Flooding in San Francisco Bay: Risks and Opportunities

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Figure 1 The urban, industrial, and natural mosaic that is the Bay: Port of Redwood City. *Source: U.S. Army Corps of Engineers Digital Visual Library*

Overview

- The San Francisco Bay Area has the highest GDP in the nation and ranks 19th in the world.
- Extreme weather events, storm surges, exceptional high tides, and sea level rise threaten billions of dollars of businesses and homes as well as the web of transportation, energy, water, and communications networks that connect the Bay Area.
- While sea level rise is gradually occurring, its combination with high tides and storm surges mean that 100 year floods will be 20 year events by 2033, and will be two year events by 2060.
- There are over 200 square miles of vulnerable low-lying lands; in many areas the ageing levee systems do not meet federal standards.
- One of the Bay Area's greatest flood management assets is its extensive Baylands: the past and present tidal wetlands. There are 44,000 acres of wetlands and efforts are underway to acquire and protect an additional 56,000 acres. Once restored these wetlands will significantly reduce flood risk in parts of the Bay at relatively low cost. Already, 36,000 of the 56,000 acres are in public ownership with restoration and flood risk management planning or implementation underway.
- Wetlands filter pollutants and improve water quality in the Bay, protecting fish wildlife, and reducing health risks.

Introduction

The San Francisco Bay Area contains one of the nation's largest and fastest growing economies. The Bay Area has the highest gross domestic product (GDP) in the nation and is the 19th largest economy in the world. Yet this economy is at high risk from coastal flooding. Much of the Bay Area —around 200 square miles—is close to the shoreline in low-lying areas, which in places is as much as 13 feet below sea level. These areas house public and private infrastructure worth more than $50 billion that is integral to the Bay Area's vibrant economy. Moreover, these low-lying areas contain much of the Bay Area's "infrastructure network"—power, water, transportation, communications—that links businesses and communities throughout the region. All of these areas are vulnerable to coastal flooding due to storm surges, "king tides" (exceptional high tides), and other extreme weather events. Rising sea level will only exacerbate the problem by increasing the frequency of extreme water levels. Failure to defend against coastal flooding will have major economic and social consequences for the Bay Area. Losses from Hurricane Katrina ($108 billion) and Hurricane Sandy ($50-70 billion) highlight how devastating such flooding can be.

There are many strategies for adapting to and reducing the impact of coastal flooding and sea level rise. In this paper we present a summary of coastal flood risks and a range of solutions, including traditional approaches, such as more robust levees, and more innovative, cost-effective approaches that make use of the natural assets of the Bay, such as tidal wetlands. There are several planning efforts underway that combine restoration of wetland and upland habitat with flood protection that have the co-benefits of improving the health of the Bay and buffering critical infrastructure and development.

The Baylands Today

The Baylands—the past and present tidal wetlands of the Bay—serve as a buffer between the waters of the Bay and areas of urban, rural, and suburban development. Where 200,000 acres of tidal marsh and wetlands lined the bay over 150 years ago, only 44,000 acres exist today. The former tidal wetlands were diked and drained for farmland, filled to facilitate urban development, or converted to salt production ponds. This has led to a complex mosaic of urban, industrial, and natural areas in the landscape (Figure 1).

The flat, low-lying nature of the Baylands facilitated development. This same geography places these areas at risk from flooding. Bay communities depend on the construction and maintenance of structures such as levees, as well as on the configuration of marshes, to manage flood risk. However, in some communities, flood defenses are inadequate. As an example, much of the South Bay is protected by salt pond levees built more than 100 years ago that do not meet current federal flood standards and are at increasing risk of failure.

Sea level rise is expected to exacerbate flood risk in the Baylands. In particular, the frequency and elevation of extreme high water events will likely increase significantly with the next few decades. These events are expected to greatly exceed water levels seen historically in the Bay. Given the mosaic of urban, industrial, and natural areas in the Baylands the presence, absence, and condition of tidal wetlands will be among the primary factors that will determine flood vulnerability of developed areas.

How Much Will Sea Level Rise?

There have been significant advances in the scientific understanding of the risk of accelerating sea level rise (NRC 2012). Mean sea level has risen by approximately 7 inches at the Presidio in San Francisco Bay during the 20th century (Figure 2). Present sea level rise projections suggest that global sea level in the 21st century will be much higher due to both the expansion of the oceans by warming and, increasingly, by the melting of land-based glaciers and ice sheets. These projections are summarized in the recent National Research Council report on West coast sea level rise (NRC 2012) which provides estimates of regional sea level rise for San Francisco. By 2030, the mid-range projection for sea level rise is 5 inches with an upper projection of 11 inches and by 2050, the mid-range projection is 11 inches with an upper projection of 24 inches (Figure 2).

