation during the late-night hours when rail services do not operate.[1] Average daily weekday ridership was approximately 200,000 in the 2009-2010 Fiscal Year, 60,000 of those being school children.

Some of AC Transit's busiest routes travel through ART project areas that are vulnerable to sea level rise and storm events. For example, Lines 72/72M/72R (average of 8,049 daily passengers (AC Transit 2008)) all travel through the same low-lying sections of Oakland and Alameda. Line 97 (average of 5,140 daily passengers (Ibid.)) travels through vulnerable areas in the cities of San Leandro, San Lorenzo, Hayward, and Union City. Other bus lines rely on isolated routes and have no feasible detour in the event of flood-related closures. The Transbay bus lines, for example, accommodate an average total of 14,000 commuters but use the Bay Bridge and rely on a limited number of accessible on-ramps to operate. Some of the less popular bus lines serve isolated communities that are both economically and physically sensitive to the impacts of inundation. These include: AC Transit Lines 314 (estimated 44 average daily passengers in 2008 (Ibid.)) and 356 (estimated 62 average daily passengers in 2008 (Ibid.)), which run along many stretches of vulnerable road through low-lying sections of Oakland; AC Transit Route 86, serving the low-lying areas of Hayward; and AC Transit Route 89, which runs through low-lying sections of San Leandro.

[1] http://www.actransit.org/about-us/facts-and-figures/ridership/

Other bus services in the ART project area include those operated by cities, such as the Emery Go Round, serving to connect destinations in and near Emeryville; the Broadway Shuttle in the City of Oakland; shuttles to and from the airport operated by a number of organizations; and Union City Transit, which provides service within Union City. Many of these bus routes provide service within low-lying areas and for transit-dependent communities that are not only vulnerable to SLR and storm events but are susceptible to very high levels of liquefaction during seismic events.

Bicycle Routes

Bicycling is a popular mode of transportation in the ART project area. People use bicycles to commute and for recreation along a variety of routes. These routes include roadways, some of which are labeled as bike routes and marked either with separate bike lanes or "sharrows," (Figure 2) as well as separate trails that cannot be used by cars, but may be shared with pedestrians. The Bay Trail includes both roads and separated trails, and is a popular corridor for bicyclists. Within the ART project area, there are 74 miles of existing and proposed Bay Trail between Emeryville and Hayward, connected to a larger continuous regional trail system around the edge of the Bay. Other trails such as the Lake Merritt connector trail connect with the Bay Trail.

Figure 2. "Sharrows" on pavement and bike route sign

BART

While the ART project area is home to a critical network of Bay Area interstates and highways, it also has one of the busiest rapid transit systems in the United States. BART, or Bay Area Rapid Transit, is a heavy-rail public transport network that accommodates an average of 365,000 weekday boardings (MTC 2011) and connects cities throughout northern San Mateo County, the City and County of San Francisco, and the East Bay. It consists of five lines, all of which travel through the ART project area. Four of the five lines cross the Bay through the Transbay Tube, an underwater section of tunnel below the San Francisco Bay that is partially within the ART project area. The Transbay Tube provides a way for residents within the ART project area and the San Francisco Peninsula to commute across the Bay as an alternative to traveling over the San Francisco-Oakland Bay Bridge by automobile or bus, or on the Bay by ferry. The ART project area contains three BART stations, which include: *West Oakland* (approximately 10,700 daily entries/exits), served by all of BART's lines except for the Richmond-Fremont line; *Lake Merritt* (approximately 11,000 daily entries/exits[2]), served by the Richmond-Fremont, Daly City-Dublin/Pleasanton and Daly City-Fremont lines; and *Coliseum/Oakland Airport* (12,000 daily entries/exits), served by the same lines as the Lake Merritt station.

Regional Rail Links

The ART project area also contains rail service that connects the greater Bay Area. Amtrak, the national railway network, terminates California Zephyr service at the Emeryville Station, while the Capitol Corridor, Amtrak's Northern California regional service, connects the Bay Area to the state capitol of Sacramento and the Sierra Nevada foothills. The Capitol Corridor is currently Amtrak's fourth busiest rail line (Amtrak 2011) and continues south through the ART

[2] http://www.bart.gov/docs/WeekdayExits.pdf

project area along at-grade railroad tracks that run roughly parallel to Interstate 880. These railroad lines are also used by national freight carriers, such as Union Pacific and the Burlington Northern Santa Fe, to deliver goods from the Port of Oakland to destinations throughout the state and across the country.

Ferry Network
The Bay Area ferries, once the dominant method of travel between San Francisco and the East Bay, now play a much smaller but nevertheless important role in the Bay Area transportation network. Three ferry terminals lie within the ART project area: the Jack London Square terminal (located close to Amtrak's rail station and downtown Oakland), the Alameda Ferry Terminal in the City of Alameda, and the Harbor Bay Ferry Terminal on Bay Farm Island. All of these terminals have service to and from San Francisco's Ferry Building and will begin to provide service to the South San Francisco Ferry Terminal in June 2012. Ferries within the ART subregion are operated by the Blue & Gold Fleet for the Water Emergency Transportation Authority, with one line serving the Jack London Square and Alameda terminals, and a separate line, which operates only on weekdays, serving the Harbor Bay Ferry terminal.

