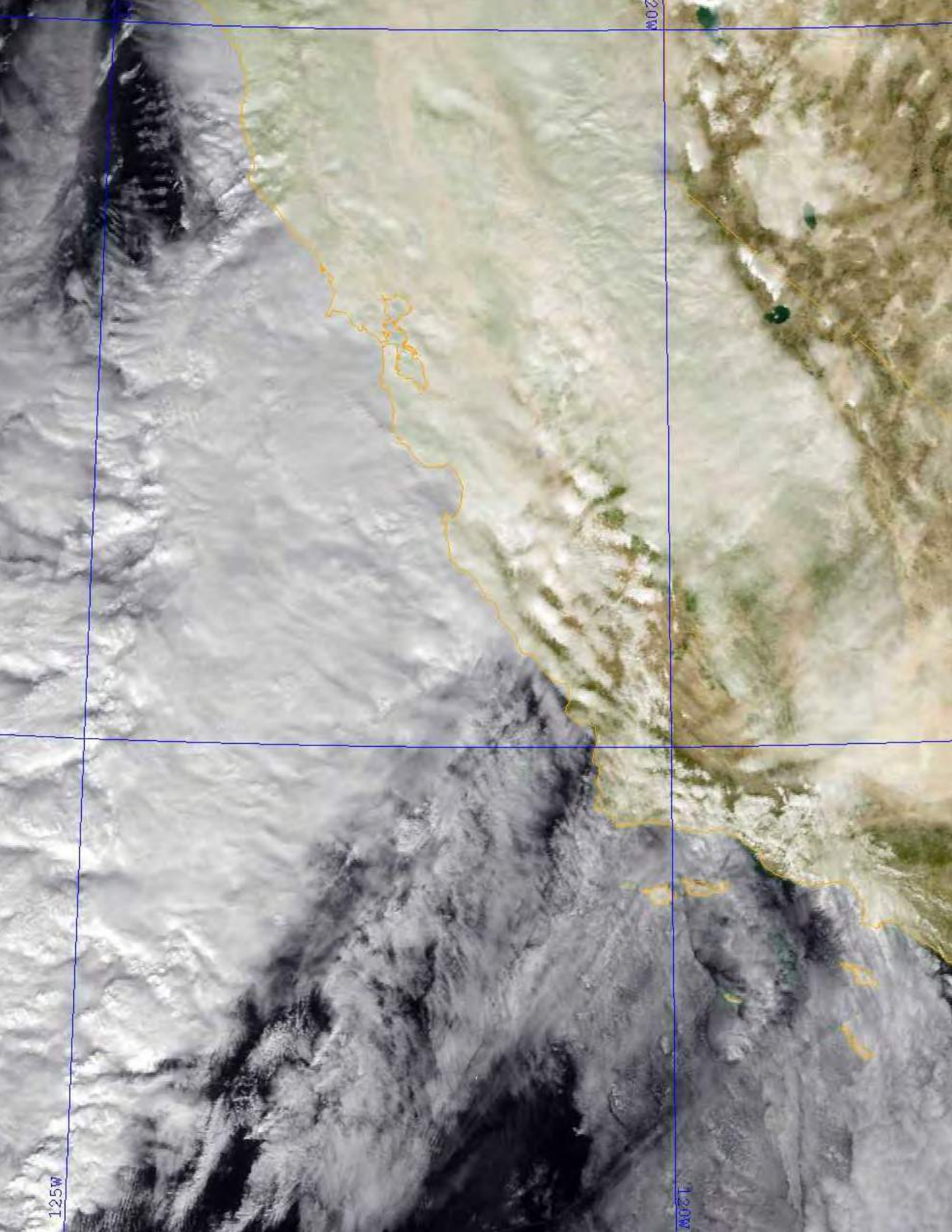




SURVIVING THE STORM

MARCH 2015



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PROJECT PARTNERS



The Bay Area Council Economic Institute is a partnership of business with labor, government, higher education, and philanthropy

that works to support the economic vitality and competitiveness of the Bay Area and California. The Association of Bay Area Governments (ABAG) is a founder and key institutional partner. The Economic Institute also supports and manages the Bay Area Science and Innovation Consortium (BASIC), a partnership of Northern California's leading scientific research universities and federal and private research laboratories. Through its economic and policy research and its many partnerships, the Economic Institute addresses key issues impacting the competitiveness, economic development, and quality of life of the region and the state, including infrastructure, globalization, science and innovation, energy, and governance. A public-private Board of Trustees oversees the development of its products and initiatives.



The Coastal Conservancy is a State agency, established in 1976, that protects and improves natural lands and waterways, helps people

get to and enjoy coastal areas, and sustains local economies along California's coast. The Conservancy works along the entire length of the coast, within the watersheds of rivers and streams that extend inland from the coast, and throughout the nine-county San Francisco Bay Area. The Conservancy is non-regulatory and achieves its goals by joining forces with local communities, nonprofit organizations, other government agencies, businesses, and private landowners.



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The Bay Area Flood Protection Agencies Association (BAFPAA) coordinates and provides mutual

support amongst Bay Area agencies who provided flood protection services. Through BAFPAA, member agencies learn from each other and gain a unified voice while working with other local, regional, State and Federal agencies. BAFPAA participates in the Integrated Regional Water Management Planning (IRWMP) efforts in the Bay Area to integrate projects and programs across all functional service areas to developed and implement regional plans.



The Gordon and Betty Moore Foundation believes in bold ideas that create enduring impact in the areas of environmental conservation, patient care and science. Intel co-founder Gordon and his wife Betty established the foundation to create positive change around the world and at home in the San Francisco Bay Area. Visit us at moore.org or follow us @moorefound.



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Powers Authority

REGIONAL LEADERS SPEAK ON FLOODS

“Protecting our residents and businesses from natural disasters is a high priority in San Jose. Continued regional, state, and federal collaboration to best prepare for Bay flooding from the likes of a 150-year storm is essential to remaining the world’s center of innovation and retaining our economic vitality in the decades ahead.”

–Mayor Sam Liccardo, City of San Jose

“This report highlights the real dangers we face from extreme weather events and climate change in the Bay Area. In San Francisco, we’re aggressively tackling these challenges by developing innovative capital planning guidelines accounting for sea level rise, meeting our greenhouse gas emission reduction targets, and investing billions to make our municipal infrastructure more resilient. San Francisco is taking the approach that preparing for tomorrow, starts today.”

–Mayor Edwin Lee, City of San Francisco

“We are fortunate to live in one of the most beautiful and geographically rich and diverse parts of the country. But with that diversity comes risk and responsibility. Knowing that we are a coastal city in a region already vulnerable to disaster and that climate change is impacting weather patterns around the globe, we have to take steps to protect ourselves from the inevitable. That means heeding the warnings and making smart local and regional investments in our physical and technological infrastructure that build the resiliency we need to safeguard our residents and communities from potential physical and financial devastation.”

–Mayor Libby Schaaf, City of Oakland

As Chair of the Assembly Select Committee on Sea Level Rise and the California Economy, I have had the opportunity to hear from experts about the

pending “double whammy” of sea level rise and major storm events. I thank the Bay Area Council Economic Institute for providing us with a wake-up call on the economic disaster that awaits the Bay Area if we do not prepare for a future extreme storm.

–Assemblymember Richard Gordon, California State Assembly

“California is no stranger to extreme weather events. Despite the ongoing drought, longtime residents know that floods come next. According to estimates from the Bay Area Council Economic Institute, a catastrophic storm event could cost the Bay Area more than \$10 billion. This is a level of damage would be equal to the Loma Prieta earthquake. To protect against this, we must reinvest in the flood control infrastructure the Bay Area desperately needs.”

–Assemblymember Marc Levine, California State Assembly

“In the event of an extreme storm, San Mateo County will be one of the hardest hit regions in the Bay Area. To avoid devastating consequences to our economy, infrastructure and communities, we must take action now to reduce flooding risks. If ever there was a case where ‘an ounce of prevention is worth a pound of cure,’ this is it.”

–Supervisor David Pine, San Mateo County Board of Supervisors

“Weather has an obvious impact on air travel and the larger economy, but an extreme storm in the San Francisco Bay area has the potential to disable our local infrastructure and cause as much as \$10 billion in economic damages—nearly as much as the Loma Prieta earthquake. It’s time for businesses and governments at the local, regional, state and federal levels to make flood defense and other preparations a priority.”

–David Cush, President & CEO, Virgin America

“We can’t say we weren’t warned. The Bay Area is past due for a major storm event unlike anything seen since the gold rush and potentially as damaging as a major earthquake. Sea level rise is only going to make the problem much, much worse.

Rather than await the inevitable Sandy or Katrina-type event, the Bay Area must proactively reinvest in the levees, sea walls and wetlands needed to defend our homes and businesses. With a little vision, the Bay Area can position itself to become the most climate resilient coastal region on earth."

**–Jim Wunderman, President & CEO,
Bay Area Council**

"The San Francisco Bay Area is at risk from flooding -- whether from rising seas or from a major storm. Either one could seriously damage our economy, with reverberations felt at the state, national and international levels. This cannot be allowed to happen. We must all work together now to adapt to the changing climate, before it is too late."

**–Carl Guardino, President & CEO,
Silicon Valley Leadership Group**

"BCDC welcomes this report on the ramifications of extreme weather – not because it is good news. Instead, it focuses on very real and important dangers to, and challenges faced by, the Bay Area. As more attention is focused on rising sea level worldwide and in our own San Francisco Bay, the critical relationships between issues of flood control and higher water levels are being recognized. I hope that this report will be disseminated widely and that it will expand the discussion of how the Bay Area needs to adapt to the inevitable dangers posed by large and extreme storms and rising sea level."

**–Zack Wasserman, Chair, San Francisco Bay
Conservation & Development Commission (BCDC)**

"Restoring the Bay will help protect our communities from flooding and promote our region's economy, all while enhancing water quality and wildlife habitat. This report shows why wetland restoration projects have overwhelming public support."

–David Lewis, Executive Director, Save the Bay

"We are fortunate in the Bay Area to not be debating whether climate change is real: we know it is, and California is leading the world in our efforts to slow it down. In the past few years, our region has come a long way toward understanding our climate

vulnerabilities, and figuring out what resilience could look like – but we need better planning, sustainable funding, infrastructure development and coordination to leverage these efforts toward a truly resilient regional approach. It is much less expensive to avoid damages – and misery – by being ready for disasters than it is to suffer them unprepared. The sooner we can scale-up our resilience efforts, the better off we all will be."

**–Laura Tam, Sustainable Development
Policy Director, SPUR**

"As the region continues to invest in its aging infrastructure, we must incorporate prudent policies and designs that will mitigate the risks associated with more extreme storm events and higher Bay water levels. The future of our Bay Area cities and economies depends on the conservation we're willing to make today, and the decisions we make for tomorrow."

**–Harlan Kelly, General Manager, San
Francisco Water Power Sewer**

"The Bay Area Council's new report on the risks from severe storms is both sobering and timely. But the report also highlights the opportunities we have regionally to address this threat with multi-benefit projects, like living shorelines and restored marshes. While not every mile of bay shoreline can be protected through such means, in many places we can create lower cost, effective shoreline protection that both protects the adjacent communities and supports our living resources so cherished by Bay Area residents."

–Judy Kelly, Director, SF Estuary Partnership

"If there's one place on earth with intellect, technology, and vision, combined with business and political leadership, to tackle the challenge of climate change, it's the San Francisco Bay Area. We're also ground zero for California's sea level rise impacts. We must take decisive leadership now so we're not chest deep in flood waters when the inevitable 150 year storm hits. For incentive, remember the last one hit 154 years ago."

**–Warner Chabot, Executive Director,
SF Estuary Institute**

EXECUTIVE SUMMARY



California's climate is famously volatile. While the state has averaged about 21 inches of precipitation per year since 1896, any given year can swing wildly from the mean, resulting in incidences of both devastating floods and remorseless drought.

Climate change is increasing the frequency and severity of such extreme weather events: 2014 was the record hottest year in state history, and according to tree-ring data, one of the driest in 500 years. At the same time, three of the wettest years in recorded California history have occurred since 1980. Along with sea level rise, extreme weather events are creating new risks to the world's great coastal and delta regions, including the San Francisco-Silicon Valley-Oakland Bay Area. Against this backdrop, and with Hurricanes Sandy and Katrina still in recent memory, what danger do extreme storms pose to the Bay Area economy today?

While the Bay Area is not exposed to hurricanes, it is vulnerable to prolonged periods of heavy rainfall, elevated tides and gale force winds known as "atmospheric rivers". These "rivers," so nicknamed for the long, ribbon-like bands of moisture that stretch across the Pacific Ocean, can be enormous. This report outlines the potential economic consequences of a hypothetical atmospheric river that contains the moisture equivalent of 10 Mississippi Rivers. In this storm event, daily life slows to a crawl as the region is pummeled by 12 inches of rain over seven days, causing widespread flooding and disruption to road and air travel.

The "100-year flood event," a hypothetical storm used by the Federal Emergency Management Agency (FEMA) for planning and insurance

purposes, is an event that statistically has a 1% chance of occurring in any given year. Based on hydrological records, information on riverine and coastal flooding, and modeling of storm events on creeks and rivers, the hypothetical storm created for this analysis is approximately a 150-year event—smaller than the catastrophic storm of 1861-62, but larger than any storm since.

High water levels in the Bay can elevate flooding risk, and are often higher during major weather events due to storm surge that results from low barometric pressure and high freshwater flows into the Bay. In the extreme storm event developed for this study, it was assumed that an extreme high tide, also known as a "King Tide", at the Golden Gate occurred in the midst of the storm.

While extreme storms are by definition rare events at any given location, when considering a larger geographic region the likelihood of an extreme event occurring somewhere within that area can be relatively high. Geologic evidence indicates that within the state, floods as large or larger than the 1861-1862 flood occur about every 200 years. It has been over 150 years since the last mega flood in California.

In the San Francisco Bay Hydrologic Region, approximately 355,000 Bay Area residents and \$46.2 billion in structures and contents are located in a 100-year floodplain; over one million residents and nearly \$134 billion in structures and contents are located in a 500-year floodplain.

These assets are exposed to flood risk—in low-lying areas along the Bay, at the downstream ends of rivers and creeks, and along the creeks themselves.

COSTS OF INACTION

This report estimates that the economic cost of an extreme storm, under 2015 conditions, will start at \$10.4 billion. For perspective, the damage from the Loma Prieta earthquake in 1989 was \$11.3 billion in inflation-adjusted dollars. Broken down, the \$10.4 billion in damage is estimated as follows: \$5.9 billion in structural damage, \$4.2 billion in damage to building contents, \$125 million in loss of electricity service damages, \$85.7 million in costs due to air transportation delays caused by temporary closures, and \$78 million in costs due to road closures.

These costs represent a snapshot of the Bay Area's vulnerability as it exists today. While substantial, these figures are likely to significantly underestimate the economic vulnerability of extreme storm events for several reasons.

First, this report is focused on damage within the Bay Area alone. Any storm of the size considered here would likely bring significant—if not greater—damage to the Bay Area's periphery, especially the Sacramento-San Joaquin Delta and the Central Valley. Delta flooding could itself render up to \$10 billion in additional economic damage to the Bay Area by cutting the region off from its second largest supply of drinking water (see disaster profile on the Delta flooding). Second, California is vulnerable to storms larger than the one considered in this report. An example is the so-called ARkStorm, a state-wide mega storm modeled by state and federal scientists, which projections show could cost up to \$725 billion statewide and require the evacuation of 1.5 million people. Third, the figures do not include damage to key infrastructure, such as communications networks,

highways and airports. Finally, the analysis does not consider future increased risk from sea-level rise. The California Climate Action Team projects California's coastal waters will increase between 5 to 24 inches by 2050, and 17 to 66 inches by 2100, levels which would result in this same storm causing potentially billions of dollars of additional damages.

The costs predicted in this report are distributed throughout the region with the greatest damage occurring in Santa Clara, San Mateo and Marin Counties, where 80% of the expected damage would be concentrated.

Finally, as the world's coastal regions consider ways to improve their defenses, rising ocean levels are steadily increasing the vulnerability to extreme storm-related damages. For the Bay Area, doing nothing is akin to going backwards, as today's typical winter rains become tomorrow's flood. Now is the time to take action.

FLOOD PROTECTION INFRASTRUCTURE

Unlike transportation, drinking water and sanitary facilities, flood protection infrastructure is rarely seen or appreciated by the public. Flood defenses are measured against an event that may not occur in a lifetime, but they provide vital security for community assets including businesses, homes, schools and more visible infrastructure like transport, energy and sanitary services.

Flood protection infrastructure includes levees, flood control channels, detention basins and tanks, wetlands, sea walls and reservoirs. Despite their essential role, funding to develop and maintain

these facilities is challenged. Historically, the federal government, through the U.S. Army Corps of Engineers or the Natural Resources Conservation Service (aka the Soil Conservation Service), was a partner with local flood management agencies in constructing many of the flood protection facilities that are protecting communities today. The federal government provided 80% and sometimes up to 90% of construction costs, and the state had a subventions program that paid 70% of right-of-way costs.

Today, however, the Corps has a backlog of unconstructed projects throughout the country, a lengthy and expensive planning process that is cost-shared 50% federal and 50% local, and cost sharing for construction that is now shared 65% federal and 35% local. In addition, the state subvention program is no longer available. These changes have increased the time and cost of building regional flood protection facilities. Also, flood protection facilities built by the Corps must be maintained by local flood control agencies. Most flood protection agencies have a backlog of deferred maintenance due to their constrained ability to fund adequate maintenance programs.

This is a looming issue, as many of the facilities that are relied on today are either near, at or beyond their design life, or do not meet federal design standards. This aging infrastructure will be under even greater pressure in the event of an extreme storm, which will generate simultaneous threats: wind-generated waves, surface water expansion from storm surge, and water levels in the Bay that make it harder for stormwater from local creeks and rivers to drain, backing up water into shoreline communities. Changing weather patterns are expected to produce

wetter storms with higher peak flows in the future, resulting in more intense flooding in creeks and rivers that drain the Bay Area's watersheds. This increased pressure does not take into account the anticipated long-term effects of sea-level rise.

Past and current efforts to address flood management issues in the region are illustrated in this report by a number of case studies: in the North Bay (Napa River and Corte Madera Creek), East Bay (Alameda Creek, Walnut Creek, and Oakland Airport), South Bay (Guadalupe River and South San Francisco Bay shoreline), and the Peninsula (San Francisquito Creek, San Francisco Airport, and San Francisco's Urban watershed).

RECOMMENDATIONS

While atmospheric conditions in California differ from the East and Gulf Coasts, New York's experience with Hurricane Sandy and the impact of Hurricane Katrina on New Orleans point to the importance of preparing for potentially catastrophic events. The good news is that comparatively small investments can provide large returns by preparing the region for these events and protecting its economy from crippling damage. Furthermore, many of these same investments can also improve the health of the Bay ecosystem. This study offers several recommendations at the local, regional, state and federal levels.

GENERAL RECOMMENDATIONS

Infrastructure

Support the development of cost-effective structural and non-structural strategies, tailored to the region's variety of local environments, to reduce flood risk. This includes sea walls, levees, wetlands, floodplains and living shorelines to defend against bay flooding, and detention basins, bioswales, restored floodplains and stream channels, and other green infrastructure to reduce fluvial flooding.

Funding

Identify new and expand existing local, regional, state and federal funding for flood infrastructure investment.

Prioritization

Identify and prioritize projects necessary to protect key economic assets such as transport, power, water, wastewater, employment centers, and communications infrastructure.

Planning

Incorporate community resilience to extreme storms into Hazard Mitigation and General Plans. Identify ways to leverage new development under regional growth plans to provide local flood protection and reduce economic vulnerability. Incorporate climate change predictions, including sea-level rise and changes in rainfall, into flood risk analyses.

Early Warnings

Support development of accurate weather and flood forecasting, particularly for lead-time on atmospheric rivers. Support the development of operational strategies for managing floodways based on such forecasts.

Emergency Response

Support the development of Flood Emergency Management Plans and increase coordination and communication among disaster responders, facility managers, and flood management planners to improve readiness for flood disasters and better prepare communities for the next storm.

Coordination

Promote coordination among flood protection agencies (such as the Bay Area Flood Protection Agencies Association) and with others (regional agencies, businesses, and cities) in developing shared strategies, methods, policies and funding mechanisms.

LOCAL LEVEL RECOMMENDATIONS

Support the work of local flood protection agencies to plan and implement flood risk management projects on creeks and rivers and on the Bay's shoreline.