It is not sea level rise, per se, that is increasing the risk of coastal flooding in the Bay Area. Rather, it is the increasing frequency and elevation of extreme water levels that will cause more extensive flooding in the near future (Figure 3). Water levels that exceed predicted tides occur due to ocean conditions such as El Niño as well as due to precipitation, wind, and low pressure during storms (e.g., “Pineapple Express” storms). Figure 3 illustrates the increasing risks from these events. Extreme water levels have been recorded at the Presidio through the past century and are shown as a cloud of blue crosses. Using this data, the recurrence intervals of extreme events can be calculated (ESA PWA 2011, Kriebel 2011). As mean sea-level rises (blue dotted line), the extreme water level of a fixed recurrence event will also rise (gray solid lines). For infrastructure at a given elevation (denoted by the orange line), the frequency of inundation will increase over time. As shown in Figure 3, a structure inundated with a 100-year recurrence interval flood in the year 2000 will be inundated by a 20-year recurrence interval flood by 2033 and a 2-year recurrence interval flood by 2060. Exposure to more frequent extreme water levels will have an impact on infrastructure much earlier than mean sea level; that is, operations will be affected by more frequent flooding long before the site is permanently inundated by sea level rise.

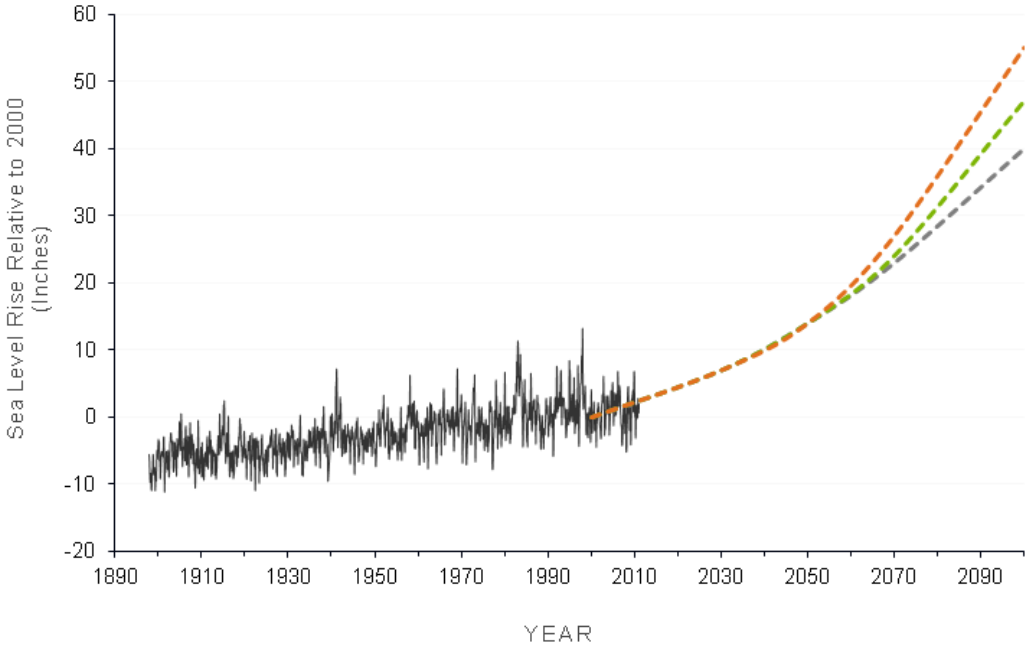

Figure 2 Historic measured and future projected sea level rise. Source: Historical (black jagged line) from Presidio tide gauge. Dotted lines indicate OPC 2013 sea level rise projections. *Source: ESA PWA.*