Exposure

Exposure is the extent to which an asset experiences a specific climate impact such as storm event flooding, tidal inundation, or elevated groundwater. The exposure of selected ground transportation assets in the ART project area to two sea level rise projections and three Bay water levels was evaluated. The two sea level rise projections, 16 inches (40 cm), and 55 inches (140 cm), correlate approximately to mid- and end-of-century. These two sea level rise projections were coupled with three Bay water levels: the new daily high tide, measured as mean higher high water (MHHW), the new 100-year extreme water level, also known as the 100-year stillwater elevation, and the 100-year extreme water level coupled with wind waves, hereafter "storm event with wind waves," or "wind waves." These water levels were selected because they represent a reasonable range of potential Bay conditions that will affect flooding and inundation along the shoreline. For each exposed facility, the average depth of inundation from the daily high tide and storm events was calculated. Whether a facility is exposed to wind waves was evaluated as a simple binary – yes or no. For more information about sea level rise projections and Bay water levels evaluated see Chapters 1 and 2.

Exposure was analyzed by network type, such as roadways or railroad, and also by individual, point-based asset, such as a single station (see Appendix C). For network type, exposure is calculated in mileage (i.e., the length of roadway or track for which inundation occurs for a specific category of transportation). For individual assets such as rail and BART stations, the average depth of inundation in each exposed facility footprint was calculated.

Exposure by Network Type
Roadways are classified by Functional Road Class (FRC), designations developed by the digital map company Tele Atlas to classify roads by the level of travel mobility that they provide relative to the overall United States road network (Table 1). Exposure of the road network in the ART project area was conducted for the extent of roads in each FRC. The 120 miles of regional rail (e.g., Union Pacific, Amtrak) in the ART project area were also evaluated to determine the mileage of railroad exposed to each scenario.

While GIS data was available for the alignment of roads and rail, elevation data – that is, whether various road and rail segments are below, at, or above grade – was not available. For certain critical road segments that are clearly below-grade, such as the entrance to the Posey and Webster Tubes connecting Oakland and Alameda and well-known underpasses and overpasses, more precise conclusions regarding their exposure were drawn. Other segments are assumed to be at grade, so further analysis is necessary to more precisely determine the exposure to different Bay water levels.

For BART, analysis using just the alignment data would not be very useful because track elevation varies so dramatically and is rarely at grade in the ART project area. However, BART is conducting its own exposure analysis using more detailed information, including track elevation. Therefore, while BART stations are included in this analysis, exposure of BART tracks is not included here.

Table 1. Tele Atlas road categories with local equivalents in the ART project area

Tele Atlas Road Class	Classification Description*	Miles of FRC in ART project area	Local Examples
FRC 0	Limited-Access Highways	70	Interstate 880
FRC 1	Major Roads	8	CA-92 (San Mateo Bridge)
FRC 2	Regional Connectors	0	CA-24
FRC 3	Secondary Roads	33	CA-61 / Doolittle Drive
FRC 4	Local Connectors	144	Hegenberger Road
FRC 5	Local Roads of High Importance	187	Broadway

*Classification descriptions from U.S. Highways and Major Roads, Pitney Bowes, Version 2011
http://reference.mapinfo.com/Data/USHighways/2011/USHighways_ProdGuide_2011.pdf

With 16 inches of sea level rise, a five-mile portion of local roads with high importance (FRC 5), will be inundated by the new daily high tide. During a storm event twenty-two more miles of local roads of high importance will be inundated, along with up to four miles of limited-access highways, seven miles of secondary roads, and eight miles of local connectors. With wind waves, nearly 200 miles of roadways across all classifications could be affected. Bus and bicycle routes along these corridors would also be exposed, as well as some roadway connections to ferry terminals and BART stations. None of the railroad in the ART project area will be exposed to the daily high tide, but 5 miles will be exposed to storm event flooding, and 60 miles could be exposed to wind waves (Table 2).

With 55 inches of sea level rise, 98 total roadway miles and 22 railroad miles will be exposed to inundation by the new daily tide. During a storm event, nearly 200 miles of the roadway network, and 61 miles of the railroad network in the ART project area will be flooded, with 267 miles of the road network exposed to wind waves, and 83 miles of rail exposed. The greatest share of roads exposed is made up of local roads of high importance such as downtown streets. The bus and bicycle routes along these corridors would also be exposed, as well as some of the roadway connections to ferry terminals and BART stations.

Table 2. Exposure of road and rail network to daily high tide and storm events with 16 and 55 inches of sea level rise. All facilities exposed to storm event flooding are also within the wind wave zone. Therefore, the mileage indicated as being exposed to wind waves only does not include the miles exposed to storm event flooding but includes all additional miles exposed to a wind wave scenario.

	16" SLR			55" SLR		
	Daily High Tide	Storm Event		Daily High Tide	Storm Event	
System Category	Miles exposed	Miles exposed	Miles exposed to wind waves only	Miles exposed	Miles exposed	Miles exposed to wind waves only
Roadways: Limited-Access Highways (FRC 0)	0	4	25	16	29	16
Roadways: Major Roads (FRC 1)	0	0	3	1	3	1
Roadways: Regional Connectors (FRC 2)	0	0	0	0	0	0
Roadways: Secondary Roads (FRC 3)	0	7	5	8	12	2
Roadways: Local Connectors (FRC 4)	0	8	50	24	58	23
Roadways: Local Roads of High Importance (FRC 5)	5	27	64	48	91	26
Total length of roadways exposed	**5**	**45**	**149**	**98**	**194**	**68**
Regional Railroads: System-Wide	**0**	**5**	**55**	**22**	**61**	**22**

Exposure by Representative Asset

The following section analyzes the exposure of selected, representative, ground transportation assets, such as a rapid transit station, ferry terminal, or a specific section of railroad track. The assets are divided into two categories: public transportation and road and rail network assets. Public transportation assets include BART and Amtrak Capitol Corridor Stations, ferry terminals, and a selected section of Amtrak rail, and are displayed in Table 3. Road and rail network assets are specific sections of road and rail (not passenger rail) selected for analysis because they are major routes near the shore. Exposure of these assets is shown in Table 4.