- Develop and support local measures and benefit assessment districts that create stable funding streams for local flood risk solutions. Consider a rate-payer model for flood protection, similar to water supply and sewer, both of which benefit from steadier funding.

Emphasize the role of cities and counties in conducting vulnerability analyses, approving development, and supporting hazard mitigation strategies that take extreme storm events and sea level rise into account.

- Incorporate methods for increasing community resilience to extreme storms into General Plans.

BAY AREA REGIONAL RECOMMENDATIONS

Regularly evaluate regional flood risk and communicate findings, including the cost of doing nothing and the cost of improving readiness, to Bay Area residents, business leaders, and elected officials.

- Develop regional flood risk reduction goals and acceptable levels of residual risk.
- Consider regional economic resilience to extreme storms on flood protection plans.

Support the identification of regional interdependencies and vulnerabilities that elevate particular flood risks beyond the local level to a level of regional significance; develop regional strategies for flood protection.

- Focus on the interdependence of transportation corridors, including transit, regional rail, and air traffic.
- Focus on the resilience/continuity of critical regional services, including power, water supply, wastewater treatment, and telecommunications.
- Evaluate and address the continuity of emergency services (flood response, fire, EMT, provisioning) during and after severe events.
- Evaluate populations and communities particularly at risk (such as the elderly, infirm, and non-English-speaking) in a major regional event.
- Evaluate and address particular land uses at risk, including landfills and hazardous waste sites.
- Assess overlaps and conflicts in needs and resources with Delta and Central Valley communities that could be concurrently affected.

Develop regional funding strategies for flood protection, including measures that provide for flood protection through wetlands restoration.

- Include regional strategies being developed to address anticipated sea-level rise, such as the Bay Conservation and Development Commission's Adapting to Rising Tides (ART) project.
- Support funding for the San Francisco Bay Restoration Authority to restore wetlands and provide associated flood protection.

STATE OF CALIFORNIA RECOMMENDATIONS

In keeping with the recommendations in the California Natural Resources Agency's Safeguarding California Plan, support funding from the State of California for flood protection and extreme-weather resiliency in the Bay Area.

- Through such agencies as the Department of Water Resources, the California Department of Fish and Wildlife, and the State Coastal Conservancy, support funding for flood protection projects and wetlands and riparian restoration through state bonds and cap and trade revenue.
- Through the Department of Water Resources, support flood subvention funding to local governments to cost-share federal flood protection projects.

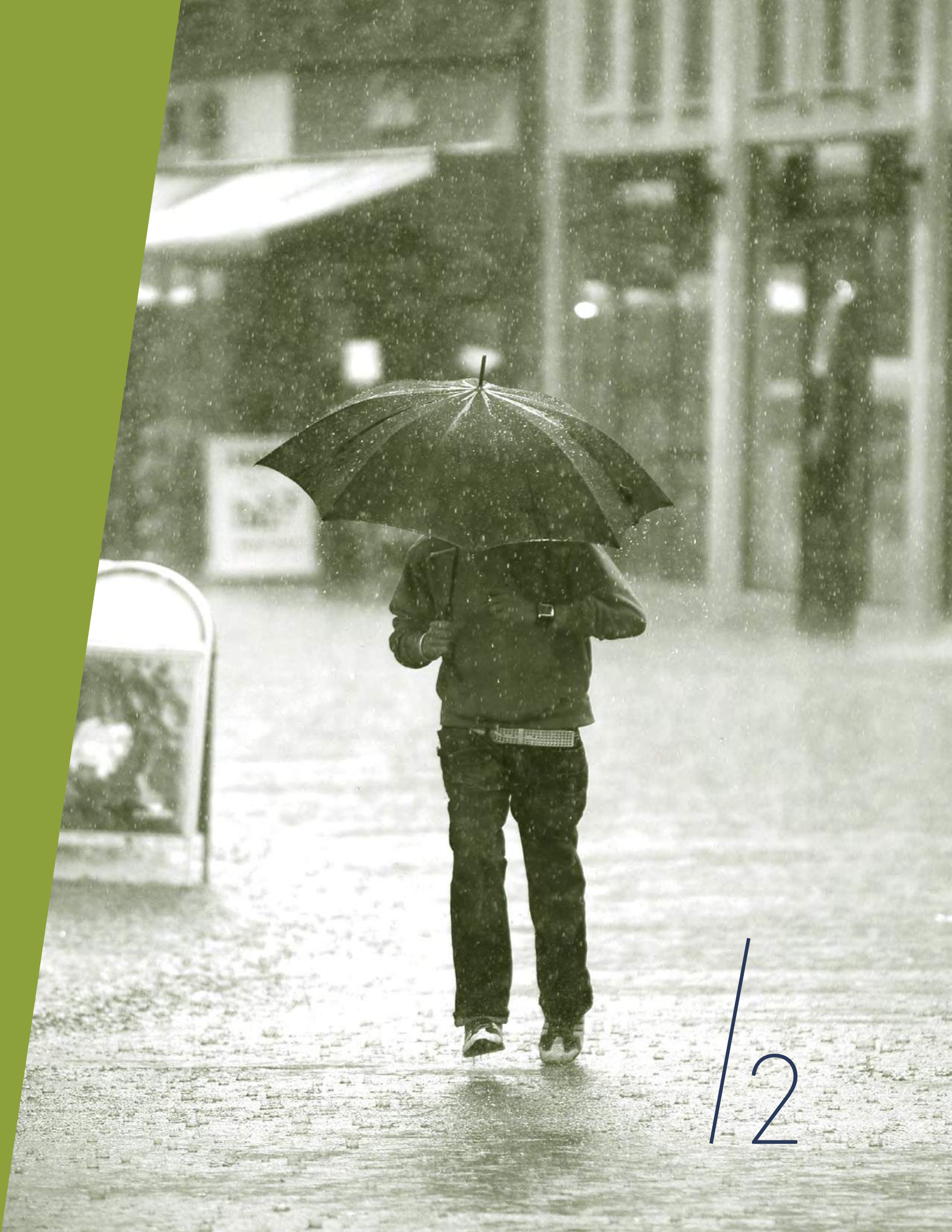
Exempt flood management fees and assessments from electoral requirements associated with Proposition 218.

FEDERAL RECOMMENDATIONS

Support the coordinated engagement in regional extreme weather planning by the federal agencies charged with flood management, water quality or weather forecasting, primarily the US Army Corps of Engineers, the US Environmental Protection Agency (EPA), FEMA, and the National Oceanic and Atmospheric Administration (NOAA).

- Support implementation of flood protection projects that provide a 100-year or greater level of protection for communities at risk of flooding, through cost-effective and efficient development of studies with the Corps of Engineers in partnership with local sponsors.
- Support the application of new standards established in the January 2015 White House executive order, requiring that federally-funded construction projects take into account the added flood risks associated with sea level rise.
- Support passage by Congress of a Water Resources Development Act every two years, to authorize new federal flood protection projects for construction, with annual appropriations by Congress to plan and construct flood protection projects.
- Provide the Corps of Engineers with greater flexibility in evaluating and constructing multi-objective projects that provide flood protection and restore wetlands or riparian habitat.
- Streamline the FEMA levee accreditation program, to reduce the financial burden on local communities.
- Provide greater flexibility to FEMA to support the rebuilding of communities after disasters to be more resilient to extreme weather events in the future.
- Support the work of NOAA to forecast major floods as well as changes in climate that could lead to more extreme events and sea-level rise, and provide local communities with modeling tools for assessing vulnerabilities and planning for resilience.
- Amend the funding formula for US EPA's major geographic initiatives to reflect watershed size.

BACKGROUND



/2

AN EXTREME STORM IN THE BAY AREA

The rains began late on a Thursday evening commute, a gentle sort common to the Bay Area in the winter, slowing the region's normal crawl home. Low, black clouds scraped across the region all morning the next day as re-awakened creeks bubbled their way to the Bay. But that night the skies opened, and 2 inches of rain fell overnight throughout Marin and Santa Clara Counties and the East Bay. Fifty-mile-per-hour winds lashed transmission lines, buffeted regional truck transport, and slowed transit to the weekend's big games. Many people waited out the wet weekend, while others began bailing flooded basements.

By Monday morning the storm had swelled into the year's worst, with almost 7 inches of rain since the start of the storm and persistent flooding along the Bay's margin. Major creeks were unable to drain, jumping their banks and flooding into neighboring communities, and portions of Highways 101 and 37 were shut down. During the morning's high tides, waves overtopped seawalls and levees around the region, resulting in deeply flooded residential areas in the South Bay and Contra Costa and Marin Counties and flooding stretches of San Francisco's Embarcadero. Lengthy delays occurred at San Francisco and Oakland International Airports throughout the next few days.

Backed by an atmospheric river with a moisture equivalent of 10 Mississippi Rivers¹, the storm continued to rage for over a week. By its end, it became the worst storm since 1862 resulting in at least \$10 billion in damage to the regional economy.

A storm of the magnitude described above hasn't happened to anyone alive in the Bay Area today, but such a large storm did occur in the early days of the state of California and will happen again. During the Great Flood of 1862, it rained for 28 of 30

days from Christmas Eve 1861 to January 21, 1862, resulting in 34 inches of rain in San Francisco (See Sidebar #1: Mega Floods). More recently, the Bay Area has suffered significant flooding from large storms during the winters of 1982-83, and again in 1996-97, and experiences routine local flooding during King Tides. In the wake of recent devastating extreme storm events afflicting the Atlantic and Gulf Coasts, this analysis seeks to explain what an extreme storm in the Bay Area would look like and the extent of physical and economic damage it would likely cause, and recommends actions that can be taken to protect our homes and the economy.

HYPOTHETICAL MEGA STORM

- Approximate 100 to 200 year return period
- Up to 12 inches of rain over 4 to 7 days*
- Elevated creek and river flows lasting over one week; peak flood flows last one day
- High tide in the Bay based on maximum observed tide which occurred in January 1983
- Area inundated by flood waters based on computer analysis of flood flows and a review of FEMA flood maps and other flood studies

*Varies by sub region, i.e., North Bay, East Bay, San Francisco, Peninsula, and South Bay

EXTREME STORMS IN CALIFORNIA

California's climate is famously volatile. While the state has averaged about 21 inches of precipitation per year since 1896, any given year can swing wildly from the mean, resulting in incidences of both devastating floods and remorseless drought.

Unlike the hurricanes of the East and Gulf Coasts or supercell thunderstorms of the Great Plains, extreme rainfall usually comes to coastal California in the form of multi-day winter storms sweeping in from the Pacific Ocean. Storms can back up in series, one after another, resulting in heavily saturated soils, clogged floodways, elevated bay water levels and multiple flooding events over days or even weeks. Some of the most extreme storm events are what are termed “atmospheric rivers,” during which the jet stream steers massive amounts of humid air toward the California coast. Often likened to a fire hose, these storms are sometimes called the “Pineapple Express.”

There is no single definition for an “extreme storm.” The label is usually applied to storms that have the potential to cause large-scale damage and/or loss of life and that occur on an infrequent basis. Just

as earthquakes vary in magnitude and epicenter, extreme storms vary in geographic area, duration, and intensity. They are typically categorized by their return frequency, i.e., the average annual risk of recurrence.

Extreme storms create extreme flood risk, and the Federal Emergency Management Agency (FEMA), the US Army Corps of Engineers, and the California Department of Water Resources all have separately developed standard models to define an extreme flood event.

FEMA uses a 1% annual flood, commonly referred to as a 100-year event, as its standard for defining floodplains for purposes of setting insurance rates. Flood insurance is required only for those structures located within the 100-year floodplain. FEMA’s maps also often show the boundaries of the 500-year or 0.2% annual chance flood.

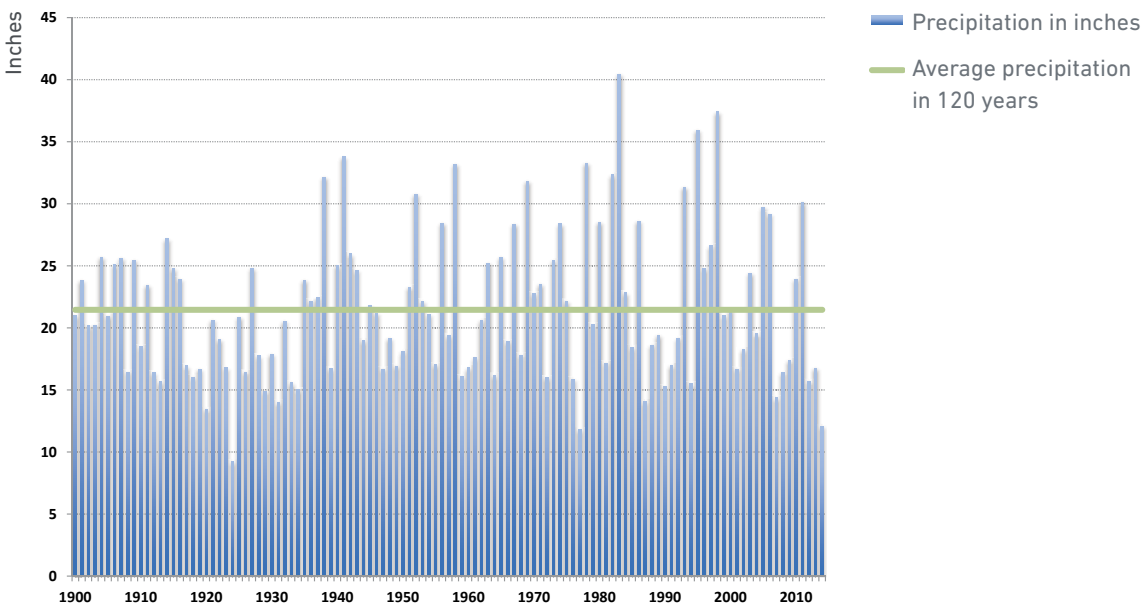


Figure 1. California Historic Annual Precipitation

Source: Western Regional Climate Center

Notes: Bars indicate the statewide average precipitation in California based on water year (October–September) since 1896. The three-year period between October 2011 and September 2014 was the driest on record.

California state law specifies a 0.5% or 200-year annual chance flood as the standard minimum for a level of flood protection for urban and urbanizing areas in the Sacramento and San Joaquin Valleys (i.e., the urban level of flood protection). This is the standard that the California Department of Water Resources uses in the design of new levees.

The US Army Corps of Engineers uses what it calls a “Standard Project Flood” to determine appropriate levels of flood protection for given areas. The Standard Project Flood is defined to

(2) Represent the flood discharge that should be selected as the design flood for the project, or approached as nearly as practicable in consideration of economic or other governing limitations, where some small degree of risk can be accepted but an unusually high degree of protection is justified by hazards to life and high property values within the area to be protected.²

While a frequency is not assigned to this standard, subsequent analysis often finds the Standard Project Flood to be in the range of a 200- to 500-year recurrence interval.³ For example, the Alameda Creek Flood Control Project in Alameda County was designed for the Standard Project Flood of 52,000 cubic feet per second; the maximum recorded flow (based on over 100 years of data) at Niles Canyon at the upstream end of the project is 29,000 cubic feet per second, which occurred during a flood event in 1955.

While extreme events can have different definitions depending on the agency defining the event and its purposes, in almost all cases the extreme event is at least a 100-year event or larger.

HOW OFTEN DO EXTREME STORMS OCCUR?

Extreme storms are by definition rare events. A 100-year flood event at a given location will occur on average once every 100 years over a long period of time. It is possible to get two 100-year events in two sequential years; it is also possible to go 200 years without ever getting an event as big as a 100-year flood event.

When looking at storms over a larger geographic area, the likelihood of an extreme event occurring somewhere in that geographic area can be relatively high.

Analyzing rainfall data provides another indicator of flooding potential. The return period calculations for precipitation events provide information that is analogous to the 100-year flood, but for rainfall instead of flow. A study conducted by the California Department of Water Resources in 1997⁴ reviewed data from precipitation gauges throughout California. The study was based on 100,000 station-years of daily rainfall observations from 3,000 gauges and defined a 1,000-year rainfall event as having a magnitude of approximately five standard deviations above the mean at a given location. The study concentrated on 46 storms from the winter of 1850 to January 1993 and concluded that California has had about 45 1,000-year storms in 90 years. Figure 2 shows the locations and dates of occurrence of 21 of these 1,000-year rainfall events. During the period covered in the study, 1,000-year rainfall events occurred at seven locations in the Bay Area (although only four of the seven locations are labeled on the Figure 2 map). These seven 1,000-year precipitation events all produced flooding, landslides and/or property damage.

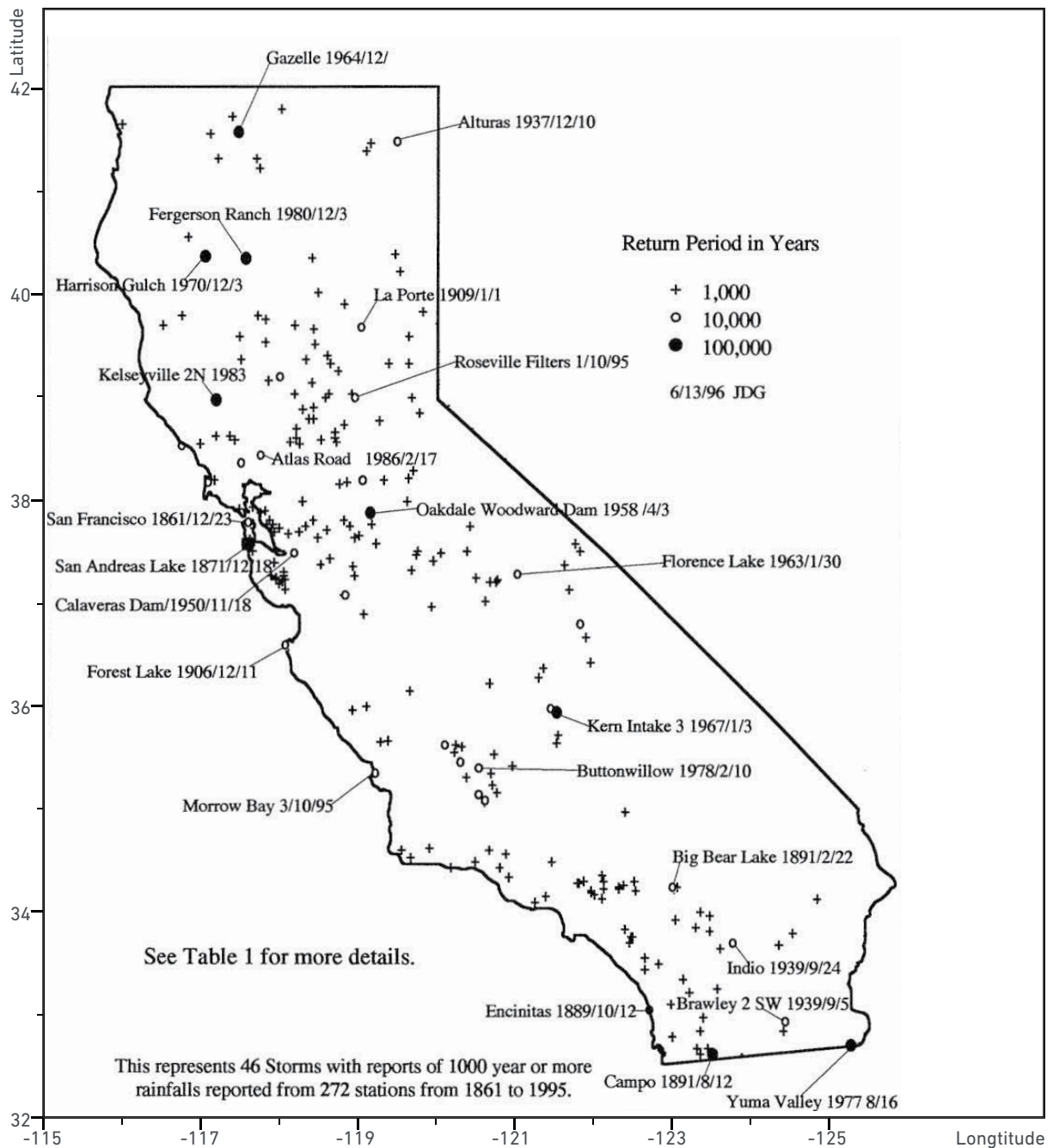


Figure 2. Locations of Extreme Rainfall Events in California, 1850–1993

Source: California Department of Water Resources, *Historic Rainstorms in California: A Study of 1,000-Year Rainfalls*, August 1997.

One of the observations in the study is that the variability of the last 50 years is far greater than the variability of the previous 50 years, indicating that large precipitation events may become more frequent.