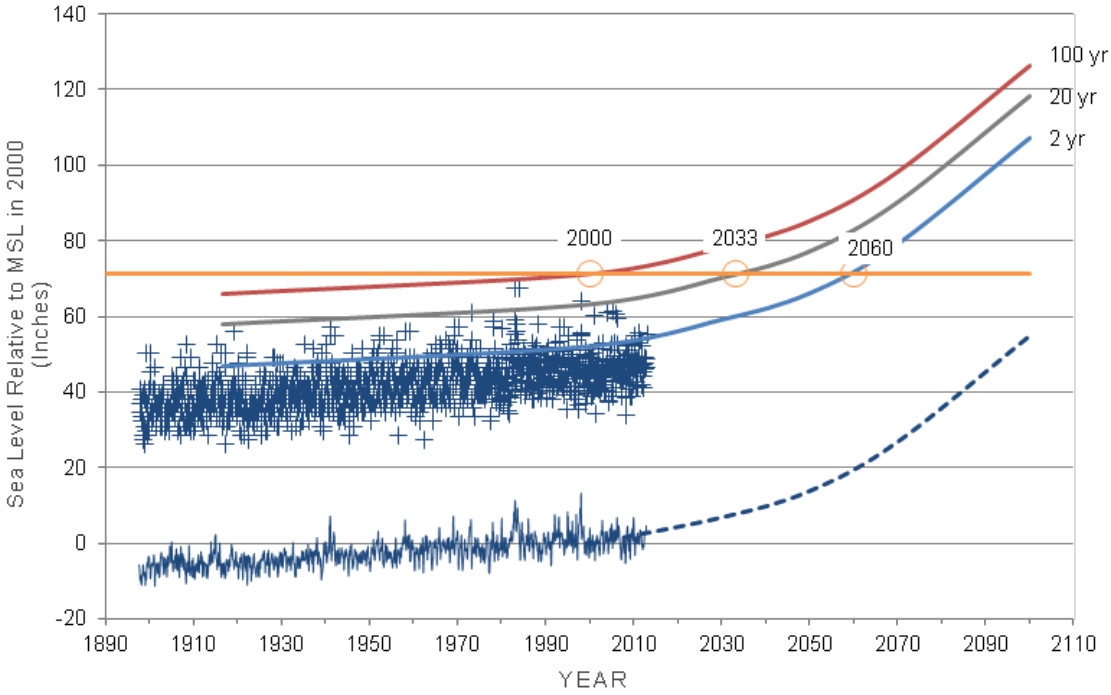

Figure 3 100-year flood events caused by extreme water levels become two-year flood events by 2060 with sea level rise. Source: Historical (blue jagged line) and annual extreme water levels (blue crosses) from Presidio tide gauge. Infrastructure impacted by flooding at a given elevation is represented by the orange line. The dashed line indicates sea level rise projection. *Source: Developed from Kriebel (2011).*

Flood Risk is High and Will Get Higher

Several recent studies have found there to be significant resources at risk along the margin of the Bay, including people and critical infrastructure. Along the South Bay shoreline alone, a 2010 U.S. Army Corps of Engineers (USACE) report estimated that there will be $624 million in structures and contents in the 500 year flood plain by 2017. With a 2 foot increase in sea level by 2067, the value of structures and contents increases to $3.1 billion in the same area. A 2013 USACE and CA Department of Water Resources report on California's flood risks estimates 360,000 people in the San Francisco Bay are currently exposed to flood hazards in the 100-year flood plain and 1,040,000 people in the 500-year flood plain (FloodSafe 2013, Table 3-1). The same report estimates that $50 billion of structures and contents are currently at risk in the Bay Area within the 100-year flood plain with the amount increasing to $130 billion in the 500-year flood plain (FloodSafe 2013, Table 3-2). Santa Clara County is particularly at risk with 60% of its population in the 500-year floodplain and over $80 billion in structures currently exposed to flood risk (FloodSafe 2013, Figure 3-5). And these estimates do not include the costs of flood damages to utilities, transportation systems, and other critical infrastructure.

It's All Connected: Infrastructure Network Disruption

Hurricane Sandy provides an example of the impact of an extreme water level event on an urban area. Damage, estimated at $50 to $70 billion, included homes, businesses, and critical infrastructure such as subways, trains, roads, hospitals, electrical substations, and wastewater treatment facilities (Figure 4). For example, untreated and partially treated sewage flowed into local waterways for several weeks after the storm as wastewater treatment facilities were damaged by coastal flooding. The estimated cost of repairing New York's wastewater treatment plants was nearly $2 billion, while New Jersey planned to allocate nearly $1 billion for facilities repair and another $1.7 billion for building resilience into the system. Damage like this to a critical service sector, such as wastewater treatment, has impacts on areas well outside the flooded area. Significant financial losses occur as business operations, public health and safety, and transportation are all affected for long periods. Businesses are particularly affected, even losing market share, when they lose competiveness against similar enterprises unaffected by a flood event.

Figure 4 Scenes from Hurricane Sandy (clockwise from top left): LaGuardia Airport, Hoboken, New York City, New Jersey coast. *Source: JetBlue, Leong Ying, USAF/Olsen.*

The Pacific Institute looked at the vulnerability of key utilities to flooding in the Bay Area (Heberger *et al* 2012). They noted the vulnerability of the extensive wastewater treatment and power generation infrastructure located in the Baylands. There are 22 wastewater treatment plants representing almost 350 MGD of treatment capacity, as well as 11 power plants representing about 1,700 MW of generation capacity, that will be vulnerable to coastal flooding in the future. The 1,700 MW accounts for 18 percent of installed electricity generation capacity in the region.

Threats to the electrical grid increase the vulnerability of water and wastewater treatment plants and other infrastructure that require electrical power to function. Many facilities have backup or emergency power supplies on-site, but are not adequately flood-proofed.

While the Bay Area may not suffer from the impacts of hurricanes, major storms have been experienced in the recent past (Figure 5). Two severe El Niño winters (1982-83 and 1997-98) triggered storms with abnormally high tides to produce the worst Bay Area flooding in almost a half-century. In the 1997-98 storm, water surged over parking lots and Highway 1 in San Francisco and six-foot waves splashed over the Embarcadero waterfront. This storm also caused over four feet of flood waters to inundate Highway 101 north of San Francisco, and hundreds of people fled homes in low-lying areas around the Bay. The winter storms of 1997-1998 caused hundreds of millions of dollars in flood and storm damage in the Bay region. The water elevations associated with these storms, while uncommon in the past, are likely to be commonplace in the near future.