Public Transportation

With 16 inches of sea level rise, none of the selected public transportation assets are exposed to the daily high tide, with the exception of those dependent upon exposed roadway segments such as bus routes, bicycle routes, and roads serving ferry and rail stations. During a storm event, the Union Pacific Martinez Subdivision would be flooded up to a foot. This Subdivision, both BART stations, both ferry terminals, and the Jack London Square Amtrak station are exposed to wind waves during a storm event.

With 55 inches of sea level rise, most of the selected public transportation assets are not exposed to inundation by the daily high tide, except for several assets in Oakland including the railroad subdivisions of Union Pacific Niles (located in Oakland and Union City within the subregion) and Union Pacific Martinez, and the Jack London Square Ferry Terminal. During a storm event, all facilities except for the ferry terminals would be inundated by several feet, with a maximum of ten feet at the Jack London Square Amtrak Station. All of the selected assets are exposed to wind waves during a storm event.

Table 3. Exposure of representative public transportation assets to the daily high tide and storm events with 16 and 55 inches of sea level rise. None of the representative assets are exposed to the daily high tide or storm event with 16 inches of sea level rise. All assets exposed to storm event are also within the wind wave zone and could experience deeper inundation than estimated because Bay water levels increase when there are wind waves.

	16" SLR	55" SLR		
	Storm Event	Daily High Tide	Storm Event	
Public Transportation Asset	Exposed to wind waves only	Average depth (ft)	Average depth (ft)	Exposed to wind waves only
BART: West Oakland Station			1	
BART: Coliseum/Oakland Airport Station	Yes		1	
RAIL: Amtrak Emeryville Station				Yes
RAIL: Amtrak Jack London Square Station	Yes	1	1	
RAIL: Amtrak railroad between Coliseum Station and 98th Avenue	Yes	1	1	
FERRY: Jack London Square Terminal	Yes		2	
FERRY: Alameda Main St. Terminal (Park & Ride, Bicycle, and ADA)	Yes	1	3	
FERRY: Alameda Harbor Bay Terminal	Yes		2	

Roads and Rail

With 16 inches of sea level rise, most of the selected sections of the road and rail network within the ART project area will not be exposed to the daily high tide. The sole exception is the SR-260 Posey Tube approach in Alameda, which would be inundated up to four feet by the new daily high tide. During a storm event, most of these selected sections would be flooded, with very high water levels concentrating around the underpasses of the Posey and Webster Tubes in Alameda (22 feet of inundation) and Airport Drive (26 feet of inundation) near Oakland International Airport. Such high depths are generated in this forecast because these stretches of road include underpasses that travel below ground level and slope downward. Airport Drive, for example, will be completely impassable with 16 inches of sea level rise under stormy conditions because the 98th Avenue / Doolittle Drive underpass travels below ground level and will collect significant amounts of water. Such physical vulnerabilities are emphasized in greater detail in the Sensitivity and Adaptive Capacity section of this report. Additionally, the approaches to the Bay Bridge toll plaza are exposed during a storm event, as are several sections of Interstate 880 that pass through the City of Oakland.

With 55 inches of sea level rise, the approaches to the Bay Bridge toll plaza are exposed to the new daily high tide, as is the Bay Farm Island Bridge and the majority of Oakland International Airport's access roads. The majority of Oakland International Airport's major access roads not listed in the exposure charts are vulnerable to flooding in a 100-year storm event. Hegenberger Road, the major street in Oakland where most of Oakland International Airport's hotels and services lie, will be inundated along its entire stretch from the airport terminals to Interstate 880. Hegenberger Road's other alternate access routes, 98^{th} Avenue and CA-61/Doolittle Road, will also be flooded in a 100-year storm event. More specific details on the impacts of sea level rise on the ground transportation network around Oakland International Airport are summarized in the airport section of this report.

The Bay Trail, an important bicycle route, is already affected by flooding. Portions of the trail have been temporarily closed or damaged due to extreme weather events. With 16 inches of sea level rise, a majority of the trail south of Marina Park in San Leandro would be affected by storm event flooding. With the exception of the Bay Trail around San Leandro Bay (in Martin Luther King Jr. Regional Shoreline), the majority of the trail in the northern portion of the ART project area is unlikely to experience significant impacts with 16 inches of sea level rise. In the longer term, most of the Bay Trail in the ART project area will be fully inundated or impaired by flooding with 55 inches of sea level rise. This includes portions of the Bay Trail on local roads, such as Harbor Bay Parkway, Doolittle Drive, Union City Boulevard, and Mandela Parkway. The Lake Merritt connector trail and the Hayward Shore Recreational Area Trail are exposed to all impacts, including the daily high tide with 16 inches of sea level rise.

Table 4. Exposure of representative road and rail network assets to the daily high tide and storm events with 16 and 55 inches of sea level rise. Assets exposed to storm event flooding are also within the wind wave zone and could experience deeper inundation than estimated because Bay water surface levels increase when there are wind waves.