The most extreme daily rainfall reported in California had a return period of 360,000 years. This event was in San Mateo County at San Andreas Lake, which received 13.63 inches of rainfall on December 19, 1871.

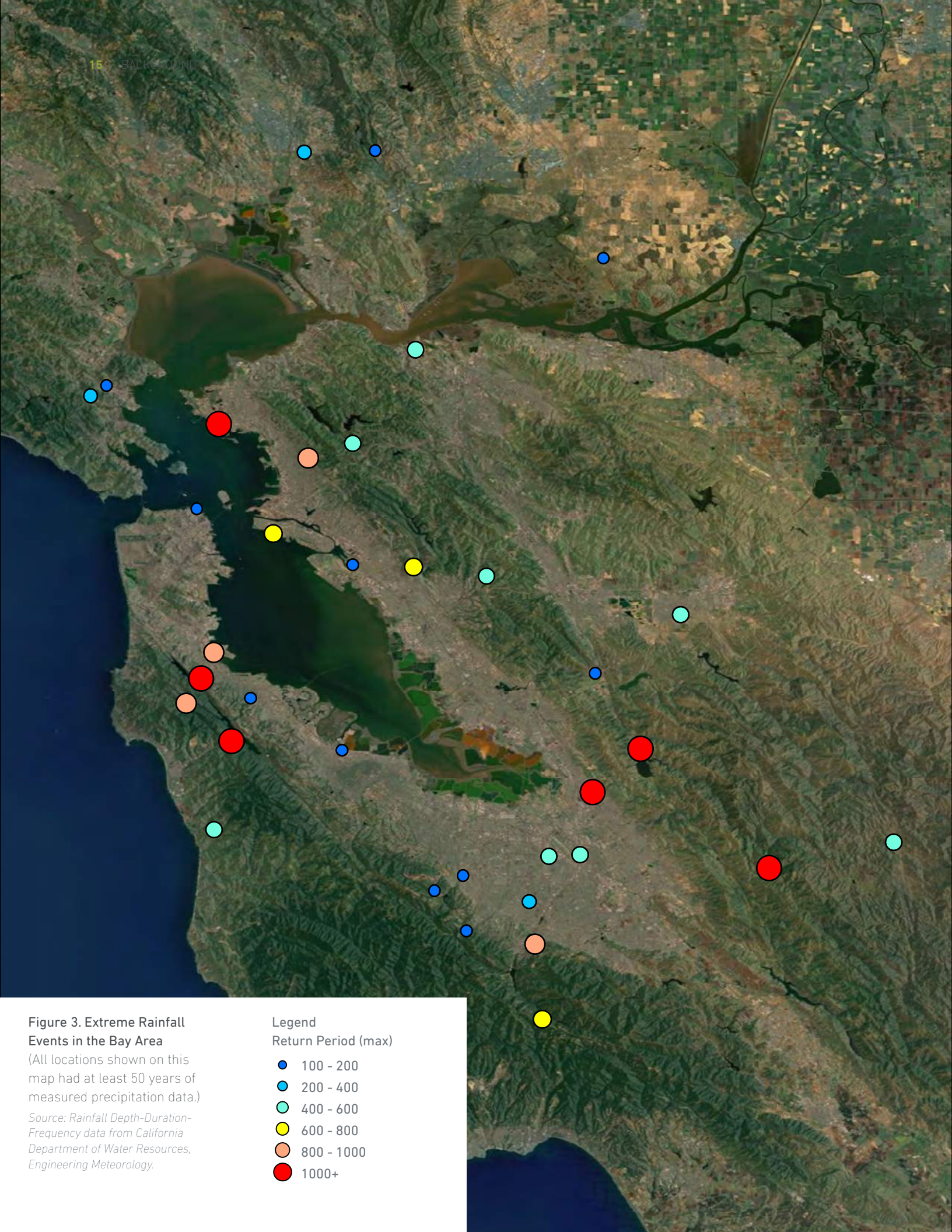


Figure 3. Extreme Rainfall Events in the Bay Area

(All locations shown on this map had at least 50 years of measured precipitation data.)

Source: Rainfall Depth-Duration-Frequency data from California Department of Water Resources, Engineering Meteorology.

- Legend**
Return Period (max)
- 100 - 200
 - 200 - 400
 - 400 - 600
 - 600 - 800
 - 800 - 1000
 - 1000+

EXTREME STORMS IN THE BAY AREA

A similar analysis of precipitation data collected in the Bay Area shows that large precipitation events occur locally more regularly than is often expected. Figure 3 shows the locations of daily rainfall events in the Bay Area with return periods greater than 100 years. Note the dozen rainfall events with return periods of 600 years or greater and the six of those with return periods greater than 1,000 years.

The very real likelihood of these events creates a situation where many more people and much more infrastructure are at risk than is commonly recognized.

In the San Francisco Bay Area, approximately 355,000 people and \$46.2 billion in structures and contents are located in a 100-year floodplain.

Table A provides a snapshot of people, structures, crops, infrastructure, and sensitive species that are exposed to flood hazards in 100-year and 500-year flood events.

Segment Exposed	100-year (1%) Floodplain	500-year (0.2%) Floodplain
Population (% total exposed)	355,000 (6%)	1,041,400 (17%)
Total Depreciated Replacement Value of Exposed Structures and Contents	\$46.2 billion	133.8 billion
Exposed Crop Value	\$17.3 billion	23.9 million
Exposed Crops (acres)	33,300	44,000
Tribal Lands	0	0
Essential Facilities (count)	140	466
High Potential Loss Facilities	168	303
Lifeline Utilities (count)	47	58
Transportation Facilities	560	1,022
Department of Defense Facilities (count)	8	8
Plant species State - or Federally listed as Threatened, Endangered, or Rare ^a	167	169
Animal species State - or Federally listed as Threatened, Endangered or Rare ^a	106	110

Table A. San Francisco Bay Hydrologic Region Exposures Within the 100-Year and 500-Year Floodplains

Note: a. Many Sensitive Species have multiple occurrences throughout the state, and some have very large geographic footprints that may overlap more than one analysis region. As a result, a single Sensitive Species could be counted in more than one analysis region. Because of this, the reported statewide totals will be less than the sum of the individual region reports.

Source: California Department of Water Resources and US Army Corps of Engineers, California's Flood Future: Recommendations for Managing the State's Flood Risk, FINAL November 2013, Attachment C: History of Flood Management in California. C-105.



Figure 4. Location of FEMA Floodplains in the Bay Area

Source: FEMA National Flood Hazard Layer (NFHL)

Figure 4 shows the location of FEMA floodplains in the Bay Area. Most of the flooding occurs in the low-lying areas along the Bay and at the most downstream ends of rivers and creeks. Flooding also occurs along major rivers and creeks and even some minor creeks. Table B provides information on the largest flows in some of the major creeks and rivers in the Bay area including the date of the storm, the peak flow rate and estimated return period and the amount of precipitation associated with the storm. Some of the floods, such as those that resulted from the 1955 storm, are the largest on record for many rivers and creeks in the Bay Area as well as many of the rivers in the northern California. Other floods were more localized and occurred on a single waterbody (such as in 2005 on the Napa River).

EXTREME STORM AND FLOOD ANALYSIS

The analysis next page is not meant to be an exhaustive study of flooding that could occur in the Bay Area. Rather it provides a basis to estimate the impacts that could occur to major economic assets of the area when an “extreme” storm event were to strike. The storm event used in this analysis is bigger than a 100-year event but significantly smaller than the flood event that occurred in 1861, bankrupting the state and destroying 25% of the state’s economy.

To conduct an assessment of the economic impacts of an extreme storm event in the San Francisco Bay Area, a specific storm profile first needed to be created. For purposes of this economic analysis, a plausible “atmospheric river” storm event was developed using hydrographic models based on the historic record of floods, analyses of existing information regarding riverine and coastal flooding, and modeling of storm events on a number creeks and rivers. The development process included a review of stream flow data and FEMA and others’ flood maps and existing flood studies. In some areas numerical modeling was conducted to estimate flood boundaries, and in other areas existing maps and studies of flood boundaries were used.

The storm profile defined in this manner places the resulting flood in line with the three major standards used by FEMA, the US Army Corps of Engineers and the California Department of Water Resources.

Extreme storm simulation requires a definition of storm size and duration. Extreme storms can occur over several hours or many days, as shown Table B. During the 1861–1862 storm, it rained almost continuously in the Bay Area for about a month. To develop a Bay Area-wide storm model that is consistent throughout the area, the flows in selected creeks and rivers for some of the events in Table B were used as the basis of an extreme event.

Waterbody	Date	Flow (CFS)	Return Period (Years)	Precipitation (Inches)	Comments
Alameda Creek	12/23/1955	29,000	100	9.54 (9 days)	1958: Levee failure on Alameda Creek destroys crops and damages industries and more than 225 homes in Fremont, Union City, and San Jose
	4/3/1958	25,500	50	4.68 (4 days)	
	1/12/1952	24,300	50	2.29 (3 days)	
Guadalupe River	3/10/1995	11,000	20-50	3.57 (3 days)	1986: Guadalupe River overflows its east bank in San Jose, flooding residences and businesses.
	4/2/1958	9,150	10 to 20	3.12 (7 days)	
	2/19/1986	9,140	10 to 20	5.41 (9 days)	
Saratoga Creek	12/22/1955	2,730	50	4.41 (5 days)	
	1/14/1978	2,580	50	1.26 (3 days)	
	2/27/1940	2,540	50	No data available	
Upper Penitencia	4/2/1958	2,100	20	3.12 (7 days)	
	3/31/1982	1,970	20	2.11 (6 days)	
	2/19/1980	1,700	10	4.67 (7 days)	
Redwood Creek	1/31/1963	644	50	4.46 (3 days)	
	2/18/1986	586	20-50	7.08 (8 days)	
	1/23/1983	473	10 to 20	2.26 (3 days)	
Walnut Creek	1/5/1982	13,300	20	3.85 (2 days)	1983: Heavy rains, high winds, flooding, and levee breaks caused a total of \$523,617,032 in damages region-wide
	1/22/1997	9,970	5 to 10	0.52 (3 days)	
	3/13/1983	8,900	5 to 10	2.10 (3 days)	
San Francisquito Creek	2/3/1998	7,200	50-100	3.78 (4 days)	2012: Floodwater impact northbound highway 101. Levee breach on the San Mateo side of San Francisquito Creek causing localized flooding in Palo Alto.
	12/22/1955	5,560	20	4.41 (5 days)	
	12/23/2012	5,400	10 to 20	1.67 (3 days)	
Corte Madera Creek	1/4/1982	7,200	500	12.5 (5 days)	1982: Record flooding occurs throughout the region. Debris flows caused three landslide-related fatalities and most of the \$18,464,000 damages in Marin County were due to landslides.
	2/17/1986	4,150	10	13.7 (6 days)	
	12/22/1955	3,620	5 to 10	11.2 (8 days)	
Napa River	2/18/1986	37,100	100	14.6 (7 days)	2005: The Napa River floods causing \$135,000,000 in damage in Napa County
	3/9/1995	32,600	20-50	3.23 (2 days)	
	12/31/2005	29,600	20-50	14.4 (7 days)	
San Lorenzo	2/3/1998	10,300	100-200	5.06 (6 days)	
	1/2/1997	5,440	10	2.28 (8 days)	
	1/13/1993	5,300	10	1.48 (1 day)	

Table B. Top 3 Flow Events on Record for a Number of Bay Area Waterbodies

Source: USGS Water Data for California, National Weather Service (NWS), University of California Statewide Integrated Pest Management (IPM) Program, and California's Flood Future: Recommendations for Managing the State's Flood Risk (by California Department of Water Resources FloodSAFE California and US Army Corps of Engineers)

Figure 5 shows the number of days before and after peak runoff for selected Bay Area creeks and rivers during large storm events. Most storms lasted about 3 days but some lasted much longer. Also included on the figure are examples of the ARkStorm (Atmospheric River 1,000 Storm) for several locations.

The ARkStorm is a very large, hypothetical storm scenario in which an atmospheric river brings large amounts of precipitation to California.⁵ The black, solid line on the figure bounds most of the storms included in the analysis and represents the Bay Area extreme storm used for analysis.

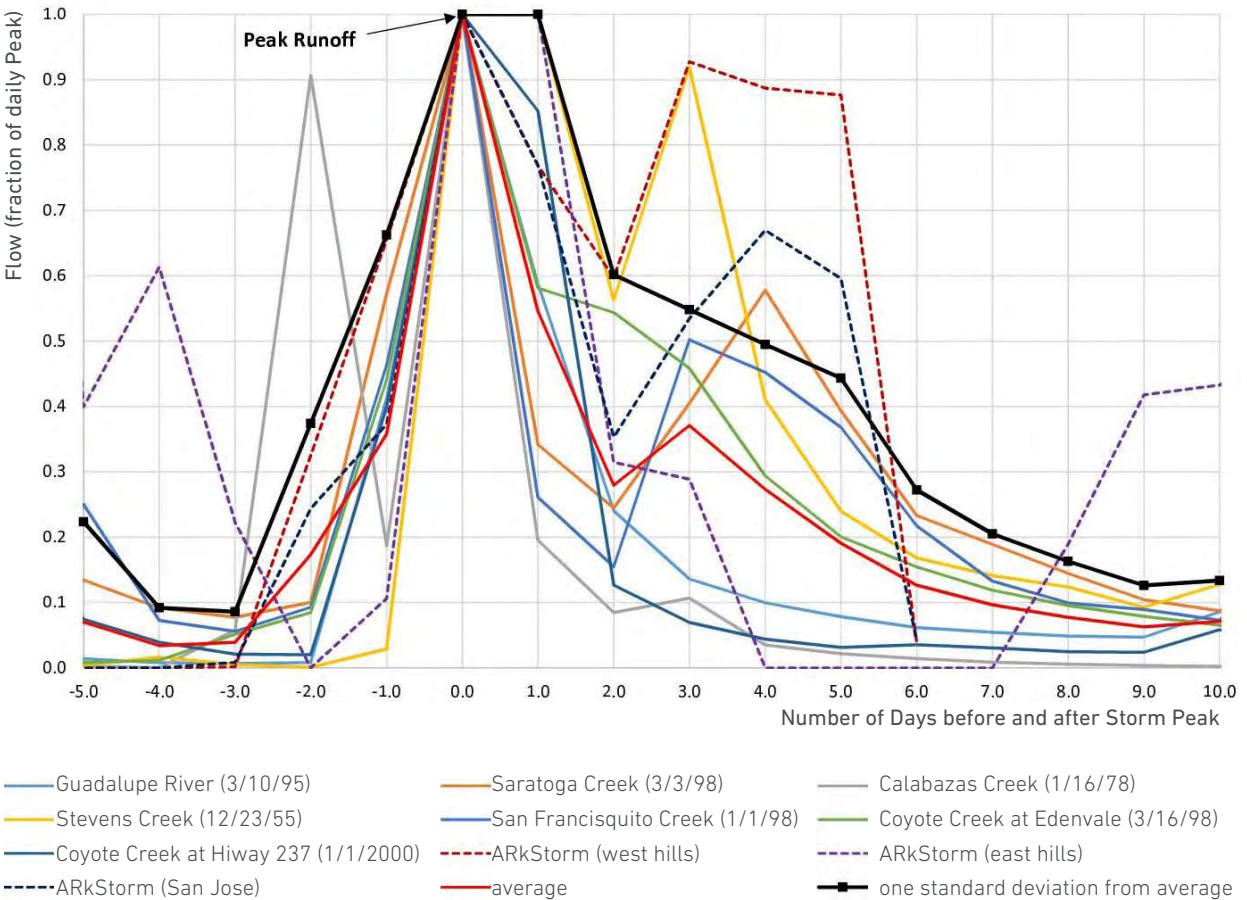


Figure 5. Model Shape Used for Bay Area Extreme Storm and Flood Analysis

Source: USGS Water Resources data

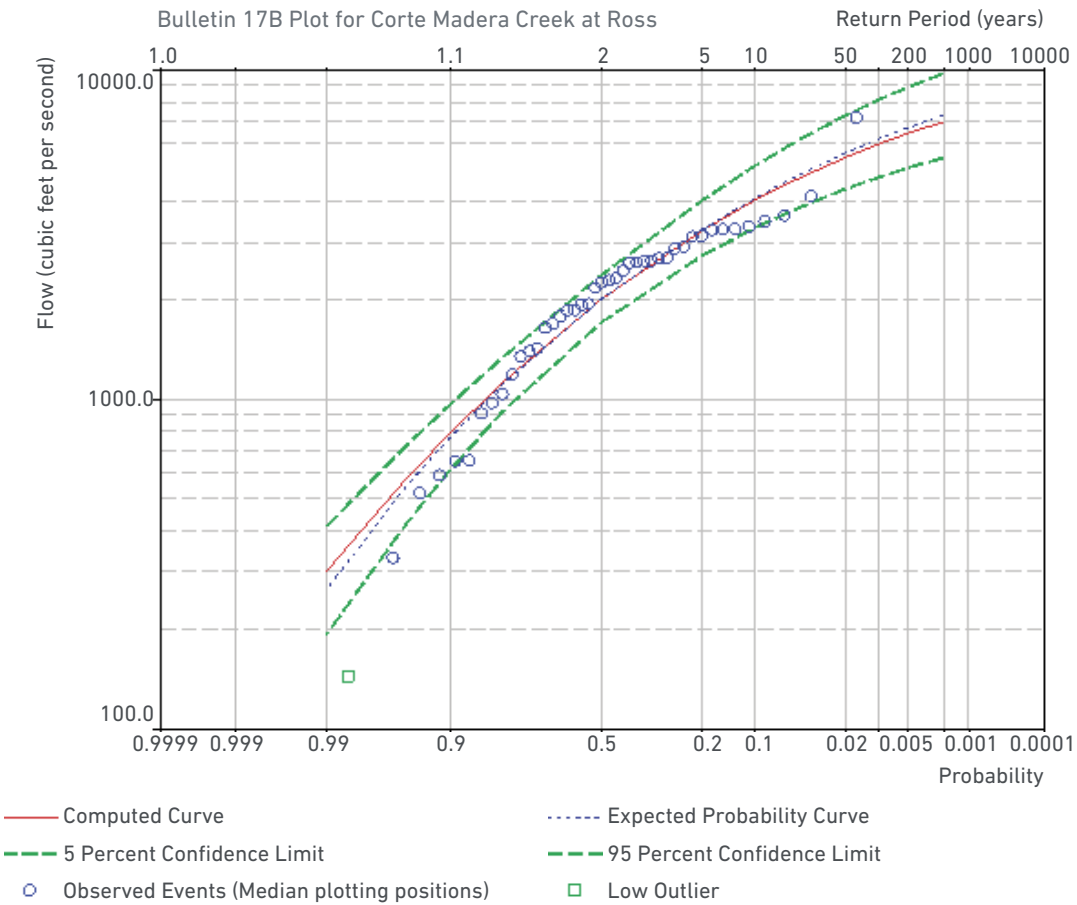


Figure 6. Example Flood Frequency Curve for Corte Madera Creek at Ross in Marin County

Source: USGS Surface-Water Daily Data for California

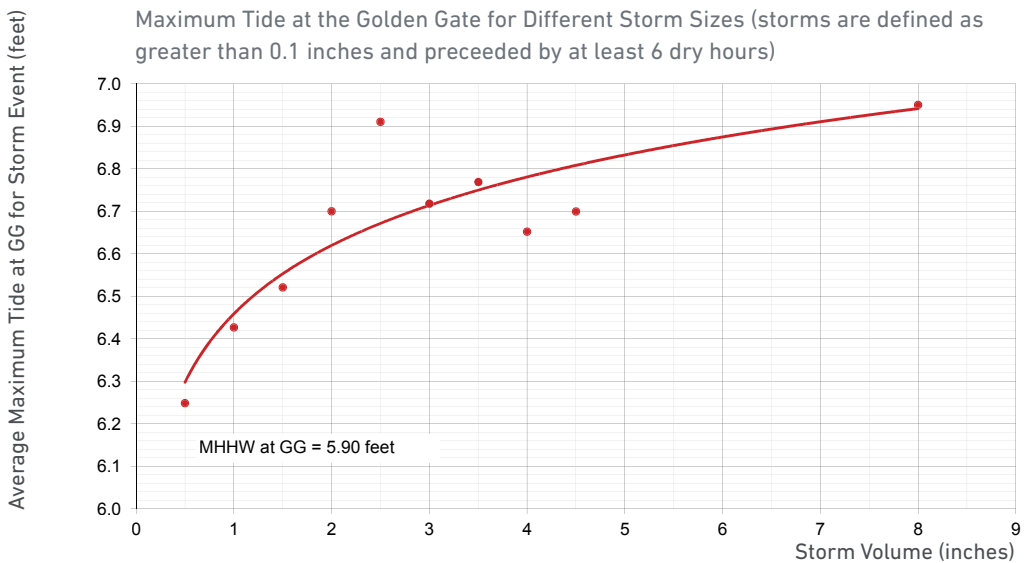


Figure 7. Golden Gate Average Maximum High Tide

Source: NOAA North American Vertical Datum of 1988

For streams throughout the Bay Area, peak flow rates were selected based upon a frequency analysis of flow records. Figure 6 shows an example of a flood frequency analysis for Corte Madera Creek in Marin County. The analysis shows the probability of any peak flow being exceeded in any year. For example, the results on the figure show that the flow of 7,200 cubic feet per second that occurred on Corte Madera Creek in January of 1982 has a return period of about 500 years. Data like this combined with existing flood information when available was used to determine peak flow and flooding characteristics of selected streams or areas. When the flows exceeded the capacity of the streams, the runoff that overflowed the banks spread throughout the floodplains until the storm had passed. In most cases, the flow ponded in low spots in the floodplain or flowed downhill towards the Bay. From the model results the maximum depth of flooding was obtained and used in the economic analysis. In most cases the duration of flooding was also obtained and used in the analysis.