Risk: the expected economic damages caused by coastal flooding

When talking about natural hazards, the term "risk" is often used to describe the potential costs associated with the hazard. One common definition of risk is: *likelihood x economic consequence*.

For flood hazards, likelihood is the frequency of flooding (number of events/year). Frequency in this case is just the inverse of recurrence interval described above. For example, a 20-year recurrence interval has a frequency of 1/20, or .05 (5%). This means that in any year there is a 5% likelihood or chance that the 20-year recurrence interval flood will occur.

The consequence of the resultant flooding from that 20-year event is the damage caused ($/event). Damage varies depending not only on the nature of the flood (depth, duration, timing, etc.), but also on the location where flooding occurs (population, property, etc.). Risk, the product of likelihood and consequence, can therefore be expressed as the expected average amount of damage per year (=$/year). But, of course, the damage only occurs in the year(s) that the flood occurs.

Bay Wide Problem

The potential for coastal flooding is not limited to a few areas in the Bay. Figure 6 shows the extent of Baylands that are under threat today. The total area vulnerable to coastal flooding will simply increase as sea level rises; in areas already vulnerable the frequency and depth of flooding will increase. Risk (likelihood x consequence), however, is not equally distributed around the Bay. The magnitude of risk will vary in large part due to the value of assets affected by flooding. The risk in the South Bay will be much higher than in parts of the North Bay that are less developed. Figure 10 on page 10 shows the extent of flood risk from sea level rise in the South Bay.

Solutions

Just as flood risks vary around the Bay, so do the solutions. Some areas with no buffer lands (i.e., no wetlands or former wetlands, such as salt ponds or diked Baylands) will have to rely on traditional engineering approaches, such as levees and sea walls, to manage risks. San Francisco Airport, for example, has no natural buffer to protect it and limited prospect of creating one. Areas that have buffers, such as South Bay communities adjacent to former salt ponds, may be able to use natural flood protection assets in ways that are more economical and resilient to sea level rise.

Since tidal wetlands are typically located between the shore and infrastructure within the Baylands, they often provide the first line of defense against storm surges and flooding. Wetlands reduce the energy of incoming waves, lowering their height, erosive force, and ability to inflict damage on shoreline infrastructure (Figure 7).

While wetlands can provide protection from short-term flooding and erosion events, they can also provide protection from the impacts of sea level rise. Wetlands are in a state of dynamic equilibrium with the Bay, and are able to adapt to rising sea levels by building vertically and migrating landward.

Figure 5 Highway 101 Sausalito on-ramp taken during a King Tide in January 2011.
Source: Yanna B.

Figure 6 The risk of flooding is a Bay wide problem. The dark blue areas indicate the extent of inundation today if levees are breached during a 100-year storm event. The light blue areas indicate the additional areas of inundation with sea level rise of 59 inches.
Source: USGS.

Flood risk management is improved when areas of tidal wetlands exist between the developed shoreline and the open waters of the Bay. Further, by using tidal wetlands in combination with a levee constructed at the landward edge of the wetland (a "horizontal levee": Figure 8), the size of the levee can be reduced significantly while still providing the same level of flood protection. This wetland-levee combination lowers costs in three ways. First, the capital cost of levee construction is reduced due to its much smaller size. Second, maintenance costs are lowered because there is reduced damage due to shoreline erosion. Finally, done well, the wetland-levee combination can self-adjust to sea level rise, something a traditional levee cannot do.

Co-Benefits

Rethinking the Bay shoreline and making better use of restored wetlands can have significant benefits, beyond reducing flood risk, and help address some of the more immediate issues faced by the Bay:

- create buffers against erosion;
- improve water quality by filtering out nutrients and contaminants,
- capture and store greenhouse gasses;
- provide tourism, fishing, and education opportunities; and,
- connect Bay Area residents to the Bay by increasing recreational opportunities, including completion of the Bay Trail.

Opportunities

Key to the restoration of the wetlands and the creation of a more resilient shoreline is the leveraging of the existing investment in publicly owned lands around the Bay (Figure 9). Over the last ten years, federal, state, and local agencies have coordinated with Bay Area foundations, including the William and Flora Hewlett Foundation, Gordon and Betty Moore Foundation, and David and Lucile Packard Foundation to acquire lands to restore and expand natural habitats. Currently there are 36,000 acres (equivalent to the size of the city of San Francisco) in public ownership awaiting restoration. Once restored, these lands will nearly double the 44,000 acres of existing wetlands.