	16" SLR		**55" SLR**	
	Daily High Tide	Storm Event and wind waves	Daily High Tide	Storm Event and wind waves
Road Section	Average depth (ft)	Average depth (ft)	Average depth (ft)	Average depth (ft)
I-80: Powell St. to Bay Bridge Toll Plaza		2	3	5
I-80: Bay Bridge from Toll Plaza to Alameda County Line		2	2	5
I-880: Oak St. to 23rd Ave.		1	1	4
I-880: High St. to 98th Ave.		2	3	5
SR-260: Posey Tube (Alameda Portal)	4	22	23	25
SR-61: Webster Tube (Alameda Portal)		22	23	25
Alameda: Bay Farm Island Bridge			1	4
SR-92: Clawiter Rd. to San Mateo Bridge				3
OAK: Airport Dr.		26	27	29
Hegenberger Rd: From San Leandro St. to Doolittle Dr.		2	3	5
RAIL: Union Pacific Martinez - 34th St. to 10th St.			3	5
RAIL: Union Pacific Niles - Magnolia to East Oakland Yard		1	2	4

Sensitivity and Adaptive Capacity

The sensitivity and adaptive capacity of ground transportation assets was assessed for three potential climate impacts that could occur due to sea level rise and storm events. The three climate impacts considered are:

- More frequent floods or floods that last longer due to storm events
- Permanent or frequent inundation by the daily high tide
- Elevated groundwater levels and saltwater intrusion

Sensitivity is the degree to which an asset or entire system (e.g., rail or roads) would be physically or functionally impaired if exposed to a climate impact. Adaptive capacity is the ability for an asset or system to accommodate or adjust to a climate impact and maintain or quickly resume its primary function. The sensitivity and adaptive capacity of ground transportation was evaluated, considering not just physical sensitivity, but also functional sensitivity as it relates to commuter and goods movement.

Primary Roadways and Bridges

Some portions of the roadway network in the ART project area are more sensitive than others to sea level rise and storm events because they vary in type of structure, elevation, or drainage, or are simply the only routes available to access community and regional assets such as residential communities, the airport, job centers, and other critical facilities.

Tunnels and underpasses are more sensitive to flooding because their approaches are below sea level. For example, the twin Alameda Tube entrances are highly sensitive to inundation because their approaches travel below grade into tunnels below sea level. Within these tunnels, the access and departure ramps from Alameda show greater exposure to rising water levels than the approaches on the Oakland side. With 16 inches of sea level rise, the Webster Tube departure in Oakland is not inundated by the new daily high tide but the Posey Tube approach in Alameda is exposed to inundation levels of approximately four feet.

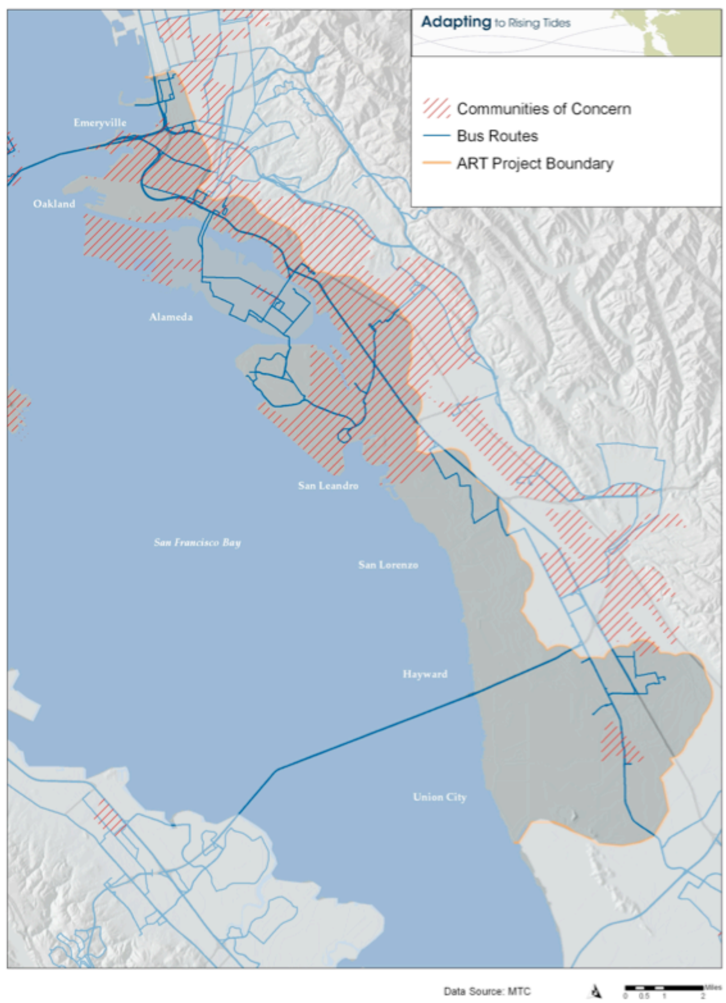
The surface-level on-ramps from the southbound Eastshore Freeway to the Bay Bridge Toll Plaza are the only on-ramps to the Bay Bridge Toll Plaza from Interstate 80 West and Interstate 580 South, two major interstates serving the region. Any type of disruption to these structures would have significant impacts on regional, state, and national passenger and cargo travel. Otherbridges, BART, and ferry routes would not have the capacity to serve as long-term alternates to the Bay Bridge. Although BART lines provide frequent daily service, departures are limited in the early morning, late evening, and weekends; there is no regular late night service, and the system does not have the capacity to meet current ridership levels as well as those displaced from Bay Bridge automobile and bus traffic. While the ferry system has been augmented to serve as an alternative to the Bay Bridge during past disruptions, it lacks the capacity to serve those displaced from the Bay Bridge and does not provide late night service. Due to reduced BART and ferry service outside of regular commute hours, these services would have to be increased, or disruptions to the Bay Bridge on-ramps would affect those who travel the Bay Bridge corridor during non-commute hours significantly.