In addition to flooding along creeks and rivers around San Francisco Bay, flooding can occur along or near the Bay’s shoreline due to high water levels in the Bay.

There are two high tides each day with one high tide higher than the other (referred to as mean higher high water). Also, during a month there are two periods when tides are higher than average (spring tides) and two periods when tides are lower than average (neap tides). During any particular storm event, depending upon when the storm occurs, the water levels in the Bay could be “average” or could be unusually high (spring tide) or low (neap tide).

However, on average, water levels tend to be higher during large storm events due to factors such as storm surge resulting from low barometric pressure and high freshwater inflows. Figure 7 shows the average maximum tide measured at the Golden Gate for various storm sizes. The data indicates that during larger storms, the average high tide is higher.

For the extreme storm analyzed in this study, it was assumed that a large storm event occurred in the Bay Area at the same time that an extreme high tide occurred at the Golden Gate. For areas subject to both riverine and coastal flooding (for example some areas in the South Bay near the Bay and along a creek) this storm represents a more extreme event (in terms of return period) than for areas subject to just coastal flooding or just riverine flooding.

The largest flood events (as opposed to the largest storm events) tend to occur when large storms happen at the same time as high tides.

Also, it was not intended that the storm have the same return period everywhere—which rarely happens—only that the storm be large everywhere. An analysis of water level in the Bay under this condition was used to determine water levels along the shoreline. Water depths for coastal flooding areas were also used in the economic analysis. For areas subject to both coastal and riverine flooding, the deepest water depth was used.

DISASTER PROFILE

CALIFORNIA MEGA FLOODS

Geologic evidence shows that truly massive floods, caused by rainfall alone, have occurred in California every 100 to 200 years.⁶

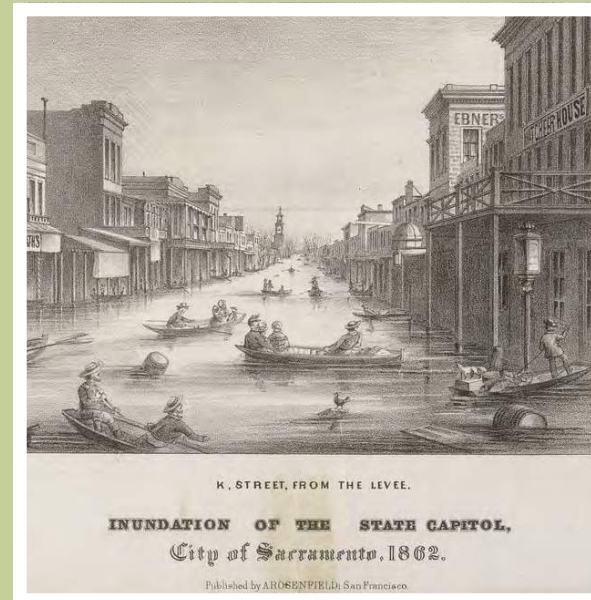
How do we know how big floods were in the distant past? Using flood-sediment deposits and botanical evidence, scientists can reconstruct the magnitude and age of large floods that have occurred before written records are available. This science called paleohydrology has been used to identify several very large storms that have occurred in California, including the Bay Area, over the last 1,000 years. Various methods can be used to identify historic floods. For example, the use of pollen grains can provide information stretching back 100,000 years; archaeological studies stretch back 5,000 years; and weather diaries stretch back just over 500 years, though in California written records go back only about 200 years.

The largest recorded flood in California occurred in 1861–1862. From December through January, over 30 inches of rain fell in San Francisco. Reports from journals of the time state that for at least ten days “water flowed through the Golden Gate in a steady torrent, blocking tide reversal.”⁷ Sacramento had to be abandoned, one-quarter of California’s economy was destroyed, and the state was forced into bankruptcy. A large flood also occurred in the 1850s, though fewer records are available.

Paleohydrology studies have identified floods as large as the 1861–1862 event between 1360–1449, 1401–1482, 1471–1538, 1553–1605, and 1642–1677; (paleohydrology studies often can only pin point a range of dates rather than a specific date). The

flood of 1650 was estimated to be 50% greater than any of the other mega floods. Paleohydrology data collected in Southern California revealed six distinct mega floods in A.D. 212, 440, 603, 1029, 1418 and 1605. Based on the paleohydrologic record, we know that many of these were statewide floods.

Evidence of these ancient floods indicates that floods as large or larger than the 1861–1862 flood occur about every 200 years. It has been over 150 years since the last mega flood in California.



Source: *California Lettersheets from the Robert B. Honeyman, Jr. Collection of Early Californian and Western American Pictorial Material, 1850–1869, UC Berkeley, Bancroft Library*

DISASTER PROFILE

DELTA FLOODING

In addition to hundreds of local creeks and rivulets, San Francisco Bay's largest source of fresh water comes from the Sacramento-San Joaquin Delta, the terminus of California's two largest rivers and the largest estuary in the western United States. The Delta's adjacent position to the Bay means it is possible that once an extreme storm moves eastward past the Bay and towards the Sierra Nevada mountains, the Sacramento-San Joaquin Delta would also face flooding.

Delta flooding would further stretch emergency response and create even greater economic and social impacts, including higher water levels in San Francisco Bay and potential impacts to drinking water supplies for Santa Clara and Alameda Counties, as well as supplies for Southern California and the Central Valley.

During the development of the 2012 Central Valley Flood Protection Plan, the Central Valley was organized into planning regions, one of which is the Lower Sacramento River/Delta North flood planning region⁸. Each region has formed a working group, led by a local agency, which consists of representatives from flood management agencies, land use agencies, flood emergency responders, permitting agencies, and environmental and agricultural interests. The Lower Sacramento River/Delta North planning region includes a vibrant agricultural economy, several cities (including large portions of the cities of Sacramento and West Sacramento), and numerous other communities.

To enhance understanding of flooding issues and solutions in the Lower Sacramento River/Delta North planning region, a history of regional flooding is included on page 26.

Heavy Rain and Storm Events

In 1955, due to heavy rainfall and snowmelt in the upper watersheds of the San Joaquin River's eastside tributaries, extensive flooding occurred along the San Joaquin River as well as its larger westside and major eastside tributaries. During this event, known as the "Christmas Floods," unusually high tides contributed to flooding by disrupting the passage of water through the Sacramento-San Joaquin Delta. The event caused widespread flooding in Sacramento County. The region experienced storm and flood damage 3 years later in 1958, followed by the October 1962 floods, which caused particularly severe damage to agricultural and public facilities along the streams flowing from westside tributaries. In the "Northern California Christmas Disaster" of 1964, a large region west of the Western Pacific Railroad tracks was flooded, and during the 1969 winter storms agricultural lands were again flooded. In 1974, floods occurred from January through March in the Sacramento Valley. Flooding and severe winter weather were again experienced during 1992, and in 1995 severe weather storms caused record high water along numerous creeks and their tributaries, while piped storm drain systems were overwhelmed, widespread street flooding occurred, and hundreds of homes were also flooded. El Niño conditions caused flooding in 1998, while 1999 brought urban and small stream flooding. More floods were experienced in 2005–2006 due to winter storms and again in 2008 due to January storms.

Levee Failures

The table next page indicates the number of levee failures that have occurred in the Delta over the last 100-years. During this period there have been over 160 breaches on 114 islands.

In June of 1972, the levee failure on Andrus Island caused significant seawater intrusion.

Excessive seawater intrusion can cause severe disruptions to the ability of the state and federal water projects to deliver water.

In January–February 1980, private levee breaches and deterioration due to high tides and flood-level flows caused inundation of roughly 11,380 acres of agricultural land. In September 1980, the 5,200-acre Lower Jones Tract flooded due to the failure of the Old River levee. A year and a half later in October–November 1981, river levels were raised by heavy storms resulting in the failure of the Prospect Island levee. The McDonald Island levee failed in August 1982, inundating 5,800 acres of farmland, and three months later in November 1982, the Venice Island levee failed due to high tides and winds.

In 1983, levees failed at Mildred Island, Shima Tract, Fay Island, Little Franks Tract, and Prospect Island in January and at Bradford Island in December. Tyler and Dead Horse Islands and McCormack-Williamson and New Hope Tracts failed in February 1986 when both record high tides and Sacramento River inflow occurred. During this event, extensive erosion was caused along the north and south levees of the American river near California State University, due to releases from Folsom Reservoir, resulting in the largest peak flow on Morrison Creek. Five miles north of downtown Sacramento,

emergency actions taken during the flood prevented the collapse of the Sacramento River's east levee. In 1987, widespread failure of the levee system and flooding to dozens of homes were caused by record flows on the Cosumnes River; traffic on Highway 99 was also disrupted as floodwater passed over.

January 1997 brought a storm during which several levee breaks occurred throughout the San Joaquin and Sacramento Valleys, as the area experienced 100-year peak flows in multiple major rivers. Over 120,000 people had to be evacuated in Northern California. In June of 2004, the Lower Jones Tract levee failed again, causing inundation of the island.

Most levee failures in the Delta have occurred due to high water conditions related to winter storms. Over the last 100 years there have been almost 160 levee failures, and 140 are projected to occur in the next 100 years unless significant improvements occur in the Delta.⁹

High water can cause through-levee seepage, under-levee seepage and overtopping failures. Depending on the severity of in-Delta storm-induced flows, multiple islands could fail during a single storm event. For example, the DWR study estimated that there is about a 30 percent chance that 15 islands will flood during a single flood event within a 25-year period.

As shown in the table next page, emergency levee repairs could cost over \$100 million for a single island (the Jones Tract failure in 2004 cost about \$90 million to repair).¹⁰ If 20 islands flooded, repairs could cost \$1 billion and take about two-three years, and if 30 islands flooded, repairs could cost about \$1.5 to 2 billion and take over four years to complete.

Decade	Number of Islands	Number of Breaches
1900 - 1910	28	57
1911 - 1920	2	3
1921 - 1930	3	3
1931 - 1940	15	18
1941 - 1950	12	14
1951 - 1960	9	12
1961 - 1970	4	5
1971 - 1980	10	10
1981 - 1990	15	24
1991 - 2000	12	15
2001 - Present	2	2
TOTAL	114	163

Distribution of Levee Failures Since 1990

Source: Poster prepared by Vivian Gaddie (AECOM), Michael Mierza (DWR, River Forecasting Section), and Jenny Marr (AECOM). www.water.ca.gov

Number of Flooded Islands	Estimated range of cost or repair and dewatering (\$Millions)	Estimated range of time to repair breaches and dewater (days)
1	30 - 110	47 - 170
3	140 - 260	240 - 450
10	490 - 680	590 - 1,060
20	990 - 1,200	930 - 1,110
30	1,500 - 1,800	1,380 - 1,580

Duration and Cost of Repairs for High Water-Related Levee Failures

Source: AECOM / Jack R. Benjamin & Associates, Delta Risk Management Strategy Phase 1 risk analysis report Executive Summary prepared by the California Department of Water Resources, (2009), 18.

DISASTER PROFILE

SEA-LEVEL RISE

Scientists widely agree that the earth's climate is changing rapidly and dramatically due to greenhouse gas emissions. Global increases in the temperature of the oceans have resulted in expansion of ocean waters and melting land ice, causing global sea-level rise. In the past century, global mean sea level (MSL) has increased by 7 to 8 inches. The rate of sea level rise is accelerating and is projected to increase throughout this century regardless of any future human action to curb greenhouse gas emissions.

The infrastructure and communities along the California coast and the San Francisco Bay shoreline will be impacted by sea level rise, which will magnify the impacts of high tides, storm waves, and large El Niño events.

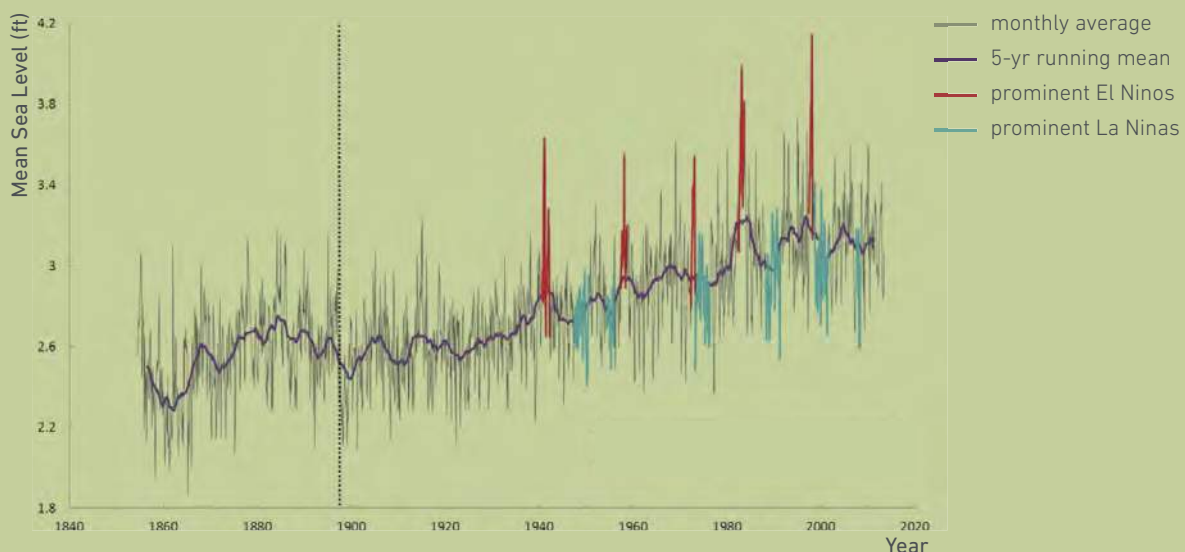
During this century, coastal flooding will become more frequent and severe in the Bay Area.

The California Coastal Commission reports that

...global projections do not account for California's regional water levels or land level changes. California's water levels are influenced by large-scale oceanographic phenomena such as the El Niño Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO), which can increase or decrease coastal water levels for extended periods of time.¹¹

California's coastal communities can expect more severe losses from El Niño events than they have experienced in the past. The graph below shows how El Niño and La Niña affect sea levels.

Mean sea-level heights (in feet) are relative to mean lower low water (MLLW). The purple line on the graph represents the 5-year running average. Note that the monthly mean sea level has varied greatly throughout the years and that several of the peaks occurred during strong El Niño events (red highlight). Periods of low sea level often occurred during strong La Niña events (blue highlight).



Variations in Monthly Mean Sea Level, Fort Point, San Francisco, 1854 to 2013

Source: NOAA CO-OPS data, Station 9414290; analysis in California Coastal Commission Draft Sea-Level Rise Policy Guidance, Public Review Draft, October 14, 2013.

The National Research Council (NRC) Committee on Sea-Level Rise in California, Oregon and Washington released a report in 2012 on regional sea-level rise trends and projections of future sea-level change. This report provides a broad examination of sea-level issues for the California coast and currently represents the best available science on the topic. The NRC Committee investigated both global and regional sea-level projections, combining projections of thermal expansion or contraction with changes in the volume of ocean water due to melting of land-based ice on Greenland and Antarctica, as well as contributions from other land-based glaciers and ice caps. The table below shows the NRC projections for global sea-level rise in California.

In the following chart from the National Climate Assessment reports that

...changes in global climate cycles, such as the PDO [Pacific Decadal Oscillation], may soon become a significant factor in accelerating regional sea-level rise. While over the past

century there has been a gradual increase in global sea levels [and sea levels along the California coast], since about 1993, California tide gauges have recorded very little long-term change in sea level. This "flat" sea level condition had been out of sync with the prevailing global rise in sea level and the historic trends in sea-level rise along the West Coast. The PDO causes differences in sea-surface elevation across the Pacific. Sea levels have been higher in the Western Pacific and lower along the California coast over the past two decades, coinciding with a warm phase of the PDO.¹²

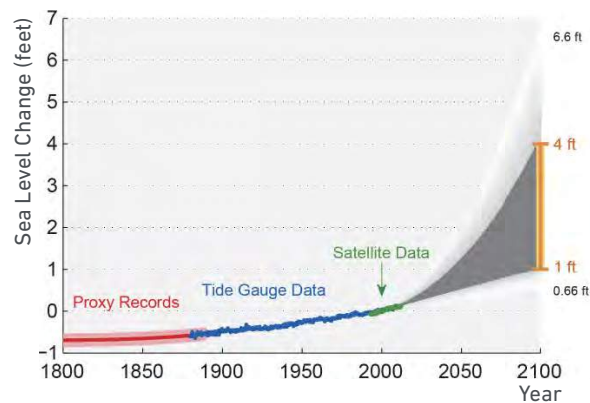
A change in the PDO could, however, result in a resumption of sea-level rise along the West Coast approaching or exceeding the global mean sea-level rise rate. In the following chart from the assessment, geologic and recent sea-level histories (from tide gauges and satellite altimetry) are combined with projections to 2100 based on climate models and empirical data.

Time Period	NRC Report 2012	
	North of Cape Mendocino*	South of Cape Mendocino
2000 – 2030	-4 – +23 cm (1.6 – +9.0 inch)	4 – 30 cm (1.6 – 12 inch)
2000 – 2050	-3 – 48 cm (-1.0 – 19.0 inch)	12 – 61cm (5 – 24 inch)
2000 – 2100	9 +10 – +143 cm (+4 – +56 inch)	42 – 167 cm (16.5 – 66 inch)

California Sea-Level Rise Projections for 2000 to 2100

**Note: with the exception of parts of Humboldt Bay and the Eel River Estuary which are experiencing subsidence and therefore a higher rate of sea-level rise than projected for the region.*

Source: California Coastal Commission Draft Sea-Level Rise Policy Guidance Public Review Draft, October 14, 2013 108



Past and Projected Changes in Global Sea Level

Source: Chapter 2 of the Climate Change Impacts in the United States: The Third National Climate Assessment report prepared by National Climate Assessment and Development Advisory Committee

DISASTER PROFILE

EARTHQUAKES AND FLOODING

What will happen to our flood protection structures when the next big earthquake hits? In 2007 the Bay Area had a 63% chance of experiencing a magnitude 6.7 or greater earthquake before 2036.¹³ We recently experienced a wake-up call with the 6.0 Napa quake. A major earthquake will produce significant ground accelerations and will likely produce ground failure, such as liquefaction, lateral spreading, and subsidence, in many areas around the Bay composed of loose or sandy soils or of man-made fill.

Many of our flood protection structures are located in areas highly vulnerable to ground failure.

However, there is staggering variation among ownership, design standards, and condition of flood protection structures with respect to seismic performance. While new levee construction requires the performance of soil and lateral loading analyses, there is no consistent standard for seismic performance. It is assumed that only a small percentage of levees in the Bay Area are US Army Corps of Engineers Certified and thus meet guaranteed seismic criteria. Even then, these seismic standards are not based on life safety but instead on assuring the insurability of structures behind the levee.

How does seismic activity cause flood control structures to fail? Bearing and sliding may be caused by loss of soil strength or destabilizing inertial load conditions due to ground shaking or weak foundation soils. Slumping and spreading can also be caused by reduced soil strength. Increased water levels and rising ground water levels can exacerbate these problems due to increased seepage, increased lateral forces, or soil erosion due to overtopping.