As an example, over the past ten years, the South Bay Salt Pond Restoration Project has restored or enhanced over 3,500 acres of former salt ponds and has a programmatic plan for restoration, flood protection, and public access for another 12,000 acres. As part of the project, USACE, the

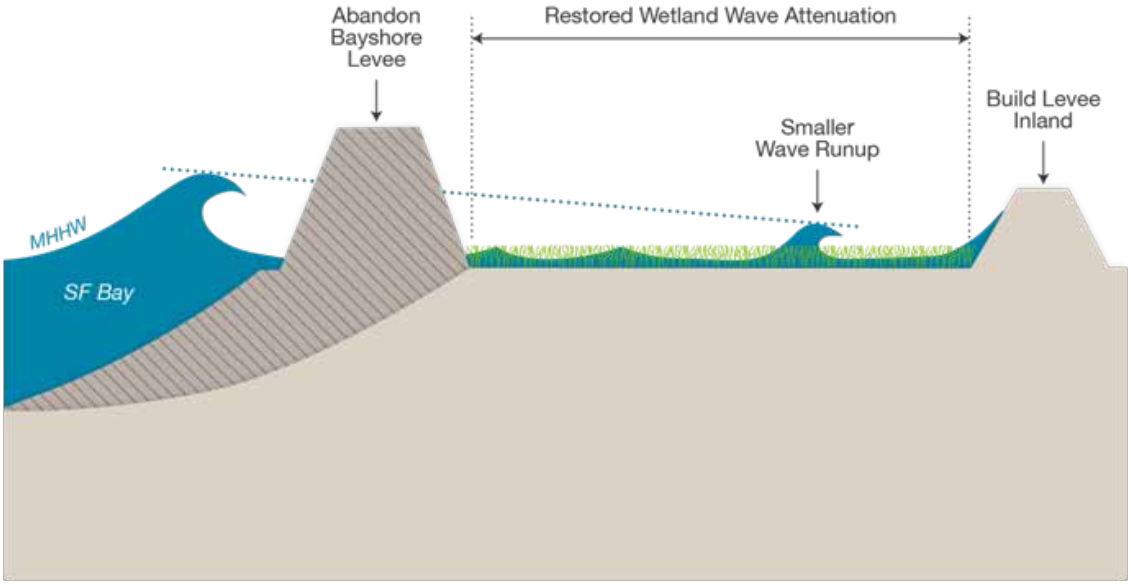

Figure 7 Wetlands in front of levees reduce wave impacts and construction costs. *Source: ESA PWA.*

Figure 8 Combining tidal wetlands, uplands, and levees in a "Horizontal Levee" provides additional benefits. *Source: Original graphic City of San Jose, modified by ESA PWA.*

State Coastal Conservancy, the Santa Clara Valley Water District, and other public agencies have undertaken a planning process, known as the Shoreline Study. The first planning phase, focused on restoration and flood protection in the Alviso area (marked as USACE Economic Impact Area 11 in Figure 10), is expected to be completed in December 2014. With a completed report, the project would qualify for federal implementation funding in a cost-share with state and local agencies. Once the Alviso planning study is complete, flood protection planning for the remaining South Bay shoreline will continue. In addition, USACE and State Coastal Conservancy, along with many local partners, have also been implementing restoration and flood protection projects in the North Bay including the Hamilton Airfield, Bel Marin Keys, and Napa-Sonoma Marsh projects.

Experts have recommended a minimum of 100,000 acres of tidal wetlands throughout the Bay to improve ecological and hydrological function. With 44,000 existing acres, the preliminary cost estimate for reaching 100,000 acres of restored wetlands with flood protection is $2 billion, far less than it would cost to recover from a single serious Bay Area flood. Federal funding is expected to cover at least 50% of the project costs with state and local funding providing the remainder.

A Solvable Problem

The increasing flood risk in the Baylands is a threat to the economy of the entire Bay Area, not just businesses and communities living along the shore. As Hurricanes Katrina and Sandy showed, ignoring or failing to properly address these risks can result in very high economic and social costs. But rather than being an intractable, expensive problem, managing flood risk and adapting

to change can be done in practical, cost-effective ways. A portfolio approach is needed, involving a mix of traditional engineering methods and new, multi-objective approaches. Of the latter, tidal wetlands remain the single greatest flood management asset in the Bay and there are numerous opportunities to restore them to support flood protection and ecosystem benefits.