Other high-traffic, limited-access corridors facilitate the movement of goods, people, and visitors throughout the entire region. For example, Interstate 880 provides a route that connects residents in the East Bay to jobs and the airport. With 16 inches of sea level rise, one segment of Interstate 880 (High Street to 98th Ave.) could be inundated up to two feet by storm event flooding. As previously noted, one foot of water is considered sufficient to render a roadway impassable. When closures occur on these roads, traffic could be bypassed through numerous local roads, but this could overwhelm local roadways and communities. Some assets could become completely isolated due to the inundation of roads for which there are no alternative routes or public transport options.

Oakland International Airport relies on low-lying roads from all directions for terminal access. With 16 inches of sea level rise, most of the airport's access roads from Alameda (Ron Cowan Parkway, Harbor Bay Parkway, and Doolittle Drive) would be inundated by storm event flooding. With 55 inches of sea level rise, inundation due to storm events is expected along Oakland International Airport's main access roads to Interstate 880 (Hegenberger Road / 98th Avenue / Doolittle Drive). By mid-2014, however, some of these access problems will be mitigated by the completion of a new, elevated Automated Guide Transit (AGT) system between Oakland Airport and the Oakland Coliseum BART station known as the Oakland Airport Connector. The Oakland Airport Connector would provide a viable above-grade alternative for Bay Area travelers in the event that local access roads are inundated.

Bus lines and bicycle routes often share the same stretches of roadway as automobiles and provide critical alternatives for those who do not own cars. All of the routes mentioned earlier in this report (Lines 72/72M/72R, 97, 314, 356, 86, 89) run through low-income and transit-dependent communities, classified as "Communities of Concern" (Figure 3) by the Metropolitan Transportation Commission (MTC).[3] Other AC Transit services, such as those within the Transbay network (B, F, NL, O, OX, SB, W, 800), also travel through such communities. Some of MTC's Communities of Concern are located within the ART project area, including western Alameda Island; the City of Oakland south of Interstate 580; Emeryville west of Interstate 80; and Union City east of CA-238 – these areas are highlighted in Figure 3.

Figure 3. Communities of Concern in the ART Project Area



Among all of these routes, adaptive capacity will vary depending on the intensity of localized climate impacts. The routes with the least adaptive capacity are popular lines that not only serve transit-dependent communities but also run

[3] MTC's "Transportation 2035 Plan for the San Francisco Bay Area" includes an Equity Analysis Report that divides the region into zones defined by minority populations, poverty, or both, and emphasizes the importance of access to transit for those who do not have cars and for "communities of concern" (MTC 2009).

along isolated routes that will likely become inundated with sea level rise. The majority of the bus lines identified in this report are within this category, including the Transbay bus routes (B, F, NL, O, OX, SB, W, 800).

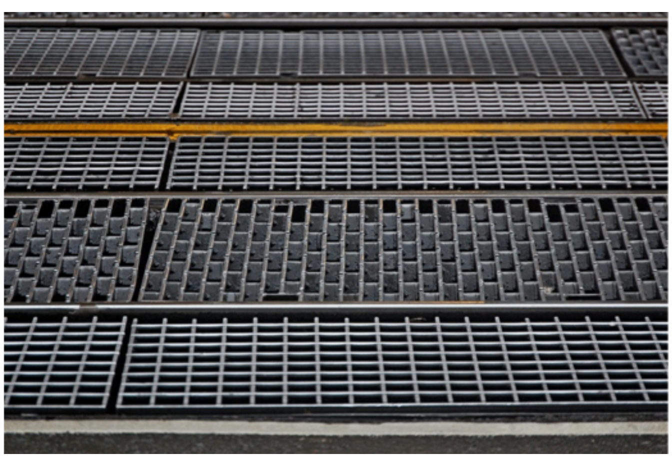
BART

While many rail structures within the BART network run along elevated routes over inundated portions of the ART project area, the track consists of fixed electric third-rail routes that are minimally protected from the elements and are highly sensitive to climate-related impacts. Within BART's various tracks and stations, many less visible infrastructure components keep BART functioning, including tunnels, ventilation tubes, and control centers. This infrastructure is often located underground and is vulnerable to water at ground elevation; many vents are connected to the sidewalks and only need a small amount of rain to begin to flood (Figure 4).

Lake Merritt Station is one example where such critical assets are at risk. Although this station is not at risk of inundation in the sea level rise scenarios considered in this report, BART officials have identified it as being subject to groundwater intrusion due to a high water table. The station is situated near Lake Merritt, a body of water connected to the San Francisco Bay via a canal that passes directly over a BART tunnel. Groundwater intrusion has already caused corrosion of some structural members in the below-grade parts of Lake Merritt station, which is currently protected by a sump pump. The major operational impacts of additional water intrusion due to sea level rise are unknown, but it is possible that storm event flooding could close some station entrances or the entire station should the capacity of sump pumps be exceeded. The other two BART stations in the subregion – West Oakland and Coliseum/Oakland Airport – are both exposed to storm event flooding with 55 inches of sea level rise.

In addition to station flooding, rising groundwater levels may increase the likelihood and extent of liquefaction, which could damage BART's underground structures during a seismic event. According to ART project data, the eastern portal of the Transbay Tube is located in an area that is highly prone to liquefaction. Tunnel leaks could potentially occur within the structure after a seismic event due to the unstable nature of the soil.