Two studies have examined the probability of levee failure in the Delta, which has a high probability of seismic activity from large Bay Area earthquakes or moderate near-source events. One study estimated that a magnitude 6.5 earthquake (6% probability of exceedance in a 50-year period) with an epicenter located in the Delta would produce 50 levee breaches and flood 21 islands.¹⁴

Another study reports that

A moderate to large earthquake in the San Francisco Bay region could cause major damage to Delta and Suisun Marsh levees, and could cause many of them to fail. Levee foundations could fail due to liquefaction or the levees themselves could deform and fail. Seismically induced levee failures would be expected to extend for thousands of feet if not miles and impact many locations simultaneously... For example, there is about a 40 percent chance that 20 or more islands will flood simultaneously as a result of an earthquake sometime over 25 years of exposure.¹⁵

The Delta alone has 1,100 miles of levees, which presents issues of scale and prioritization for action to address seismic instability of levees.

The Delta is not the only place that may experience significant flood control failure in a major seismic event. San Francisco's sea wall runs roughly four miles from Hyde Street and Fisherman's Wharf in the north to Pier 54 and Channel Street in the south. It was constructed between 1878 and 1924, using a variety of design and construction methods. It can

be assumed that the composition of the sea wall is largely rocks, sand, and clayey mud. Much of the land area directly behind the wall is man-made fill, composed of sands, clays, and some gravel. This fill rests against the sea wall. Both the sea wall and the land behind it are vulnerable to ground failure damage in a major seismic event. The sea wall and the area around it experienced ground failure in both the 1906 San Andreas earthquake and the 1989 Loma Prieta earthquake. Following the Loma Prieta quake, the City of San Francisco commissioned a study of liquefaction risks for a portion of the sea wall and neighborhoods behind it. The study estimated that there could be 0.25 to 2 feet of vertical settlement and 0.25 to 1 foot of lateral spreading along the seawall from a magnitude 8 earthquake on the San Andreas Fault.¹⁶ The consequences of this ground failure could be catastrophic to the utilities that cross the seawall or land uses near the sea wall. If any major portion of the sea wall or piers collapses, there may be significant damage to the Embarcadero and other roadways. Natural degradation due to age and the impacts of sea-level rise make the sea wall, and the land behind it, even more vulnerable.

ECONOMIC IMPACTS



3

OVERVIEW

The economic impacts of the storm modeled for this report are substantial. We have included the largest damage components—structural damage and building content losses and transportation delay costs resulting from road airport closures, and the estimated cost of lost electricity service.

The cost of these components across the nine Bay Area counties totals \$10.4 billion. For context, the 1989 Loma Prieta earthquake is estimated to have caused \$11.3 billion in damages, adjusted for inflation.

Damage Category	Estimated Damages
Structural damages	\$5,932
Content damages	\$4,180
Air transportation delay damages	\$86
Road transportation delay damages	\$78
Electricity service interruption costs	\$125
Total	\$10,401

Table 1. Summary of Damages (Millions of Dollars)

Notes: See Table 2 for structural and content damage details.

See Table 3 for air and road transportation delay damage details.

Source: Analysis by The Brattle Group

These costs represent a snapshot of the Bay Area’s vulnerability as it exists today. While substantial, these figures are likely to significantly underestimate the economic vulnerability of extreme storm events for several reasons.

First, this report is focused on damage within the Bay Area alone. Any storm of the size considered here would likely bring significant—if not greater—damage to the Bay Area’s periphery, especially the Sacramento-San Joaquin Delta and the Central Valley. Delta flooding could itself render up to \$10 billion in additional economic damage to the Bay Area by cutting the region off from its second largest supply of drinking water (see sidebar on the Delta). Second, California is vulnerable to storms larger than the one considered in this report. An example is the so-called ARKStorm, a state-wide mega storm modeled by state and federal scientists, which projections show could cost up to \$725 billion statewide and require the evacuation of 1.5 million people. Third, the figures do not include damage to key infrastructure, such as communications networks, highways and airports. Finally, the analysis does not consider future increased risk from sea-level rise. The California Climate Action Team projects California’s coastal waters will increase between 5 to 24 inches by 2050, and 17 to 66 inches by 2100, levels which would result in this same storm causing potentially billions of dollars of additional damages.

STRUCTURAL AND CONTENTS DAMAGES

Table 2 presents structural and content damages by county totaling \$10.1 billion. These damages are calculated by taking the flood’s parameters (area affected, flood depth and duration) and applying them to the Federal Emergency Management Agency’s Hazus Model.¹⁷ This model accounts for land use, structure type, and typical contents. Damages are calculated based on replacement costs for structural repairs and content replacement adjusted for depreciation.¹⁸ These impacts account for both riverine and coastal flooding associated with the hypothetical storm.

Since an even more substantial storm than hypothesized here is possible, it is also worth noting that a recent study conducted by the California Department of Water Resources estimated that the cost of replacing structures and contents in the Bay Area could reach \$51 billion should all properties exposed in the 100-year flood plain require replacement.¹⁹

As shown in Table 2,

Santa Clara, San Mateo and Marin Counties account for about 80% of structural and content damages.

The largest losses in Santa Clara County will be incurred in and near downtown San Jose from riverine flooding. Losses in San Mateo County will occur primarily in Foster City, San Mateo, and Redwood City from coastal and riverine flooding.

Losses in Marin County will occur primarily in Novato from coastal flooding and in San Rafael and San Anselmo from riverine flooding. Alameda County losses will occur largely in Union City from coastal flooding. Contra Costa County losses will occur in Concord, Martinez and Pacheco primarily from riverine flooding. Losses in Solano County will occur primarily in Vallejo and Suisun City from coastal flooding. Losses in Sonoma County will occur primarily in Petaluma and Sonoma from coastal and riverine flooding. While San Francisco's hilly topography and lack of major rivers limits the city's vulnerability to extreme damage, there will be some local flooding from sewer backups as a result of the expected rainfall rates. San Francisco faced costs of about \$5 million following a major storm in 2004 for damage claims from property owners including property diminution, interest, and attorney expenses.

County Name	Structural Damages [1]	Content Damages [2]	Structural and Contents Damages [3]=[1]+[2]
Alameda	\$394	\$345	\$739
Contra Costra	\$448	\$310	\$758
Marin	\$715	\$487	\$1,202
Napa	\$22	\$14	\$36
San Francisco	\$0	\$5	\$5
San Mateo	\$680	\$412	\$1,092
Santa Clara	\$3,586	\$2,553	\$6,140
Solano	\$84	\$52	\$137
Sonoma	\$2	\$1	\$3
Total	\$5,932	\$4,180	\$10,112

Table 2. Structural and Content Damage Estimates (Millions of Dollars)

Note: Structural and content damages are calculated using FEMA's Hazus model.

Source: Analysis by The Brattle Group

TRANSPORTATION DELAY

Damage Category	Delay Damages
Airports	
SFO	\$69
OAK	\$17
Road	\$78
Total	\$164

Table 3. Road and Air Transportation Delay Damage Estimates (Millions of Dollars)

Notes: Air transportation damages are calculated following the methodology outlined in Welman et. al, "Calculating Delay Propagation Multipliers for Cost-Benefit Analysis," 2010.

Road Transportation damages are calculated following the methodology outlined in the 2011 report by the US Army Corps of Engineers on damages from a San Francisquito Creek flood. See pp. 30–32 of that report for further details.

Source: Analysis by BrattleGroup

COSTS

Table 3 presents the transportation delays resulting from temporary highway and airport closures totaling \$164 million. Airport damages, which total \$86 million, were calculated by taking AECOM flood depth and duration estimates and applying them to a travel delay model created for the Federal Aviation Administration.²⁰ This model accounts for delays throughout the airline system caused by delays at specific airports. Delays were calculated at the San Francisco and Oakland airports. No delays were expected at the San Jose airport.

The highway delay damages, which total \$78 million, are calculated by taking the flood data regarding duration and applying them to a model employed by the Army Corps of Engineers.²¹ Note that these costs reflect the assumption that airports and roads resume full service at the storm's end. They do not include any delay because of repairs or repair expenditures. The roads most affected by flooding include Interstates 580, 880, and 680, and Highways 101, 237, 84, and 37.

ELECTRICITY SERVICE INTERRUPTION COSTS

At the request of the Bay Area Council Economic Institute, Pacific Gas and Electric Company (PG&E) prepared a preliminary review of the risk of flooding to its substations in the San Francisco Bay Area as a result of the hypothetical storm scenario. The utility estimated that the storm event could disrupt six of its substations, resulting in an economic impact of up to approximately \$125 million.

This estimate represents the associated outage cost—or loss of value—to PG&E customers. It includes the net costs incurred by commercial customers to temporarily relocate or continue their business operations and also reflects the inconvenience to residential customers, but does not factor other costs, such as those for repairing property damaged by the flooding, emergency response agencies, or lost economic activity outside the flood zones due to the service interruptions.

PG&E notes that there is significant uncertainty associated with this estimate due to a number of factors, including, but not limited to, the underlying flooding scenario models, duration and extent of flooding, extent of damage to substation equipment as a result of flooding, and access to affected substations after the flooding event. PG&E also notes that it has a redundant electric system. Its substations are interconnected through the electric grid and typically can play a back-up role to one another to help minimize customer service interruptions.

THE ROLE OF FLOOD INSURANCE

Superstorm Sandy provides a useful but sobering preview of the types of insurance and risk management issues that Bay Area business and residents will face given the prospects of a catastrophic storm.

Exclusions, sublimits and other coverage terms relevant to certain types of natural disasters can have a major impact on policyholder recovery after a storm. Businesses and homeowners think of policies as an off-the-shelf product, but there is a great variety of coverage restrictions and expansions that may be present or that can be shaped.

Insurance litigator Robert Wallan and infrastructure development lawyer Rob James of Pillsbury Winthrop Shaw Pittman LLP identify the following issues for insureds that have been hotly contested in the wake of major storms elsewhere.

Flood versus Named Storm

Typical property policies exclude flood losses, but may be less restrictive for storms officially named or declared as emergencies. Ordinary flood coverage can usually be purchased, but this is often expensive and requires careful attention to special deductibles and sublimits.

Hurricane versus Named Storm

At the other end of the spectrum, some policies exclude coverage for hurricanes but not for lesser storm damage. Sandy did not meet federal government standards to be a hurricane, but some insurers still questioned coverage based on “named storm” exclusionary language.

Concurrent Causation Issues

In many instances losses may be not only the result of excluded perils like flood, but also the product of

covered perils like wind. Insurers have long sought to deny coverage if any excluded peril is a factor. The California courts have limited insurers’ success on such arguments, but the insurance industry routinely modifies policy language to respond to such decisions. Concepts like ensuing loss, efficient proximate cause and anti-concurrent causation have become significant areas of dispute following major catastrophes.

Civil Authority and Ingress/Egress Issues

Business owners typically obtain coverage for business interruption losses, but coverage for such conditions may depend on whether access is prevented versus merely impaired, whether the government issued written evacuation orders, and whether the specific policy requires physical loss as a condition of recovery.

Service Interruption

This coverage may address the impacts of sustained power outages—which can drive added payroll expense, lead to event cancellations, and cause spoiled food or medicine, among other impacts. Such coverage is usually constrained by waiting periods before taking effect and will vary from policy to policy.

“Loss of Market” Exclusions

Major storms can lead to long-term declines in customer base, extending business interruption losses well beyond what might apply for a limited event. Some insurers have cited these exclusions to limit coverage, and this is an area that has led to significant dispute over the calculation of losses.

Waiting Periods

Policies typically provide a waiting period, effectively a form of deductible. Following Sandy, at least one insurer argued that a 72-hour waiting period should be calculated as nine working days, arguing that only business hours should be considered.

FLOOD MANAGEMENT IN THE BAY AREA



ROAD
CLOSED

THE FLOODING OF TICE CREEK AND THE DECEMBER 2002 STORM

During a strong December 2002 storm over Walnut Creek, a local resident stepped onto her back porch to discover that the nearby Tice Creek had swollen beyond recognition and had submerged her backyard beneath its fast-moving waters. The water was flowing away from the porch to a large drainage pipe, now invisible somewhere toward the back of her yard. Suddenly, water had come over the porch and swept her cat into the flood. She had jumped in to save her pet, struggling desperately to reach it and swim to safety—lest she be sucked downward herself by the current.

This was one of many stories told at a public meeting held by the Contra Costa County Flood Control and Water Conservation District to collect experiences from the flooding of Tice Creek in 2002. Tice Creek, in the Walnut Creek watershed, had overtopped its banks and flooded the surrounding neighborhoods. The meeting, packed with over 300 people, was a cathartic exercise for the property owners, and a call for a solution to the sorts of dangers that are managed every day by a wide range of community-based local flood control districts around the region.

The Flood Control District held several subsequent meetings in which it worked through a community-based planning process to identify all options for addressing the flooding problem. The District's long-range plan called for the installation of over a mile of large diameter pipe at a cost of \$17 million, but the District had less than \$1 million in funds available at the time. The community and the Flood Control District agreed on expanding a nearby detention basin as the best and most affordable option to improve flood protection services for the

downstream neighborhoods. Two years later, the Flood District cut the ribbon for the project, while several downstream residents described the lingering impacts of the flood. One had spent thousands of dollars raising the foundation of his house, using all his savings. Another had been suffering from a series of illnesses until she discovered mold in her walls and had it remediated. Sadly the flood had a lasting impact on the lives of many residents.

BAY AREA FLOOD PROTECTION: A COMPLEX TAPESTRY

There is a wide array of agencies that provide flood protection services in the Bay Area, including flood control districts, water agencies, water districts, and several cities. These agencies are constantly seeking funding to build needed flood protection infrastructure for their communities. Sometimes, however, as in the case following the 2002 flooding of Tice Creek, the development of a project or a portion of a project is accelerated.

Traditionally, regional flood protection services have been organized at the county level. On the statewide level there are efforts to integrate planning activities across all water sectors: drinking water, wastewater, stormwater (including flood protection), and environmental water.

The most efficient service area—and natural planning unit—is the watershed. Watershed boundaries don't always coincide with county boundaries. In some cases, joint powers authorities have been formed to provide planning on a watershed basis, such as the San Francisquito Creek Joint Powers Authority.

This approach hasn't spread much in the Bay Area, as there are a large number of creeks with relatively small watersheds. As the flood protection agencies in the Bay Area go about their business of planning and developing flood protection projects, there are several pieces of a complicated puzzle to consider as these projects move forward.

LEVEL OF PROTECTION

The gold standard for current risk is to provide a 100-year level of protection against flooding. This is consistent with the Federal Emergency Management Agency (FEMA) Flood Insurance Program that requires flood insurance for properties with less than a 100-year level of protection that are subject to flooding. This is also known as providing protection against the "100-year storm," which is a storm that statistically has a one percent chance of occurring in any given year. However, not every community desires or can afford a 100-year level of protection. Many communities with historical downtown districts do not want to remove historic buildings in order to widen a creek to provide increased capacity, and they will accept a lower level of protection at 25 years or 50 years.

Watersheds, creeks and rivers are dynamic systems forever changing over time. The level of protection designed for a project often deteriorates with time once the flood protection facility is constructed.

This is due to intensified upstream development that generates additional runoff, other changes in upstream land use such as deforestation or grazing, more accurate rainfall data, or decreases in channel capacity due to sediment buildup. For example, it was discovered in one watershed in the North Bay

that flood protection facilities built in the 1960s now experience a 40% increase in flows compared to the specifications of the original design.

Remediating the loss in the level of protection is not easy, especially in the lower parts of the watershed. It is particularly difficult to increase the level of protection when a creek or facility is squeezed into a tight urban landscape with no room to expand. There are no easy options for a community in this situation. Accepting the status quo results in more frequent flooding. Removing a row of houses along a creek bank allows for widening the creek channel and increased flood protection but is disruptive to the community. Raising levees along creek banks increases flood protection for the broader community, but the drainage on the back side of levees can't get into creek channels due to the higher levee crest level, thus resulting in localized flooding.

Based on information from the Bay Area Flood Protection Agencies Association (BAFPAA), the vast majority of the flood control channels in the Bay Area have been designed for 50 or 100 years of protection with only a few built for 25 years of protection or less. Flood control channels (i.e., creeks) capable of handling a 100-year flood event include:

- Walnut Creek
- Galindo Creek
- Grayson Creek
- Pacheco Creek
- Pine Creek
- San Ramon Bypass
- Sycamore Creek
- San Pablo Creek
- Wildcat Creek
- Alameda Creek
- Old Alameda Creek
- San Lorenzo Creek
- Estudillo Canal
- San Leandro Creek
- Bockman Canal
- Sulphur Creek

However, most of these flood control channels were constructed in the 1950s and 1960s, and many no longer provide the level of protection they once did—due to sedimentation and upstream development that have both reduced channel capacity and increased the “flashiness” of watersheds. In addition, flood service levels differ in different parts of a drainage basin depending on local needs. A small tributary that several neighborhoods drain into and that may be one square mile in area would be designed for a 25-year level of protection. At the other end of the spectrum is the major creek or river channel draining the entire watershed, which would be designed for a 100-year level of protection. There have been many times in the past where sizeable storms have occurred that were contained easily within the regional flood protection system that caused extensive, localized neighborhood flooding.

Many strategies have been developed to try to address the watershed problems created by intensified urbanization, including the creation of flood detention basins, setbacks to open up floodplains, and day lighting of creeks. Many jurisdictions today are pursuing “urban retrofits” through introduction of green infrastructure measures that slow, reduce and help treat urban storm runoff, such as bioswales, green roofs, rain gardens, and permeable paving. However, due to high costs and land use constraints, in many places these strategies remain limited in their application.

While the focus of flood protection infrastructure in the Bay Area has historically been on creeks and rivers, coastal flood protection is a growing concern to flood management agencies, as sea level rises and extreme high tides combine with waves generated by storms, threatening bayside communities. The San Francisco Bay’s present tidal wetlands serve as a buffer between the Bay and urban, rural, and suburban development including water, power, transportation, and communication infrastructure

linking businesses and communities within the Bay Area and beyond. Most of the tidal wetlands have been diked and drained for farmland, filled to facilitate urban development, or converted to salt production ponds. Where 200,000 acres of tidal marsh and wetlands lined the Bay over 150 years ago, only 44,000 acres remain. Much of the South Bay is heavily subsided due to unsustainable groundwater pumping of the past, and protected by levees that do not meet federal flood standards and must be repaired often. These levees and the land behind them, including the Silicon Valley, are at increasing risk of failure.

FLOOD PROTECTION INFRASTRUCTURE

Unlike transportation, drinking water and sanitary facilities, flood protection infrastructure is rarely seen or used by the public.

Flood defenses are measured by an event that may not occur in a lifetime, and their value is therefore more hidden from the public than the value of other vital services.

These facilities are really only tested every several years, but they protect the essentials of human community, including businesses, homes, schools, and more visible critical infrastructure like transport, energy and sanitary services. Flood protection agencies can become victims of their own success, struggling to identify resources to maintain and improve aging infrastructure.

The city of Walnut Creek offers a typical example of the difficulty involved in improving local flood infrastructure. Downtown Walnut Creek is located at the confluence of three major creeks: San Ramon Creek, Tice Creek, and Las Trampas Creek. These three creeks come together to form Walnut Creek,

the namesake of the city. The commercial district in downtown Walnut Creek is one of the most vibrant and economically successful in the East Bay. However, in the 1950s, before the construction of the current flood protection facilities, the downtown business district was flooded under 2 to 3 feet of water in 1952, 1955, and 1958. Today, the infrastructure that protects this business district is hidden from view and many people don't know it exists. There are two generations of residents in the Walnut Creek watershed that have never experienced flooding because flood protection facilities have been in place since the 1960s to protect them. As a result, discussion of the importance of flood protection facilities is often met with indifference. The inability

of the Flood Control District to replace deteriorating facilities due to lack of funding and the residents' indifference to the importance of the infrastructure places the community at risk of repeating the flooding of the 1950s when facilities begin to fail.