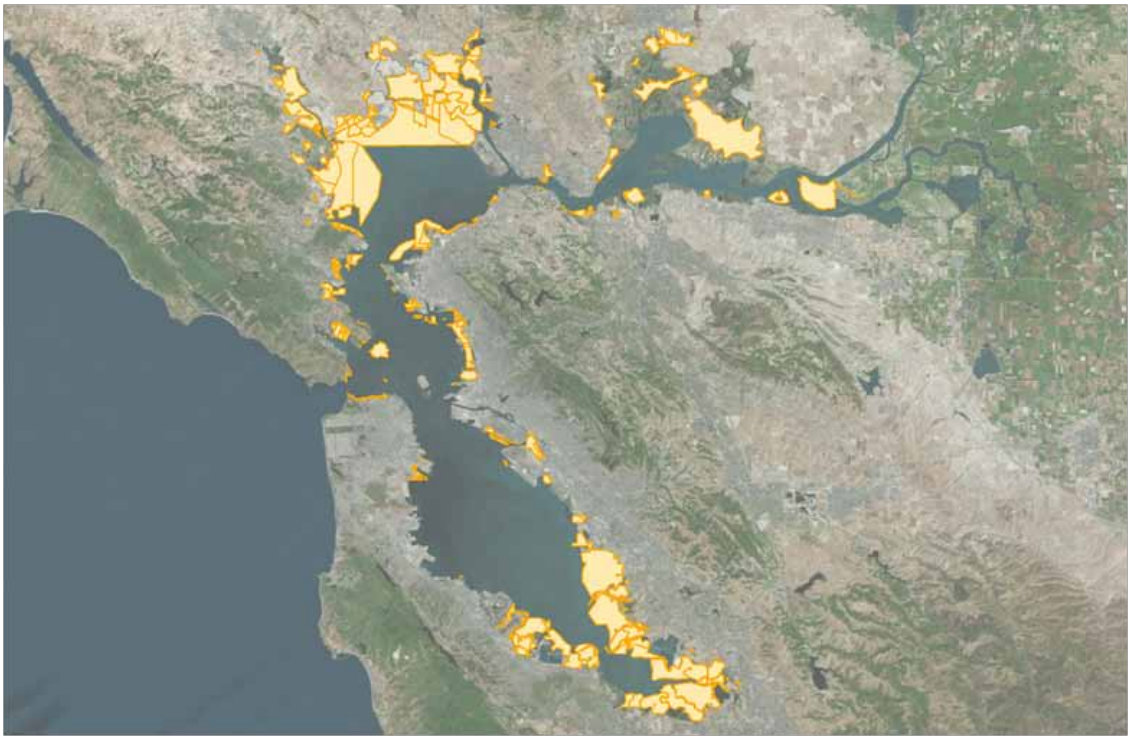

Figure 9 Publicly owned lands around the Bay that offer opportunities for restoration and flood protection. *Source: GreenInfo Network.*

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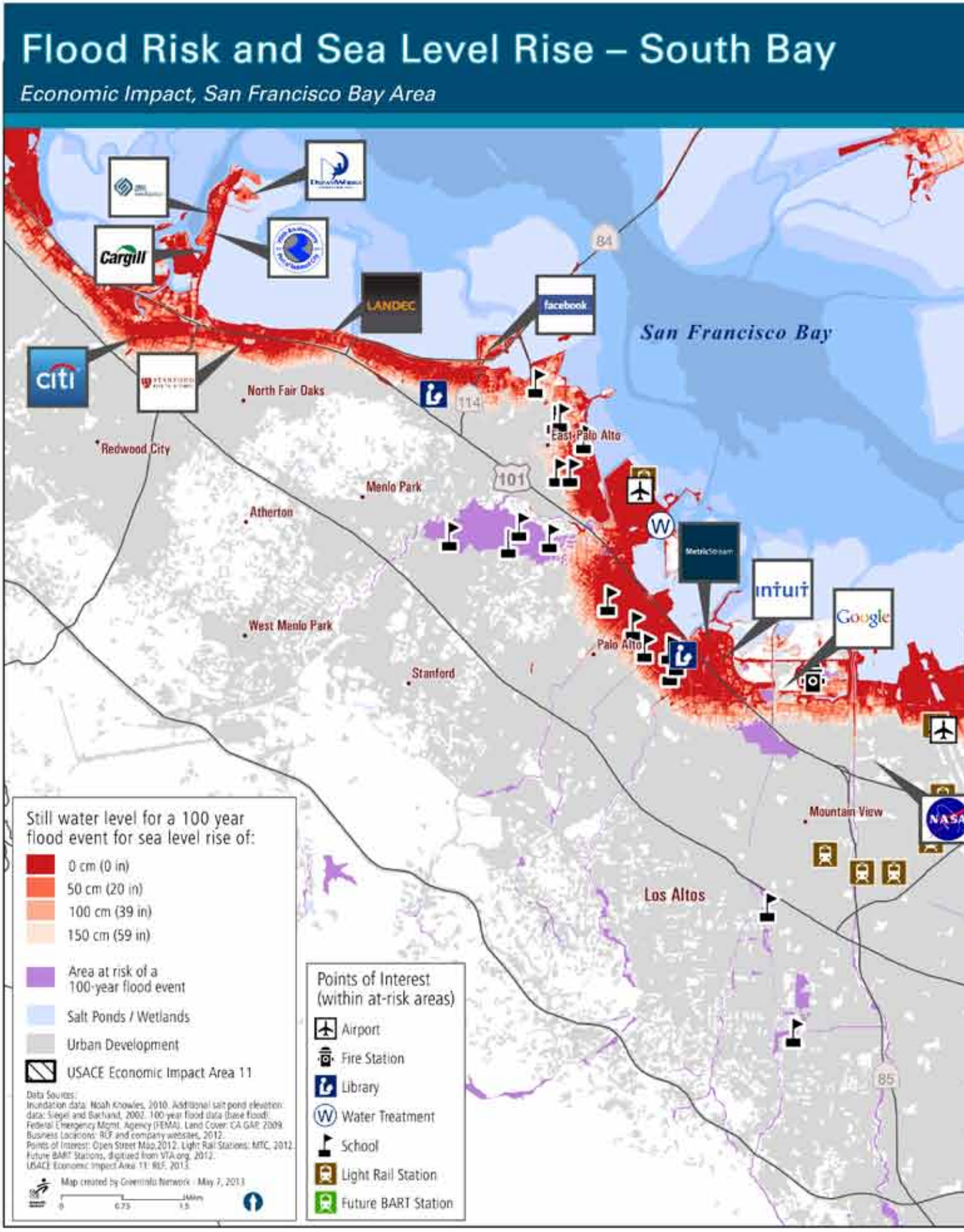
To Learn More Visit:

- South Bay Salt Ponds: www.southbayrestoration.org
- San Francisco Bay Joint Venture http://www.yourwetlands.org/
- Napa-Sonoma Marshes www.napa-sonoma-marsh.org
- Hamilton website http://hamiltonwetlands.scc.ca.gov/
- EcoAtlas: http://www.ecoatlas.org/regions/ecoregion/bay-delta

Figure 10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LANDEC
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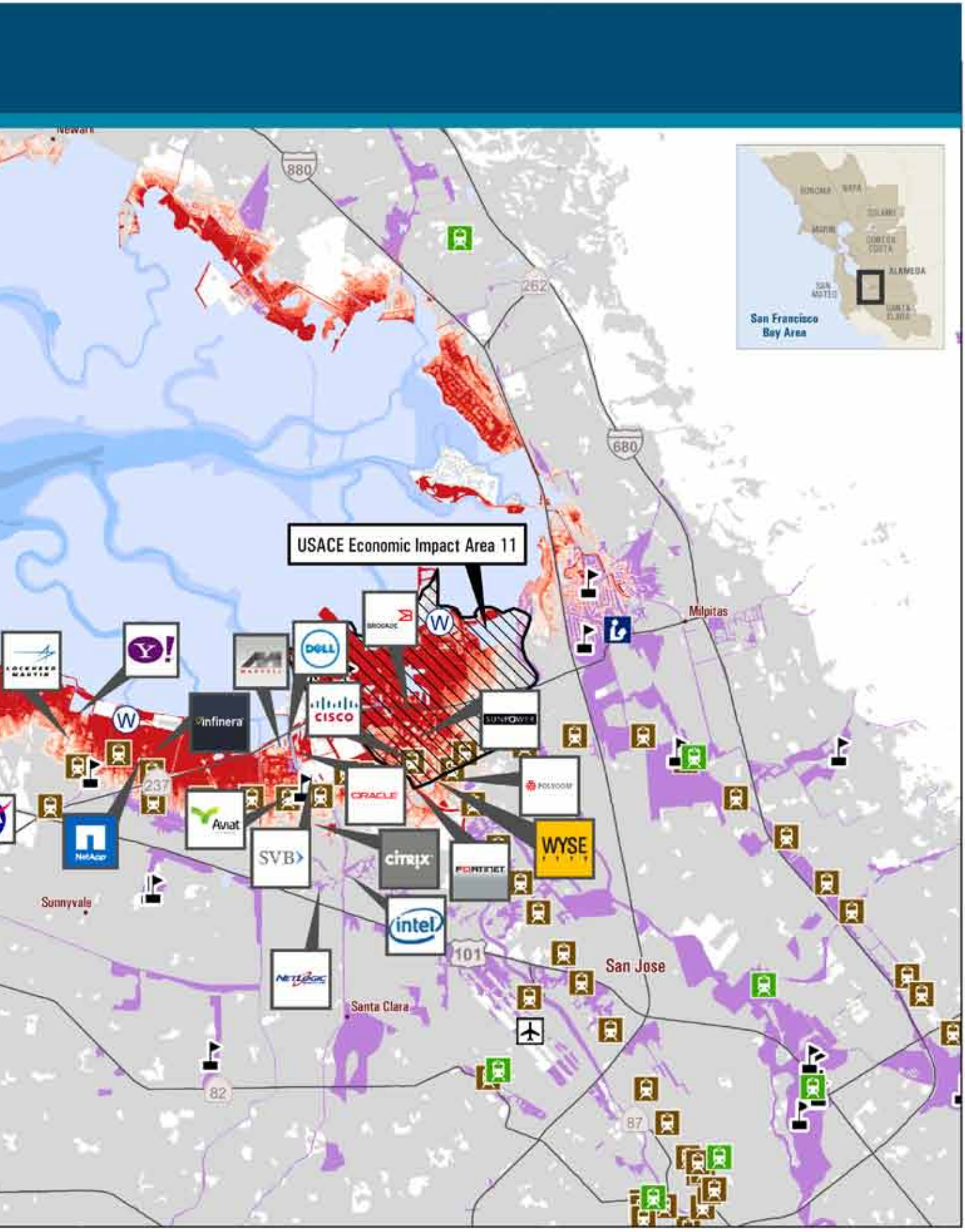
citi
North Fair Oaks
Redwood City
Menlo Park
Atherton
West Menlo Park
East Palo Alto
Palo Alto
Stanford
Mountain View
Los Altos
intuit
Google
84
101
114
85
Still water level for a 100 year flood event for sea level rise of:
0 cm (0 in)
50 cm (20 in)
100 cm (39 in)
150 cm (59 in)
Area at risk of a 100-year flood event
Salt Ponds / Wetlands
Urban Development
USACE Economic Impact Area 11
Points of Interest (within at-risk areas)
Airport
Fire Station
Library
Water Treatment
School
Light Rail Station
Future BART Station