Figure 4. Example of BART street-level subway vents along Market Street, San Francisco (Source: http://nikdaum.com/news/10sf540big.jpg)



The high cost of heavy rail construction limits BART's adaptive capacity to cope with sea level rise relative to other more flexible modes of public transportation, such as buses. Should flooding or tidal inundation necessitate relocation, the majority of BART's network would be difficult to move or reconstruct due to a lack of available land and the high cost of constructing and maintaining a heavy rail system. Unlike buses or other forms of vehicular transportation, BART lines operate on fixed rail; in other words, any kind of inundation of BART's rail line on the ground could also interrupt service on its elevated structures, or possibly the entire BART network. Moreover, BART lines are very expensive to construct;

while highway construction in dense urban areas costs an average of $7-15 million per mile[4], recent BART extensions have been estimated at over $200 million per mile[5].

Regional Rail Links

Similar to BART, other regional rail links such as the Capitol Corridor and the Union Pacific Martinez and Niles subdivisions also have limited adaptive capacity because they cannot be easily reconstructed or relocated, and a localized impact in the system could affect the entire network's ability to function. One major difference between the Capitol Corridor and BART is that most stretches of rail in the ART project portion of the Capitol Corridor are at-grade and close to the shoreline, resulting in a very high level of sensitivity to sea level rise.

Portions of both the Union Pacific Martinez subdivision in the north and Niles subdivision in the south will be inundated between four to five feet with 55 inches of sea level rise during a storm event. Storm event flooding on portions of the Niles subdivision begin to occur with 16 inches of inch sea level rise. This rail infrastructure is not only the most vulnerable to sea level rise but is also the only link for trains in the Capitol Corridor system to reach the lower East Bay from northern East Bay communities. This means that even if significant portions of the rail network were not sensitive to flooding impacts, immediate work would have to be performed on the inundated sections of rail in order for the entire network to function. Additionally, the Capitol Corridor is supported by an operations and maintenance facility that adjoins the Union Pacific Niles Subdivision in Oakland and is highly susceptible to liquefaction and will be exposed to the daily high tide and storm events with 55 inches of sea level rise. No adequate alternative is available for this asset, given both its location and function in an isolated area of railroad tracks. Therefore, adaptive capacity for the Capitol Corridor's maintenance facilities is limited and could jeopardize the ability of the entire system to run at full system capability.

Figure 5. Alameda / Oakland Ferry docked in Jack London Square (Source: http://en.wikipedia.org/wiki/File:Alameda_Oakland_Ferry.JPG)

Ferry Network

Ferry piers, when viewed as independent assets, are not very sensitive to sea level rise because they are highly adaptable to the daily rise and fall of the tide (Figure 5). Additionally, ferry piers appear not to be exposed directly to sea level rise because they are situated high enough above current Bay level and beyond the shoreline. Damage caused by storm events to the portions of the piers that are exposed to waves could be an

[4] http://www.railstotrails.org/resources/documents/whatwedo/policy/07-29-2008%20Generic%20Response%20to%20Cost%20per%20Lane%20Mile%20for%20widening%20and%20new%20construction.pdf

[5] http://www.bayrailalliance.org/q_why_not_replace_caltrain_bart_wont_cost_same_ele

issue for some of the ferry terminals. Ferry piers are also highly affected by changing weather conditions and access from nearby roads. Ferry piers are more sensitive to high winds than the ground transport networks discussed in this report because such events significantly affect the safe docking and operation of ferries. Even with today's sea level, ferry service has occasionally been suspended during storms.

Roadway access to the ferry terminals is highly sensitive to climate impacts because access roads travel through low-lying areas. Ferry piers are obviously dependent on water, and therefore access roads must run close to the shoreline. More specifically, access roads for the Alameda Ferry Terminal are located in disconnected low-lying areas behind man-made flood protection features. These roads would be especially vulnerable to overtopping because they lie at a lower elevation than the San Francisco Bay. Their inundation would prohibit passengers from accessing the ferry piers.

The access roads to the Jack London Square Ferry Terminal and the Alameda Gateway Ferry Terminal would be flooded in a storm event with 16 inches of sea level rise. There are only a few other pier structures in the area, which leaves limited options for ferry operators to embark or disembark passengers at alternate docking locations. Likewise, if the main ferry piers were to become damaged by storms, the system's ability to function would be affected.

Consequences

The potential consequences of daily tidal inundation, storm event flooding, or elevated groundwater on the ground transportation network in the ART project area must be considered for both the physical infrastructure and the functional purpose that infrastructure serves within the communities and the subregion. Consequences are the magnitude of the social, economic, legal, and environmental effects if an impact occurs. Factors that inform the magnitude of the potential consequences include the severity of the impact on community and regional mobility, the cost of responding to the impact by either repairing or replacing the exposed infrastructure, the size and demographics of the population served by the exposed infrastructure, the type of natural resources affected, and the cost of the disruption to the economy of the subregion and region.

Economy

A number of key road and transport routes in the ART project area run through areas that could be inundated as a result of sea level rise. Interstate 880 is a major corridor that connects several regionally and nationally important facilities along its route. These include the Oakland International Airport, the Port of Oakland, Oracle Arena, and the Oakland/Alameda County Coliseum. It is one of the busiest transportation corridors in the Bay Area, with an average annual daily traffic of 226,000 vehicles in the corridor between Oak Street and 23rd Avenue, and 212,000 vehicles in the corridor between High Street and 98th Avenue. A large amount of truck traffic (10.3% of total daily use[6]) depends on Interstate 880 to transport goods, especially from the Port of Oakland, as there are trucking restrictions on Interstate 580 (a parallel interstate that is located to the east of the ART project area along the East Bay hills). Any inundation of one foot or more along Interstate 880, therefore, could interrupt the transport of goods and translate into enormous economic losses for the Port of Oakland and the Bay Area economy. During a 2002 contract dispute, for example, a work slowdown at West Coast ports cost the U.S. economy an estimated $1 billion to $2 billion per day (Heberger et al. 2009).