The figures in Chart 1 show the value of properties in each county which remain unprotected from flood hazard. These values are determined based on floodplain maps created by FEMA's flood hazard mapping program, which has the twofold goal of guiding states and communities in their flood mitigation efforts and of providing the basis for National Flood Insurance Program regulations and flood insurance requirements. Dating back to the

County Name		Value of Structures and Contents Exposed	Value of Crops Exposed	Total Exposed Value
Alameda County	100-year event	\$5,600,000,000	\$290,800	\$ 5,600,290,800
	500-year event	\$16,700,000,000	\$447,000	\$16,700,447,000
Costra Costa County	100-year event	\$4,900,000,000	\$48,400,000	\$4,948,400,000
	500-year event	\$8,700,000,000	\$62,000,000	\$8,762,000,000
Marin County	100-year event	\$5,600,000,000	\$677,400	\$5,600,677,400
	500-year event	\$9,300,000,000	\$679,100	\$9,300,679,100
Napa County	100-year event	\$1,500,000,000	\$336,900	\$1,500,336,900
	500-year event	\$1,900,000,000	\$342,200	\$1,900,342,200
San Francisco County	100-year event	N/A	N/A	N/A
	500-year event	N/A	N/A	N/A
San Mateo County	100-year event	\$13,800,000,000	\$3,000,000	\$13,803,000,000
	500-year event	\$19,200,000,000	\$3,000,000	\$19,203,000,000
Santa Clara County	100-year event	\$15,200,000,000	\$50,500,000	\$15,250,500,000
	500-year event	\$84,300,000,000	\$68,400,000	\$84,368,400,000
Solano County	100-year event	\$2,500,000,000	\$95,400,000	\$2,595,400,000
	500-year event	\$7,600,000,000	\$133,900,000	\$7,733,900,000
Sonoma County	100-year event	\$2,100,000,000	\$8,200,000	\$2,108,200,000
	500-year event	\$3,300,000,000	\$8,400,000	\$3,308,400,000
Nine-County Bay Area	100-year event	\$51,200,045,500	\$206,805,100	\$51,406,850,600
	500-year event	\$151,000,045,500	\$277,168,300	\$151,277,213,800

Chart 1. Flood Hazard Exposure in the Nine-County Bay Area

Note: Exposure information in San Francisco County has not been completed; chart does not include properties protected by flood prevention facilities with a 100-year level of protection; data obtained from California's Flood Future: Recommendations for Managing the State's Flood Risk, Attachment D, available from <http://www.water.ca.gov/sfmp/resources.cfm#mapbook>

Source: Analysis by Bay Area Flood Protection Agencies Association

1980s, many FEMA floodplain maps are based on the development in place at that time and therefore consider neither the impacts of recent urban development nor the existing general plan build-out of many areas. As a result, exposure values based on FEMA floodplain maps are extremely conservative and often do not reflect today’s landscape.

With that in mind, however, the example of Contra Costa County provides valuable insight about the important service flood protection facilities do provide. A 2013 analysis of the status of flood protection infrastructure in Contra Costa County reported that regional flood protection infrastructure protects over \$25 billion in assessed property value in the county.²² In the same year, a State Department of Water Resources analysis indicated that in Contra Costa County \$4.9 billion in structures are still located in a floodplain and remain exposed to flooding in a 100-year event (see Chart 1)²³. Based on these assessments, the total value of structures in the floodplain is \$29.9 billion—\$25 billion that is protected and \$4.9 billion that is unprotected. This

analysis suggests that approximately 83% of flood risk in Contra Costa County has been managed, while 17% remains at risk. If a comparable ratio prevails across the region, this suggests that

a high proportion of otherwise at-risk properties in the Bay Area benefit from some level of flood protection, but a large number remain vulnerable to floods.

Many of the Bay Area’s flood protection facilities are depicted in Map 1. These include levees, flood control channels, detention basins and reservoirs. Reservoirs are often used for both water supply and flood protection. Chart 2 identifies the miles of flood protection channels, the number of detention basins and number of reservoirs for each county. Levees are also a critical element of the flood protection system in the Bay Area, primarily along the Bay shoreline. Chart 3 shows the miles of levees in each county managed by local flood protection agencies.

Agency	Miles of Channels	Detention Basins	Reservoirs
Contra Costa County Flood Control & Water Conservation District	79	29	1
City of Martinez	0.7	0	0
Vallejo Sanitation and Flood Control Districts	6	1	0
Solano County Water Agency	3.5	0	0
Santa Clara Valley Water District	275	11+/-	10
Marin County Flood Control and Water Conservation District	42.8	3	0
Alameda County Flood Control and Water Conservation District	141	20+	3
Alameda County Flood Control and Water Conservation District, Zone 7	37	0	0*

Chart 2. Regional Flood Protection Facilities in the Bay Area: CHANNELS AND BASINS

**Note: one local reservoir is owned and managed by DWR*

Source: Bay Area Flood Protection Agencies Association

Agency	Miles of Levees
Contra Costa County Flood Control & Water Conservation District	30.0
Vallejo Sanitation and Flood Control Districts	1.0
Marin County Flood Control and Water Conservation District	13.7
Alameda County Flood Control and Water Conservation District, Zone 7	0.0
Santa Clara Valley Water District	105.5
Alameda County Flood Control and Water Conservation District	66.2

Chart 3. Regional Flood Protection Facilities in the Bay Area: LEVEES

Source: Bay Area Flood Protection Agencies Association

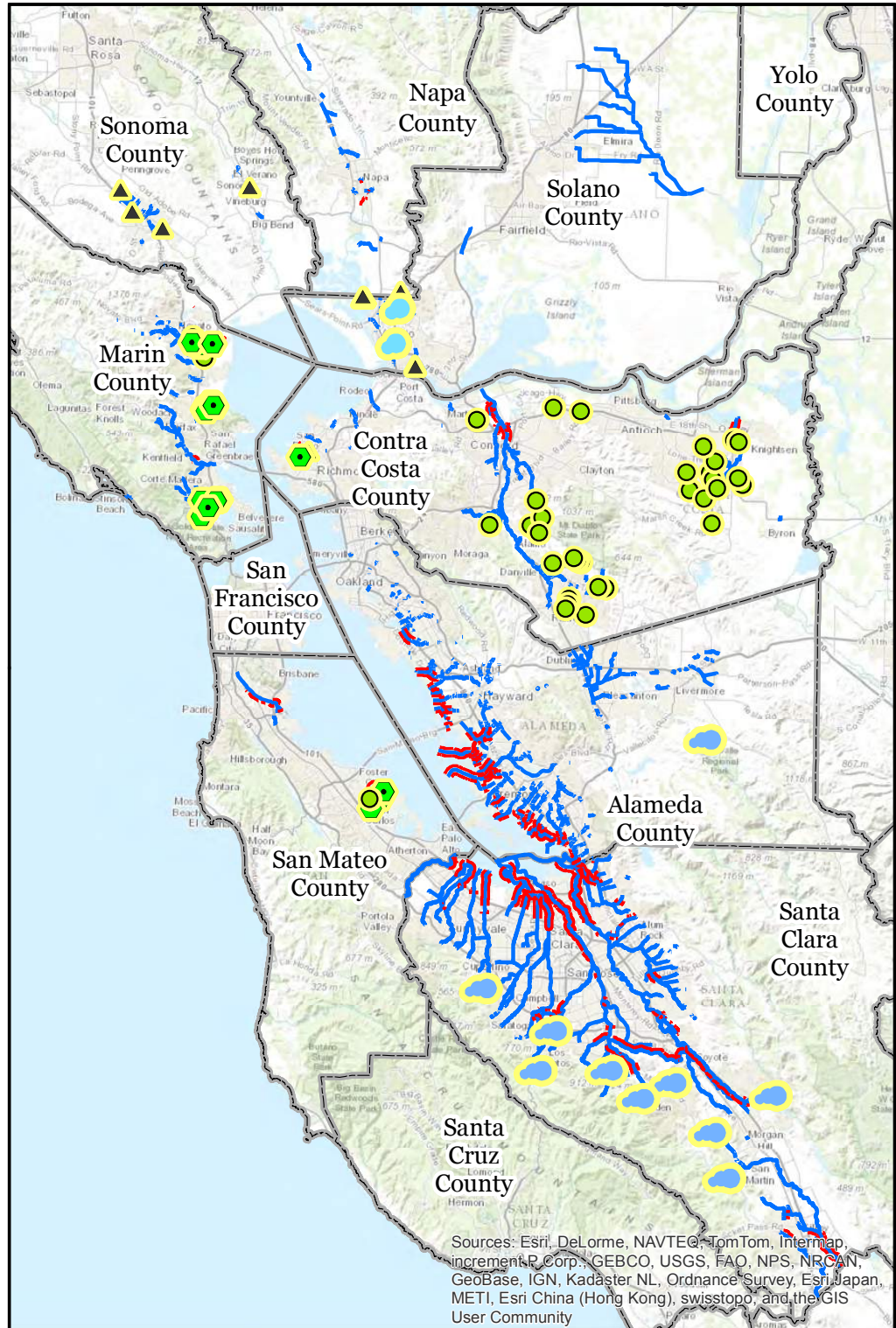
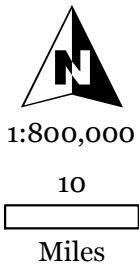


Location Map

Data Source: Bay Area Flood Protection Agencies Association members. All data should be considered draft.

- Channels
- Levees*
- Reservoir
- Detention Basin
- Sediment Basin
- Lake
- Pump Station

* Levees may be offset from actual position for clarity.



Sources: Esri, DeLorme, NAVTEQ, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, and the GIS User Community

Map 1. Flood Protection Facilities in the Bay Area

Note: The appendix provides more detailed maps for each sub-region

Source: Bay Area Flood Protection Agencies Association; reprinted with permission.

FUNDING FLOOD PROTECTION SERVICES

In the 1950s through 1970s the Bay Area was focused on providing adequate infrastructure for development of its communities. The federal government, through the US Army Corps of Engineers or the Natural Resources Conservation Service (previously the Soil Conservation Service), was a partner with local flood control agencies in constructing many of the flood protection facilities protecting Bay Area communities today. During that time, the federal government provided 80% and sometimes up to 90% funding of the construction costs. In addition, the state had a subventions program that paid 70% of the right-of-way costs. This funding formula supplied local communities with a cost effective way to provide flood protection facilities. Today, however, the Corps has a backlog of unconstructed projects throughout the country, a lengthy and expensive planning process that is cost-shared 50% federal and 50% local, and cost sharing for construction that is now 65% federal and 35% local. In addition, the state subvention program is no longer available. Project-specific funding in the federal budget was the traditional method for the Corps to receive funding to plan and construct flood protection projects. For the last several years, these “earmarks” have been eliminated from the federal budget process. These changes have increased the time and cost of building regional flood protection facilities in the Bay Area and nationwide.

After the Corps builds a flood protection facility, the facility must be maintained by a local flood protection agency. The flood protection agency signs a maintenance agreement with the Corps to ensure that maintenance is kept to a specific standard, and each year the Corps inspects the facility to ensure compliance with the maintenance requirements.

Flood protection agencies typically receive a portion of the property tax to fund flood protection services. In 1978, with the passage of Proposition 13, the tax rate for flood protection agencies was frozen at the 1976 tax rate. Flood protection agencies face the challenge of keeping up with the increasing costs of maintaining a facility with a tax rate locked in over 35 years ago. After Proposition 13, some flood protection agencies recognized the need for increased funding and formed Benefit Assessment Districts. However, with the passage of Proposition 218 in 1996, flood protection agencies cannot raise the assessments in their Benefit Assessment Districts and are now faced with maintaining facilities with rates locked in almost 20 years ago.

Most flood protection agencies have a backlog of deferred maintenance due to the lack of ability to fund an adequate maintenance program.

At the same time, development in watersheds added additional impervious surface, increasing the pace of runoff and flood risk in many Bay Area watersheds.

AGING FACILITIES

Most communities in the Bay Area originated as small fishing villages or agricultural communities in the valleys sprinkled around the hills surrounding San Francisco Bay. These communities began to grow rapidly around the shoreline after World War II. Historically, when flooding occurred, communities simply rebuilt the damaged structures and the pioneering people learned to build their homes above the flood waters. However, by the 1950s with urbanization blossoming in many communities, there was a strong demand for controlling flood waters. The cry for flood protection became

particularly pronounced after the severe floods of 1952, 1955 and 1958. Flood Control Districts were formed and flood protection facilities began to be constructed in the 1950s and the 1960s.

Many of the facilities relied on today in the Bay Area are 50 years old or older, and are near, at or beyond their 50-year design life. Much of Silicon Valley is protected by primitive earthen salt-pond levees built in the early 20th century.

Fortunately, flood protection facilities will provide service longer than 50 years, but the time to think about their replacement is now. Concrete structures today are designed for a 75-year service life and most flood protection officials believe their facilities will perform for at least 75 years before needing replacement. The actual service life depends on environmental factors and the loading on the concrete structure for those sections of the flood protection system that are constructed of concrete.

MANY PROBLEMS AT ONCE

An extreme storm creates many problems at once, which can combine to make flooding worse for local communities. These include large waves forming from wind blowing over expanses of water such as San Francisco Bay, driving water up against shoreline protection and pushing back against waters flowing out of creeks draining to the Bay. The Bay water surface can also be increased by storm surge from prior storms. For example, several years ago the water elevation in the North Bay was 1½ feet higher than normal due to all of the stormwater draining from the San Joaquin/Sacramento Delta Region from storms that occurred a day or two earlier. Higher water levels in the Bay make it harder for the

stormwaters from local creeks and rivers to drain into the Bay and backs their water up into shoreline communities. Sea level has risen over the last century and will continue to rise, so flood waters draining from local creeks and rivers into the Bay will also back up more frequently. In addition, it is expected that changing weather patterns will produce wetter storms with higher peak flows than those we have experienced in the recent past. These higher peak flows will result in more intense flooding in the creeks and rivers that drain Bay Area watersheds.

THE FUTURE OF FLOOD PROTECTION

Many flood protection officials have evaluated the current system and believe that changes must be made in order to provide adequate flood protection today and into the future. It is clear that

the Bay Area is today unprepared for an extreme weather event and that the risk will increase over time given rising seas and aging infrastructure.

Elected officials and flood control managers should focus on how to accommodate regional economic growth using both traditional and natural flood protection strategies, for example, leveraging new development to improve local flood defense or utilizing wetlands along the shoreline to attenuate wave energy and protect shoreline levees. Public officials should also consider ways to naturalize aging flood protection facilities, as they are being replaced, to resemble a more natural stream system, potentially with back water channels to store and slow water down and with ways to use basins and wetlands to hold back stormwater in the upper and middle watersheds, thus helping to reduce flooding in the middle and lower portions of the watershed.

FLOOD PROTECTION INFRASTRUCTURE

In an extreme storm, the Bay Area will face flood risk from both an elevated San Francisco Bay, and from overtopped local creeks. However, the San Francisco Bay coastline is 1,000 miles long and includes a diversity of landforms, each with their own peculiar flood challenge. Urban watersheds also greatly differ in the potential for engineers to control and reduce runoff. From Fisherman's Wharf to the South Bay Salt Ponds, there is no one-size-fits-all strategy.

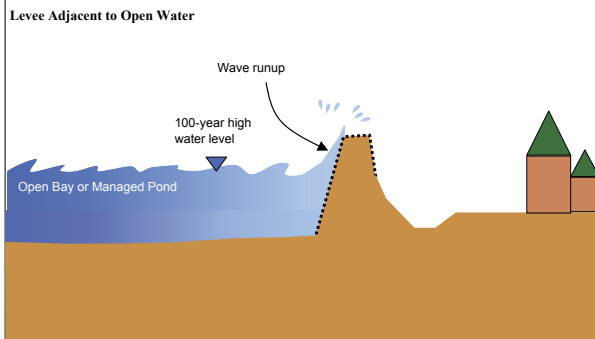
Much existing flood protection in the region relies on traditional "hard" or "grey" structures – such as floodwalls, trapezoidal channels, and riprap – solutions that provide design certainty and longevity but are often difficult or expensive to maintain and adjust over time. In addition to these traditional approaches,

recent engineering innovations are making it increasingly possible to use wetlands and other natural systems to provide reliable and cost-effective flood protection while providing wildlife habitat and other ecosystem benefits.

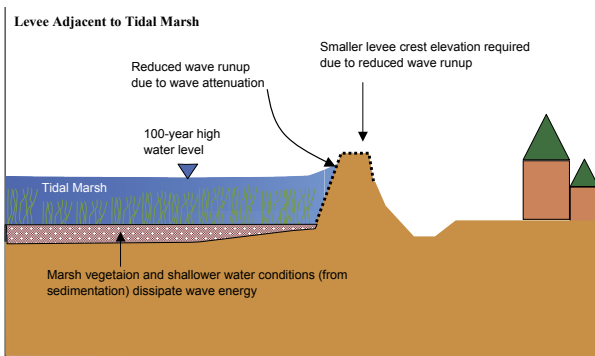
For bay and coastal settings, flood solutions typically involve either blocking water through traditional (grey) infrastructure such as levees or sea walls, absorbing tidal energy through natural (green) infrastructure such as wetlands, or a combination of the two. An innovative approach termed the "horizontal levee" integrates traditional flood protection structures with gradually sloping transitional features that assist in flood protection while increasing habitat diversity within the marsh.

In the creeks and tributaries of the urban watershed, practices such as floodplain setbacks and the opening up of previously channelized streams help reduce potential flood levels, while green infrastructure strategies such as bioswales, green streets, and green roofs provide ways to slow and treat urban runoff before it impacts major floodways.

BAY



Traditional Levee without Wetlands (Grey Infrastructure)



Traditional Levee with Wetlands (Green + Grey Infrastructure)

Source: South Bay Salt Pond Restoration Project

RIVER / CREEKS



Bioswale (Green Infrastructure)

Source: SFPUC



Seawalls (Grey Infrastructure)

Source: Dave Rauenbuehler



Storage Tunnels (Grey Infrastructure)

Source: SFPUC



Horizontal Levee (Green + Grey Infrastructure)

Source: The City of San Jose



Green Streets (Green Infrastructure)

Source: SFPUC

FLOOD MANAGEMENT STORIES

From around the Bay Area

There are many creeks, rivers, and shorelines around the San Francisco Bay that are prone to flooding. The following stories highlight a handful of watersheds and shoreline areas, namely the Napa River and Ross Valley in the North Bay; Alameda Creek, Walnut Creek, and Oakland Airport in the East Bay; Guadalupe River and South San Francisco Bay Shoreline in the South Bay; and San Francisquito Creek, San Francisco Airport and San Francisco's Urban Watershed on the Peninsula. Many of these places have a long history of flooding. All have been the subject of flood management planning by local agencies. They are each at different stages of project implementation and demonstrate the time and effort necessary to plan, construct, and maintain flood protection infrastructure, as well as the complexity of providing flood protection in a highly urbanized environment while also trying to achieve other objectives, such as wildlife habitat, water quality, water supply, and recreation.



Napa River Watershed

Ross Valley Watershed

Walnut Creek Watershed

San Francisco's Urban Watershed

Oakland International Airport

San Francisco International Airport

Alameda Creek Watershed

South San Francisco Bay Shoreline

San Francisquito Creek Watershed

Guadalupe River Watershed

Note: all watershed locations are approximate

5

NORTH BAY

NAPA RIVER WATERSHED

I. History and Problem

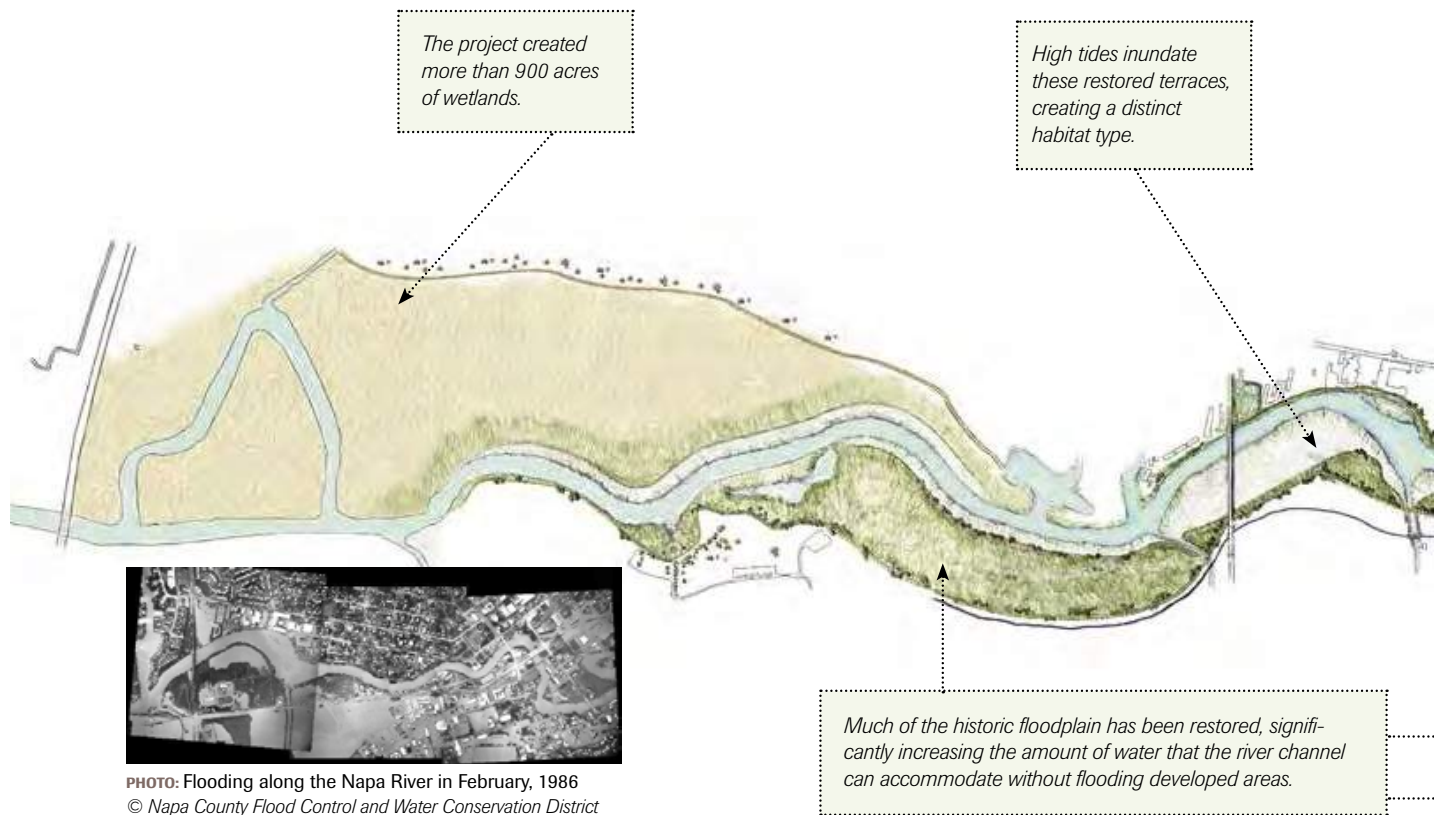
Historically, both Napa Creek and the Napa River presented a substantial flood risk to the City of Napa, and from 1970 to 1998 damage from floods amounted to \$542 million. The 1986 50-year flood event caused \$100 million in damage alone (figure in 1986 dollars).²⁴

In 1965 Congress authorized a flood control project for the Napa River, and in 1975 the Army Corps of Engineers prepared a plan to deepen, straighten and armor the river channel, although local residents voted against a sales tax increase to fund the project.