USACE Economic Impact Area 11
San Francisco Bay Area
Milpitas
San Jose
Santa Clara
Sunnyvale
880
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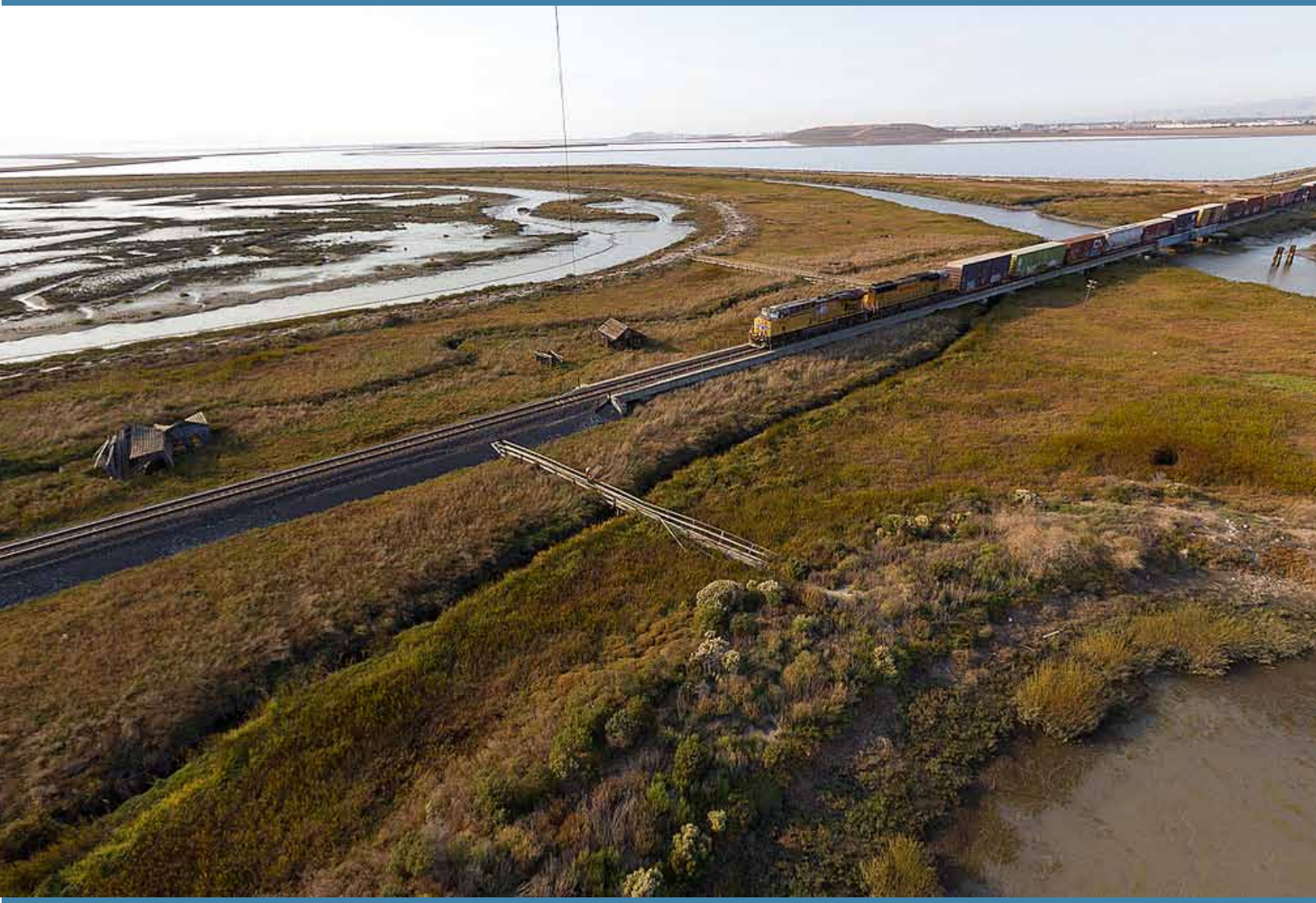

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