Other corridors could also be affected by sea level rise. For example, the surface-level approaches from Interstate 80/580 to the Bay Bridge Toll Plaza will be inundated with 16 inches

[6] http://i880corridor.com/index.php/about-the-project/faqs

of sea level rise, and because there are few alternatives this could affect more than 250,000 passenger vehicles that use this route each day. The Transbay bus network uses the same approaches to access the Bay Bridge. More than 27 bus routes use the Bay Bridge, carrying a total of around 14,000 daily passengers.[7] Temporary disruption of these routes would mean that these passengers would have to rely on alternative forms of transport to commute across the San Francisco Bay, whether it is via BART or via automobile on an alternative bridge crossing.

Other important road and transport routes that could be affected by sea level rise include roads that travel below ground level. In Alameda, a closure of the Webster and Posey Tubes would lead to increased congestion on its smaller overland bridges which do not have the capacity for the average daily number of trips on and off the island. Approximately 22,300 vehicles and 18,333 transit riders use the tubes daily, and they provide a quick connection from Alameda to downtown Oakland, including the Jack London Square Ferry Terminal and the Amtrak station. One of AC Transit's busiest bus lines, Line 51A (with 11,445 average daily passengers), travels through the tubes. Closure of either of these tubes could mean that all forms of transport would be redirected to the bridges, meaning greater delays and losses in economic productivity.

Another critical belowground transportation asset is BART's Transbay Tube, which connects the East Bay with San Francisco under the Bay along the same general corridor as the Bay Bridge. In the event of a Transbay Tube closure, the entire BART network would be affected because there is no other alternative for trains to connect San Francisco with the East Bay. Four out of the five lines in the BART system use the Transbay Tube, which carries about half of the system's 365,000 daily weekday riders (Alameda Patch 2012). Without the Transbay Tube and BART service along this corridor, the Bay Bridge and other area bridges would likely experience a sharp rise in congestion and use, and the economic and social impacts of the loss of BART service would be significant.

<u>Society</u>
Sea level rise could have a serious effect on residents identified by MTC as Communities of Concern in the ART project area, especially for transit dependent residents who rely on local bus lines for their commute. For transit-dependent individuals in these areas, assistance may be needed to compensate for lack of access to services and jobs. Such assistance would be needed the most under stormy conditions. During significant storm events such as Hurricane Andrew, for example, low-income communities have been unable to evacuate due to lack of financial means to buy supplies or transportation (Heberger et al. 2009). If Communities of Concern in the ART project area are flooded, these communities could become temporarily isolated, translating into a loss in local economic productivity and reduced public safety.

<u>Environment</u>
The environmental consequences of ground transportation are largely related to air and water quality. Vehicle emissions cause local air pollution, and oil and other fluids used in vehicles can be washed off of roadways into local water bodies. The exposure of ground transportation assets could cause an increase in certain types of transportation – for example, if transit or bike paths are unavailable more people may drive private vehicles, increasing overall emissions – as well as a shift in where vehicles travel. If traffic shifts from exposed routes to inland roads, there could be local increases in air and water pollution in those neighborhoods.

<u>Governance</u>
The governance structures related to transportation projects and assets are sensitive to climate impacts transportation planning requires significant interagency involvement at all levels of

[7] http://www.actransit.org/about-us/facts-and-figures/ridership/

government (funding agencies, operating agencies, regulatory, agencies, land owners and land managers, etc.).

AC Transit, for example, receives funding from a broad mix of federal, state, and local government subsidies, as well as voter-approved funding initiatives. Over the past decade, voters in the Alameda-Contra Costa Transit District approved two special parcel tax measures (Measure BB and Measure VV) to provide additional temporary funding to AC Transit. Measure VV extended the funding initially provided through Measure BB until June 30, 2019, but such funding is clearly vulnerable to voter shifts and political change.

Currently, a significant improvement project is being undertaken by Caltrans to rehabilitate many aging sections of Interstate 880. One of the most important undertakings is the 5th Avenue Seismic Retrofit Project, a $130 million project developed through a partnership with the City of Oakland, the Port of Oakland, Union Pacific Railroad, and the Alameda County Transportation Commission. Construction began in summer 2009 and is scheduled to be complete in spring 2014. While the investment to improve this section of road is significant, this project will not reduce the area's vulnerability to inundation. In other words, while efforts were made to pool funds from a variety of governing agencies for this transportation project, future sea level rise may nevertheless affect long-term operations and maintenance costs.

Key Findings

Ground transportation in the ART project area consists of a system of roadways, interstates, Bay Area Rapid Transit, rail lines, bus routes, ferry routes and bicycle and pedestrian pathways. The system includes both physical assets such as rail stations, bus stops, ferry terminals, rail and road infrastructure, and the functional role of linking people with community facilities and services, jobs, family and friends, recreation, and other important destinations. The ground transportation system has components that are projected to be exposed to earlier sea level rise scenarios; while only a few are exposed to the daily high tide with 16 inches of sea level rise, a number of important assets become exposed with 16 inches of sea level rise and a storm event. Ground transportation is quite sensitive to sea level rise and storm events, as many of the systems cannot operate when exposed to even small amounts of water. The overall system has medium to high adaptive capacity, as there is a lot of redundancy in the region's ground transportation system. However, certain components of the system-such as rail serving cargo and the shoreline bicycle and pedestrian pathways–do not have much redundancy.