The Corps proposed a similar plan in 1995, but it was also abandoned due to opposition from local groups as well as state water quality regulators.²⁵

II. Current Issues and Solutions

From 1995 through 1997, local leaders worked with the Corps, as well as environmental and business groups and state agencies, to draft a "Living River" plan that would provide 100-year flood protection. The Living River plan was a combined approach consisting of both hard flood protection



infrastructure and natural infrastructure (gray and green infrastructure measures) including 135 acres of restored floodplain and 900 acres of restored tidal wetlands combined with levees and rock and concrete structures where needed. The Living River plan not only improves the aesthetics and visibility of the river, but provides wildlife habitat, trails, and a downtown river promenade. The Living River project is located along the Napa River, from Trancas Road, Napa, to where Highway 29 crosses the river, as well as Napa Creek from the confluence to one mile upstream.²⁶

III. Planning for the Future and Funding

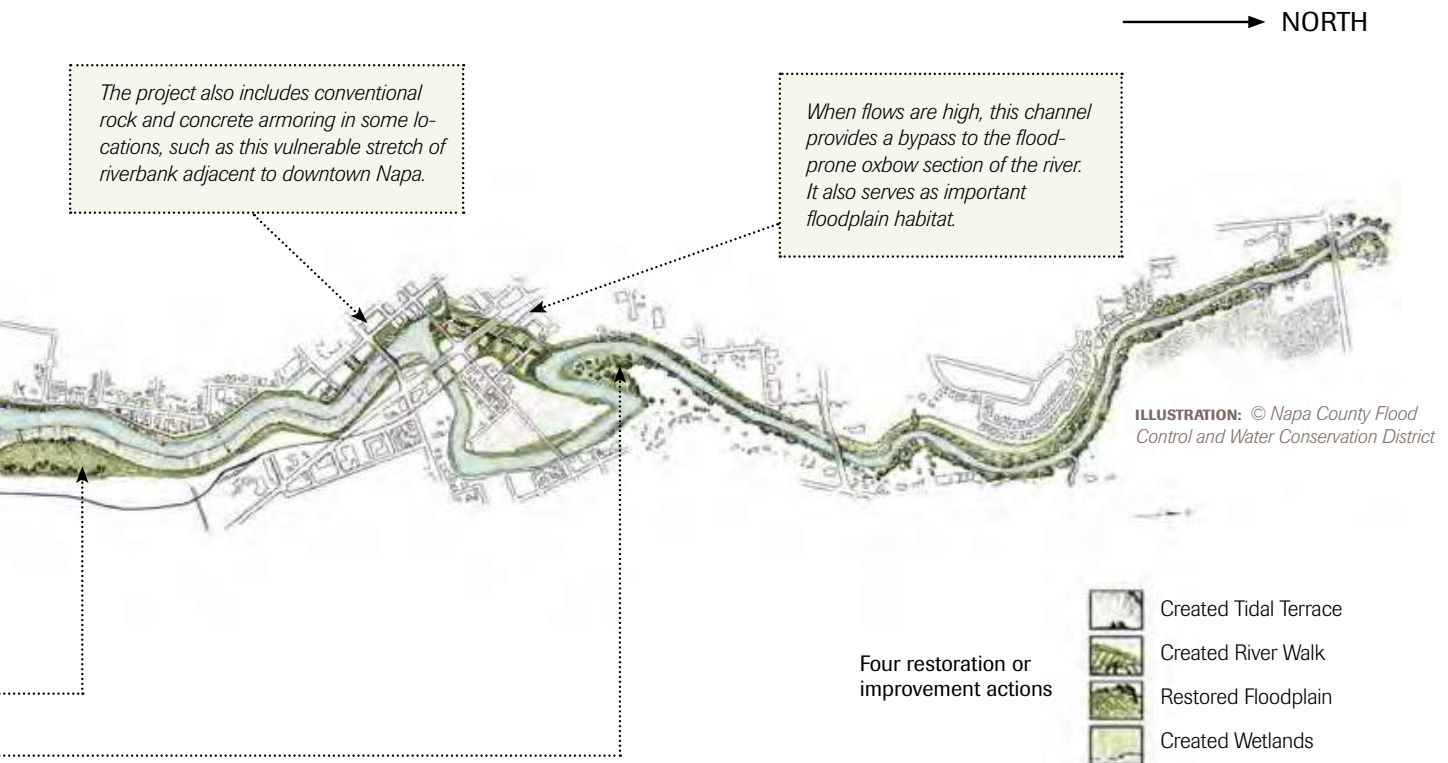
Through a two-thirds majority vote of Napa County residents, a sales tax increase was approved in 1997 to provide the local share of project funding.²⁷ The current cost estimate for the project is \$555 million, and as of June 2014 the project is roughly 75 percent complete with the most significant flood reduction project element, the Oxbow dry bypass, currently under construction in downtown Napa.

For more information:

Napa County Flood Control and Water Conservation District

Tinyurl.com/m6nok3z

Richard Thomasser: Richard.thomasser@countyofnapa.org



"Living River" Project

Source: Napa County Flood Control and Water Conservation District as published by The Nature Conservancy in *Reducing Climate Risks with Natural Infrastructure*, 2013.

NORTH BAY

ROSS VALLEY WATERSHED

I. History and Problem

Ross Valley's Corte Madera Creek watershed includes the central Marin County communities of Greenbrae, Larkspur, Kentfield, Ross, San Anselmo, Sleepy Hollow, Oak Manor and Fairfax.

The Ross Valley Watershed has been one of the highest FEMA damage claims locations in Northern California. San Anselmo ranks seventh among all communities in California for National Flood Insurance Program claims, and the town of Ross ranks tenth. Since the federal program was started in 1968, San Anselmo residents have filed 255 claims totaling nearly \$11.3 million in flood losses, and Ross residents have filed 237 claims totaling about \$9.6 million in flood losses.²⁸



Ross Valley Watershed Area

Source: Marin County Department of Public Works

Before the creation of the Ross Valley Watershed and Flood Protection Program, Corte Madera Creek and its tributaries presented a severe flood risk to the communities in Ross Valley. From 1951 to 2005, 15 flood events were recorded. Of these, the most severe floods occurred in 1982 and 2005. Recurrent flooding caused extensive property damage and economic hardship to residents, businesses, and local governments and has threatened the lives of those living in the floodplain, with at least one recorded death occurring in the 1955 flood and at least one rescue of a stranded motorist during the 2005 flood. The flood of December 31, 2005, an approximate 100-year event, caused significant damage to private residences, private property, businesses, schools and municipal infrastructure in the towns of Fairfax, San Anselmo, Ross, and Larkspur and in the unincorporated communities of Kentfield and Greenbrae. Total property damage has been estimated at well over \$100 million.

II. Current Issues and Solutions

The Ross Valley Watershed and Flood Protection Program was initiated by the County of Marin in partnership with the towns and cities in Ross Valley after the 2005 New Year's Eve flood. This comprehensive flood protection program integrates environmental stewardship and restoration while providing up to 1% annual exceedance probability protection, commonly called the "100-year flood." The program was developed to identify comprehensive watershed solutions by implementing a region-wide flood management program that promotes healthy watershed processes and integrates environmental stewardship and restoration. Projects include multi-use detention basins, bridge replacements, culvert enlargements, creek improvement measures, erosion control and stream bank repairs, fish habitat improvements, and enhancements to tidal flows.

III. Planning for the Future and Funding

In 2007, Ross Valley parcel owners voted and approved a parcel fee on all parcels that drain into the Ross Valley watershed to help pay a portion of the annual costs for a flood protection program. Since 2012, over \$31 million in grant funds have been secured for the program's flood control projects. The cost of the current Ross Valley Watershed and Flood Protection Program is estimated at \$130 million. The first phase of the program is the detention basins, and it is anticipated that these basins will be constructed in the next five years.



Downtown San Anselmo. 2006 New Years Flood

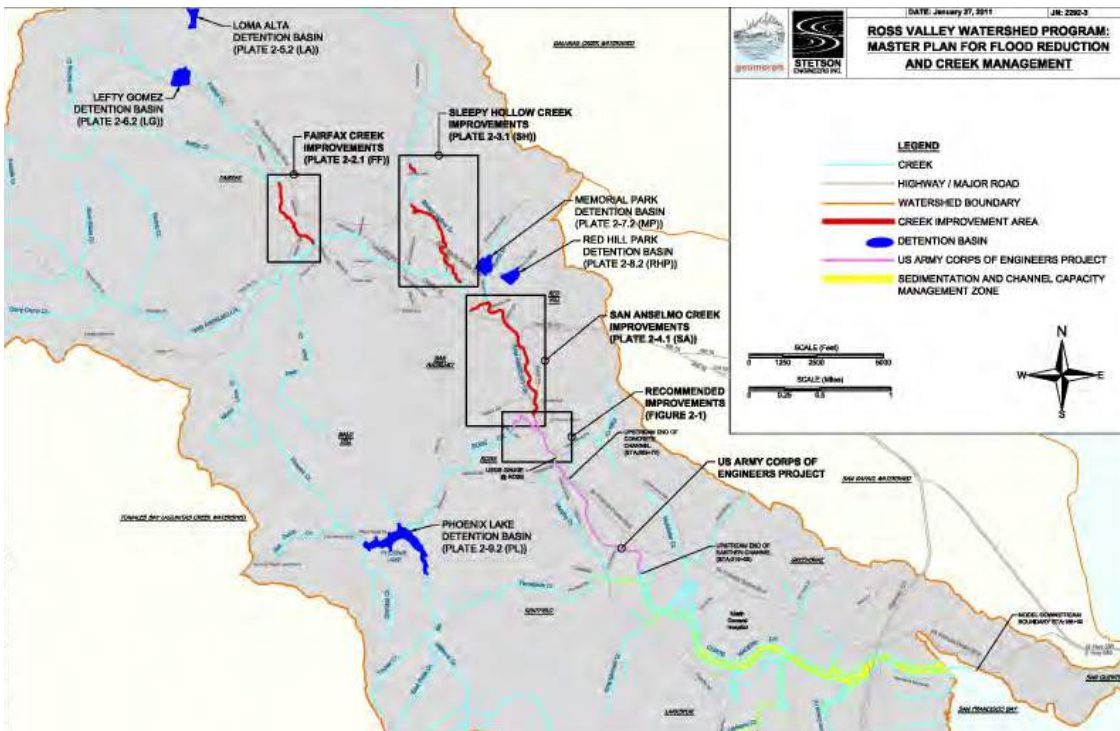
Source: Marin County Department of Public Works

For more information:

Ross Valley Watershed and Flood Protection Program,
Marin County Department of Public Works (DPW)

<http://RossValleyWatershed.org>

Tracy Clay: tclay@marincounty.org



Ross Valley Watershed Program 10-Year Work Program Projects

Source: Marin County Department of Public Works

EAST BAY

ALAMEDA CREEK WATERSHED

I. History and Problem

The Alameda Creek watershed is the third largest watershed draining into San Francisco Bay (after the Sacramento and San Joaquin rivers), covering about 700 square miles. Historically, the upper watershed consisted of several arroyos and intermittent streams which would drain to a large tule marsh that would absorb water and sediment and slowly release them down the Arroyo de la Laguna to Alameda Creek, through Niles Canyon, and finally across the alluvial fan and out to San Francisco Bay.

The historical channelization of streams and construction of dams and other in-channel structures changed the system dramatically. The tule marsh was drained, developed, and today no longer buffers downstream areas from high velocity flows. Today, the upper tributary areas and the reach through Niles Canyon are largely untouched by urbanization and remain for the most part in a natural state. However, the watercourses through urbanized areas of the Tri-Valley and downstream of Niles Canyon have been channelized and are greatly altered.

II. Current Issues and Solutions

Increased impervious surfaces and upstream impoundments have created an imbalance of water and sediment along the watercourse all the way out to the Bay. The majority of coarse sediment is captured behind the three dams in the watershed, while historically disconnected streams now flow year-round and distribute fine sediment which settles within the channels. The straightening and simplification of channels has reduced the ability of channels to store sediment. Instead, sediment often accumulates at bridge pilings and other

man-made depositional environments. The annual sediment load to the downstream Alameda Creek flood control channel has increased from 74,000 tons in the 1970s to 156,000 tons in the 1990s. Additionally, levees and channel incision (the process where a stream cuts downward, steepening its banks and causing erosion) have disconnected channels from their floodplains, reducing floodplain deposition. These changes have led to localized erosion in some places and deposition in others.

Today the watershed is a highly engineered system, the result of a series of historical modifications designed to maximize water output for nearby towns. The creeks and channels now serve multiple purposes, among them flood water conveyance, groundwater recharge, recreation, and habitat. The implications of sediment imbalance are that channel incision threatens the stability of flood control channels, while excessive sedimentation increases flooding risk due to decreased channel capacity.

III. Planning for the Future and Funding

As changes are made to the ways that water is stored and transported through such an engineered system, the resulting problems with erosion and sedimentation also need to be resolved. Multi-use channels require specialized maintenance and management—a combination of measures that will slow down the flow of runoff, reduce the sediment loads, and improve sediment transport in the flood control channels, helping to alleviate the erosion and sedimentation issues affecting Alameda Creek and its tributaries.

Following are two case studies illustrating issues and possible solutions—one in the Livermore-Amador Valley upper watershed and one in the lower watershed.



Note: The Alameda Creek Watershed drains approximately 700 square miles, across three counties (Alameda, Contra Costa, and Santa Clara). Three major reservoirs in the upper reaches impound water and sediment and influence the downstream hydrology. Where the watershed drains to the bay, the stream is armored and channelized. Sediment and flood flows that historically spread out over a broad estuary and marsh complex are now contained within the Flood Control Channel.

Source: Zone 7 Water Agency

CASE STUDY 1

UPPER WATERSHED, LIVERMORE-AMADOR VALLEY

Location

Arroyo Las Positas downstream of Portola Avenue, Livermore to where Interstate 580 crosses the arroyo.

Estimated Cost

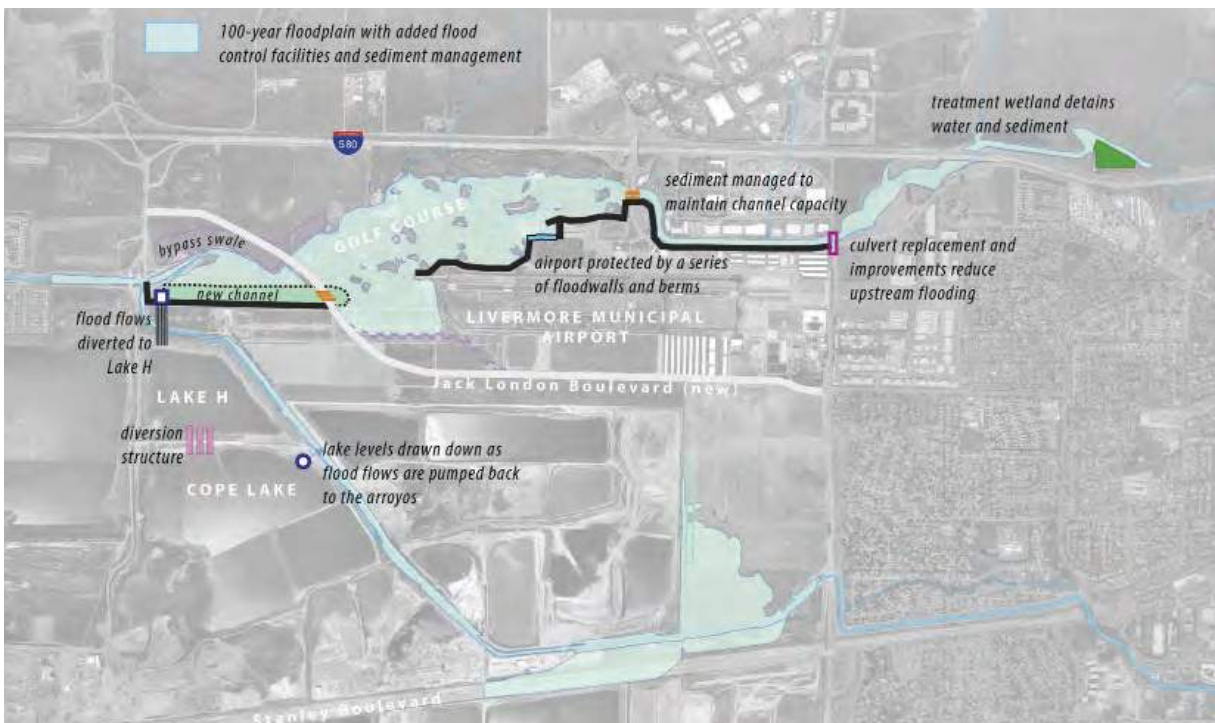
\$15 million

Summary

Arroyo Las Positas Treatment Wetland #1 is intended to improve the water quality of urban stormwater runoff from Arroyo Las Positas, while also slowing the flow and removing sediment before the flow re-enters the channel downstream. This project is part of Zone 7's 2006 Stream Management Master Plan (SMMP) and its associated Environmental Impact Report that was created to establish a long-term plan to accept and manage stormwater runoff.

Vulnerability Addressed

Channel incision is currently occurring along the upper reaches of Arroyo Las Positas, due in part to the expansion of impermeable surfaces and artificial increases in stream flow which create an imbalance of water and sediment. The degree of incision is especially great between North Livermore Avenue and Portola Avenue, where the channel is as much as several meters below the valley bottom. Further downstream, sedimentation is occurring at the I-580 and Airway Boulevard bridges. One



Zone 7 has a larger plan in place to contain a 100-year event and protect critical facilities in the Chain of Lakes area. This plan is currently being updated as part of Zone 7 Water Agency's Stream Management Master Plan update.

Source: Zone 7 Water Agency



Conceptual design of Arroyo Las Positas Treatment Wetland #1

Source: Zone 7 Water Agency

consequence of this sedimentation is increased flooding risk due to decreased channel capacity.

Floodplain creation at strategic locations along Arroyo Las Positas could help alleviate local channel incision and sedimentation occurring downstream. Although sediment storage was not the primary function provided by this stream system historically, channelization, increased stream flow, and road construction have created a need for greater sediment storage capacity along this reach.

The Project

The Arroyo Las Positas Treatment Wetland #1 will be constructed along Arroyo Las Positas (ALP), north of I-580 near the City of Livermore, to improve the water quality of urban stormwater runoff from ALP, while also slowing the flow and removing sediment before the flow re-enters the channel downstream. The treatment wetland would be constructed by excavating the already existing, but elevated and disconnected, floodplain plateau to below the creek flow line elevation.