The ground transportation assets that are exposed earliest – to either the daily high tide or storm events with 16 inches of sea level rise – include the Webster and Posey Tubes that link the City of Alameda and the City of Oakland; portions of Interstate 80/580 and Interstate 880; the approaches to the Bay Bridge, the roadways to Oakland International Airport; the passenger and cargo rail lines, the Bay Trail; and a number of local streets and roadways near the shoreline that provide access to shoreline communities, parks, the Bay Trail, and ferry terminals. With 55 inches of sea level rise, the number of ground transportation assets exposed to the daily high tide and storm events increases significantly.

The majority of the BART system within the subregion does not appear to be exposed to the daily high tide or storm events with 16 inches of sea level rise. Even with 55 inches of sea level rise, BART does not appear to have significant exposure to and the daily high tide or storm events. Many of BART's assets are elevated, which eliminates the possibility of exposure to those parts of the BART system. However, a number of BART's assets are also underground, including rail, the Transbay Tube that links the City of San Francisco with the City of Oakland, and important electrical components. Although BART does not appear to be exposed to most of the daily high tide and storm scenarios, it may be exposed to rising groundwater. Additionally, BART's underground assets and electrical components are highly sensitive to even small amounts of water and the consequences of exposure of these assets can mean that the entire BART system or a significant portion of the system will be shut down. The presence of the Transbay Tube within the subregion, and its critical role as the only location where BART crosses the Bay, makes this a particularly sensitive asset. The consequences to the economy, society, and environment of any BART shutdown in this area are significant even though there is redundancy in the ground transportation system. A partial or system-wide BART closure results in more people driving, more emissions and associated air and water quality issues, more congestion, and an increased number of riders on other modes of transportation. The vulnerability of the BART system is **acute,** due to the high consequences of disruption to the system.

The system of ferry routes and terminals does not appear to be exposed to the daily high tide or storm events with 16 inches of sea level rise. Additionally, much of the infrastructure for ferry terminals is adaptive to water exposure and increased water levels. The primary exposure for the ferry system is the exposure of the roadways, parking, and pedestrian and bicycle pathways that serve the ferry terminals. Without the ability to access the ferry terminals, passengers would be unable to use the service even if the terminals were not affected. It is also important to note that ferry operations are extremely sensitive to storm events and with a certain amount of wind and waves, must be shut down. The consequences of delayed or temporarily unavailable service in Oakland and Alameda would be displaced riders, increased congestion on the roadways and effects on air and water quality. The vulnerability of the ferry system is low to medium due to its lack of exposure and the redundancy of other forms of transportation that are available.

The Bay Trail is exposed to the daily high tide and storm events with 16 inches of sea level rise, and would be significantly affected by the daily high tide and storm events with 55 inches of sea level rise. Due to the nature of its construction and its location within the subregion, the Bay Trail is highly sensitive to sea level rise and flooding affects. Erosion, poor drainage, and surface damage can all result in the closure or elimination of a portion of the Bay Trail. Due to the importance of the Bay Trail as a system of interlinked pathways, the consequence of closing or eliminating a portion of the Bay Trail can be significant. Although there are adaptive measures that can be taken such as different types of construction and construction materials, improved drainage, and the design of boardwalks and bridges, at a certain level of exposure, many of these adaptive measures could be overwhelmed. The vulnerability of the Bay Trail is high due to its exposure to early sea level rise and storm events, its sensitivity to water exposure and the fact that adaptive measures may be overwhelmed in some cases. The consequences of this vulnerability for society, economy, and environment will depend upon the location of the closure or elimination. It may result in reduced access opportunities for people with disabilities or reduced mobility, and could result in more people driving rather than walking or bicycling to their destinations. The lack of redundancy results in an acute vulnerability.

The passenger and cargo rail infrastructure is exposed to the daily high tide and storm events with 16 inches of sea level rise. Rail infrastructure is highly sensitive to even small amounts of water and if a portion of a rail line is exposed it often results in the closure of many miles of tracks. The rail lines within the subregion do not have redundant, adjacent, or alternative tracks to use in the case of a closure, reducing the adaptive capacity of the rail system. The planning, financing and implementation of additional or rehabilitated rail infrastructure would take a significant amount of time and money as it is difficult to move rail either laterally or vertically without making changes to many miles of track.

The consequences of the effects on the passenger rail system would be an increase in the number of people driving, decreased transit opportunities for those without access to a car, and the displacement of rail passengers to other forms of transit. The consequences of the effects on the cargo rail system would be an increase in the number of trucks needed to transport cargo, with associated local and regional effects on congestion, air quality, and community noise and quality of life. The vulnerability of the passenger and cargo rail system is high due to its exposure to the daily high tide and storm events with 16 inches of sea level rise.

The bus routes in the subregion use local roads, highways, and interstates, some of which are likely to be exposed to the daily high tide and storm events with 16 inches of sea level rise. Bus routes and bus stops may be sensitive to these impacts and unable to operate at a certain level of inundation. However, bus routes and bus stops are mostly highly adaptive and can be rerouted to adjacent roadways quite easily. The society and equity consequences of rerouting a bus route or relocating a bus stop could be locally significant and should be considered on a case–by-case basis. Due to their adaptive nature, buses and bus routes will likely serve a significant short-term and long-term role in regional adaptation. The vulnerability of bus routes and bus stops is low due to the high adaptive capacity of most of the bus system.

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