During routine storm events, gates or other control devices would open to receive flow, allowing the treatment of urban stormwater runoff via filtration through planned vegetation, while also slowing velocities to promote sediment deposition. The project also includes strategic riparian plantings to alleviate elevated water temperatures that, along

with suspended sediment, are contributing to lower dissolved oxygen levels. During larger storm events, the water level would overtop the berm separating the wetland from the ALP channel.

Any future maintenance within the wetland area can be facilitated by use of flow control structures that allow the wetland to be isolated from the ALP channel. The flow control structures also allow the water to be metered out of the wetland to act similarly to a hydromodification basin—as flow passes through the treatment wetland, the stormwater slows, allowing more contact time with wetland vegetation. By slowing the water, the project will reduce potential flooding downstream and allow sediment to drop out, helping to reduce sediment accumulation downstream where channel capacity is currently limited.

Status

Baseline monitoring of temperature and benthic macroinvertebrates has already been conducted by Zone 7 on this arroyo as a part of the update to the SMMP. Modeling of the site for flow and sediment transport is ongoing. Subsequent to implementation, sediment and hydrologic monitoring, followed by evaluation, would be conducted to identify successful strategies for future projects.

For more information:

Zone 7 Water Agency: Zone7water.com

Brad Ledesma: bledesman@zone7water.com

CASE STUDY 2

LOWER WATERSHED, NILES CANYON TO SAN FRANCISCO BAY

Alameda Creek Federal Project Low Flow Channel And Fish Passage Project

Location

Alameda Creek from the Mission Boulevard bridge crossing at Niles Canyon to Coyote Hills Regional Park near San Francisco Bay.

Background

The lower segment of Alameda Creek (commonly referred to as the Alameda Creek Flood Control Channel) in western Alameda County between Niles Canyon and San Francisco Bay was channelized by the

United States Army Corps of Engineers (USACE) in response to a series of flood events that occurred in the 1950s.

Since the channel was completed in 1975, the Alameda County Flood Control and Water Conservation District has desilted the channel numerous times, removing nearly one million cubic yards of sediment. With heightened scrutiny by the regulatory agencies, particularly with regard to impacts on water quality, habitat and fisheries, permits to desilt the channel in a manner conforming to USACE requirements are becoming much more difficult to obtain.

The Project

More than a decade ago, the District began taking a more holistic approach in evaluating the channel by considering the greater watershed and watercourse characteristics, studying the geomorphology of the watercourse, analyzing sediment characteristics and identifying sediment sources, studying the hydro-dynamics and sedimentation processes, and studying fish passage issues and assessing biological value. In this effort, the District has gained a better understanding of how the watercourse actually wants to function.

The channel has three distinct reaches, each with its own characteristics. The upper reach, from the mouth of Niles Canyon to the BART Weir/Rubber Dam is relatively steep and does not exhibit as much of a sedimentation problem as the lower reaches.

The middle reach, between the BART Weir/Rubber Dam and the tidal boundary near the Union Pacific Railroad crossing is subject to a combination of erosional incision and fluvial sediment deposition. Due to natural morphological processes, the upper half of this middle reach is subject to incision, and the creek tends to form a low-flow channel. The lower half of the middle reach has seen the bulk of the District's desilting activity. For the full length of this reach, the proposed project will create a permanent continuous low-flow channel, maximized for sediment transport and for fish passage. The meanderings of the low-flow channel will also be armored where necessary, using biotechnical means to prevent undermining



Flood of 1955. View looking upstream toward Niles Canyon. Source: Alameda County Flood Control and Water Conservation District

the channel banks and bridge piers. The lower reach, which extends from the Union Pacific Railroad crossing to the Bay, is tidally influenced and is subject to both fluvial sedimentation as well as sedimentation from the Bay. Mechanical removal of sediment from this reach has proven to be futile, due to the endless supply of sediment from the Bay deposited with the daily tides. Along this reach, tidal action has already formed a sustained low-flow channel that is adequate for sediment transport and fish passage. However, due to the buildup of tidal sediments which reduce flood capacity, the proposed project will include raising of the levees where necessary.

It is further envisioned that with the channel optimized for sediment transport, re-establishing a connection between Alameda Creek and the tidal wetland restoration work at the Eden Landing Ecological Reserve will speed up the accretion rate in the former salt production ponds to accelerate

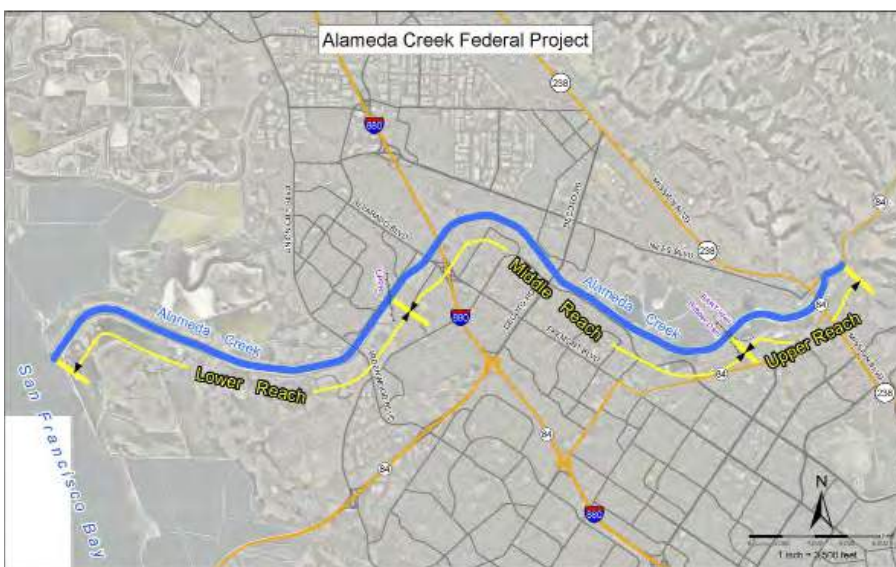
the establishment of wetland habitat. The delivery of sediment to restored tidal marshes would have an added benefit of providing habitat and a fresh-brackish transition for a host of species.

Ultimately, the District's goal is to reduce the cost of sediment removal while preserving the ecological value of the channel by reconfiguring and enhancing the channel cross section. A re-visioned channel form will be necessary for the District to address the sedimentation issue while providing for the flood protection, water supply, wildlife habitat, fish passage, and recreation needs of today.

For more information:

Alameda County Flood Control and Water Conservation District

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Alameda Creek Federal Project. Three distinct reaches of the flood control channel

Source: Alameda County Flood Control and Water Conservation District

EAST BAY

WALNUT CREEK WATERSHED

I. History and Problem

At what point do communities organize and advocate for flood protection? It seems the early settlers of the Walnut Creek watershed lived with flooding. This was partly due to their pioneering spirit and partly due to insufficient population and investment value to organize and finance flood protection infrastructure. In the mid nineteenth century, the flat bottom lands of Ygnacio Valley and San Ramon Valley were covered with fields of grain, and the steeper slopes were covered in vineyards. These crops gave way to walnut trees and fruit trees later on, as they were better-paying crops and irrigation was in place that allowed for more intensive farming.

The flood of 1861 was the largest in the state's history and washed a warehouse in the Town of Pacheco into Suisun Bay. In 1869, flooding battered Pacheco so hard that many residents and merchants packed up and moved to higher ground to found the community of Concord. There were four more damaging floods from 1938 to 1951.

In 1941, a group of Walnut Creek landowners spearheaded a campaign to resolve flooding and erosion problems and voted to establish the Contra Costa Soil Conservation District. Ten years later, the Legislature formed the Contra Costa County Flood Control & Water Conservation District. While large agricultural landowners started the effort to address flooding, the watershed itself was changing demographically and becoming more and more developed and urbanized. In 1950 there were 53,000 people living in the Walnut Creek watershed; by 1966 the population exceeded 250,000 and half of the land had been converted from agriculture to urban development. Major flooding in 1952, 1955 and 1958 solidified support for flood protection infrastructure.

The county's Soil Conservation District and Flood Control District and the federal Soil Conservation Service approved a work plan in 1953 to provide flood protection. This resulted in developing 11 miles of stream channel "improvements," 13 control structures, and one detention basin. This work was all completed by December 1964. Subsequently, the Flood Control District partnered with the US Army Corps of Engineers to expand the flood protection infrastructure to include a total of 53 miles of channels, 32 control structures and two more detention basins. Approximately 12 miles of channel are lined with concrete. This flood protection system has performed remarkably well since it was constructed, preventing flood damage from large storms for the communities within the watershed.

II. Current Issues and Solutions

Today, the Walnut Creek flood protection system has two looming issues that need to be addressed. The first is eventual replacement of the infrastructure. The Lafayette Creek concrete channel was completed in November of 1955. It was built with a 50-year design life. That 50-year design life has come and gone; with proper maintenance the facility is expected to last for another 20 years. The second issue is the inability to adequately maintain the facilities that were designed and built 50 years ago in today's regulatory and environmental climate. For example, the lower Walnut Creek channel, where it drains into Suisun Bay, is filled with 800,000 cubic yards of sediment that has settled into the channel and has reduced flood capacity. The Army Corps of Engineers is requiring the county Flood Control District to remove the sediment and restore flood capacity, but it is virtually impossible to get regulatory permits to perform this work in an area with endangered species, and it is prohibitively expensive. It is also unsustainable; the sediment, once removed, will be replaced by nature in about 7 years.

III. Planning for the Future and Funding

The Contra Costa County Flood Control & Water Conservation District is embarking on a community-based planning process to develop a more sustainable project in this portion of their flood protection system. The Lower Walnut Creek Restoration Project includes the restoration of 120 acres of land known as Pacheco Marsh, acquired by the Flood Control District, the Muir Heritage Land Trust and the East Bay Regional Park District. The Flood Control District's planning process will result in a project that will restore flood capacity while preserving and enhancing habitat value and providing recreational opportunities. This effort will produce a flood protection project for the 21st century where all objectives, not just flood protection, will be met. This is a different approach from the single-purpose projects built in the 1950s and 1960s for which flood protection was the only goal. Unlike the projects of yesteryear, when there were no environmental requirements or regulations, today's projects provide a better balance of societal and ecosystem objectives. This project will also be the first effort in the watershed to demonstrate the vision of the Flood Control District's 50-year plan to replace its aging traditionally designed facilities with natural stream systems. Over the next two generations, the Flood Control District will be replacing worn out flood protection infrastructure with natural streams that will also allow cities and towns to better incorporate Walnut Creek and its tributaries into their communities.

For more information:

Contra Costa Flood Control District

<http://www.co.contra-costa.ca.us/442/Flood-Control>

Mitch Avalon: maval@pw.cccounty.us



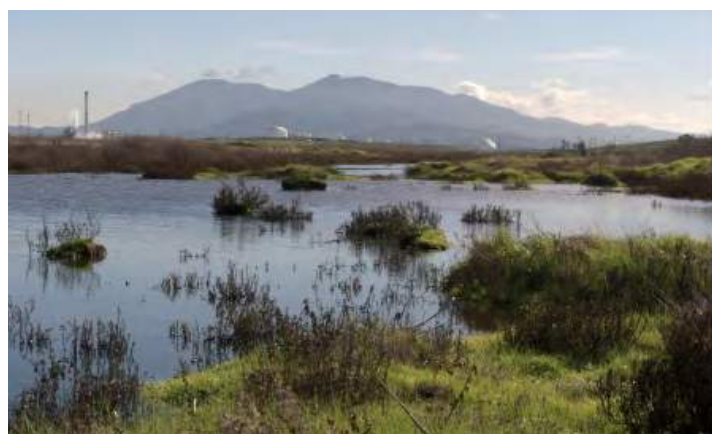
Flooding in downtown Walnut Creek, 1958

Source: Contra Costa Flood Control District



Confluence of the East Branch and West Branch of Grayson Creek, 1957

Source: Contra Costa County Flood Control & Water Conservation District



Pacheco Marsh, looking east towards Mount Diablo

Source: Contra Costa County Flood Control & Water Conservation District

EAST BAY

OAKLAND AIRPORT

I. History and Problem

The Oakland International Airport was born from marshes and mud. At the time it was constructed in 1927, the original Oakland airport had the world's longest runway, a 7,020-foot strip that served as the takeoff point for the first flight across the 2,400 miles from the mainland to Hawaii, as well as Amelia Earhart's final flight in 1937. That airport, now called North Field, is still in operation today for air cargo, general aviation and corporate jet activities. Commercial passenger and cargo jet aircraft also operate from South Field, which opened in 1962.

Expansion in the late 1950s resulted in the reclamation of today's Oakland International Airport from tidal marshes and shallow water areas of San Francisco Bay by constructing a perimeter dike and placing sand fill within the diked area. The dike juts out approximately 1½ miles into the Bay at the east and west ends, and it is 4.5 miles long. The depth of Bay water filled ranged from 3 to 6 feet below mean lower low water.

Available information on the history of the dike indicates that the dike was constructed in three phases. In the first phase, which took place in the late 1950s, the original dike was built with dredged Bay mud enclosing an area of about 1,400 acres of marshland. In the second phase, which took place in the early 1960s, the original dike was extended approximately 3,000 feet to the northwest for the extension of runways from 7,000 feet to 10,000 feet. In the third phase, which occurred in 1970, a second dike extension was constructed. This construction extended the dike approximately 2,500 feet farther north, toward the City of Alameda, to allow for a future runway extension. Construction documents indicate that dredged sand and gravel were placed hydraulically to build the dike during the second and third phases of construction. Hence, these portions of

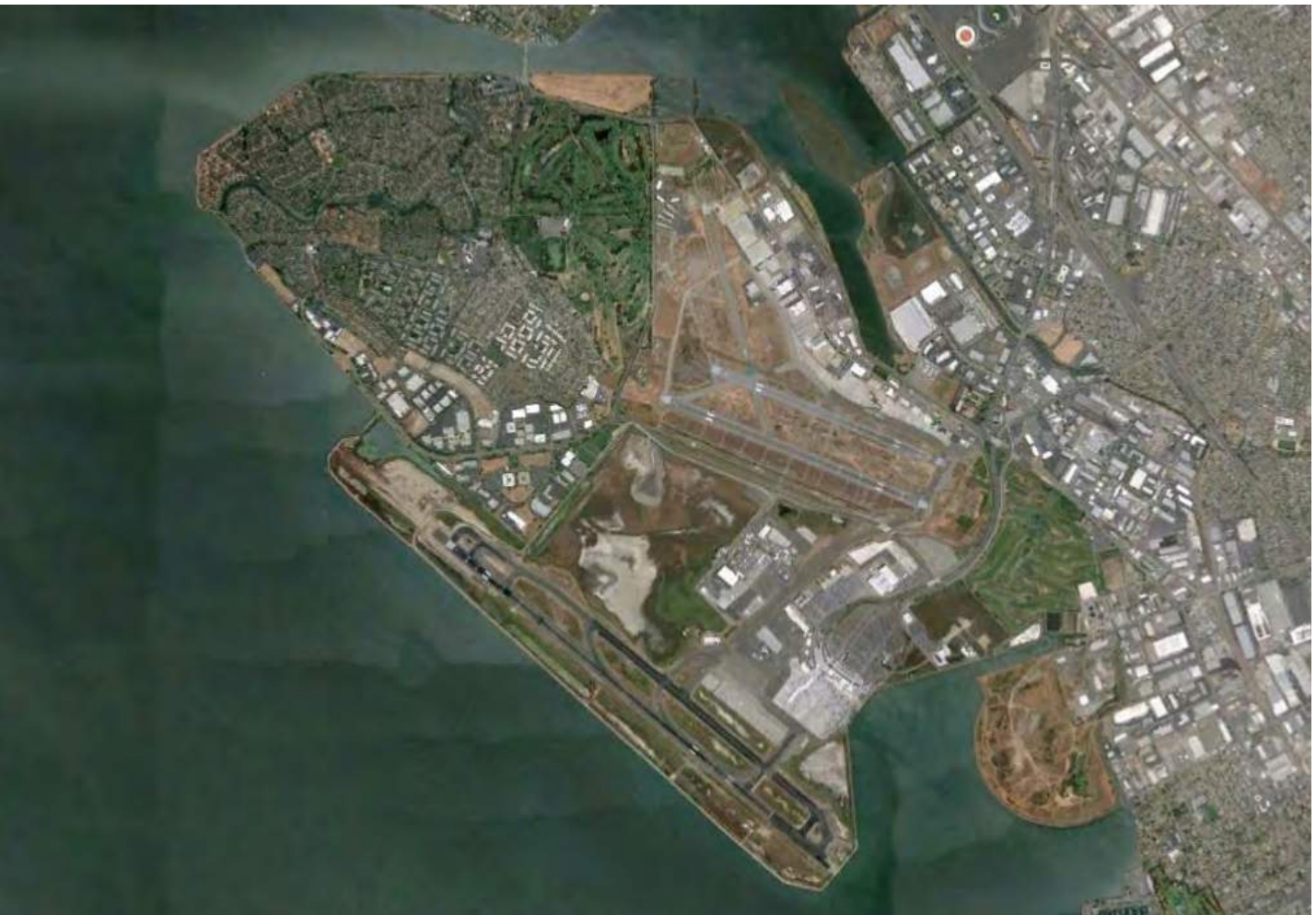
the perimeter dike are referred to as "sand and gravel" dike or "sand" dike. Soil investigations have generally confirmed the existence and extent of the sand and clay dikes as disclosed in the construction records.

In general, the perimeter dike has performed well since its construction in the 1950s. The portions of the perimeter dike constructed during the second phase of construction in the 1960s experienced considerable damage as a result of a severe winter storm in December 1983. Wind-induced waves overtopped the dike and caused erosion of the inboard (runway side) levee slope. The other portions of the dike (the portions constructed during the first and third phases) experienced only minor damage from the storm. After the 1983 winter storm, the dike was repaired by filling the eroded inboard slopes with gravel and constructing a concrete rubble berm.

II. Current Issues and Solutions

The airport is presently located within a FEMA-designated flood hazard area, though it is labeled as protected by provisionally accredited levees. Without any flood improvements, it is anticipated that portions of the airport will be included in a 1% annual chance flood hazard area when updated FEMA maps are finalized. FEMA is currently working with the Airport and the Alameda County Flood Control District to perform more sophisticated two-dimensional modeling of potential flood hazards that take into account the existing active stormwater collection and pumping facilities of the airport.

The airport has conducted hydrodynamic and wave analyses and slope stability, seepage, and seismic analyses to develop possible improvement projects for portions of the dike in order to obtain FEMA certification to remove the airport from a flood hazard area and to strengthen the levees to reduce seismic deformations during earthquakes. These improvements include the following:



- Minor grading to raise portions of the dike that are lower than elevation 12.0 feet (including one foot for sea-level rise).
- The provision of 100-year flood protection by raising portions of the dike crest structure to meet FEMA certification requirements plus one additional foot for sea-level rise.
- Augmentation of slope protection on the outboard slope at the locations identified to be deficient.
- Improvement of the dike to mitigate through-seepage in the portions of the dike constructed with sand.
- Remediation of liquefaction and seismic deformations through the placement of stone columns throughout the dike.

III. Planning for the Future and Funding

The airport is in the process of designing these improvements and anticipates completing the design and starting construction of the initial phases in 2015. The overall project cost is currently estimated to be \$45 million.

For more information:

Oakland International Airport

Joshua Polston: jpolston@portoakland.com

SOUTH BAY AND PENINSULA

GUADALUPE RIVER WATERSHED

I. History and Problem

The Guadalupe River, which has a 170-square-mile watershed, has frequently flooded San Jose's downtown and the Alviso community, with severe flooding in 1862, 1895, 1911, 1955, 1958, 1963, 1969, 1982, 1983, 1986, and 1995. The Guadalupe River's natural channel directly upstream of the Los Gatos Creek confluence had a capacity of 7,000 cubic feet per second, roughly the flow of a 10% or 10-year flood event. In February 1986, the river overflowed



Chinook Salmon on the Guadalupe River in 1998

Source: Santa Clara Valley Water District

its east bank upstream of St. John Street, flooding residences and businesses. In January 1995, a similar flood occurred in the same area. In March 1995, severe flooding occurred when the Guadalupe River and Los Gatos Creek combined to produce the highest flow in 50 years. In the most extensive flooding of the San Jose city core in four decades, streets turned into rivers, forcing residents from their homes and driving office workers from high-rise buildings. Approximately 300 homes and businesses were flooded by four separate breakouts along the river, with damage estimates of up to \$10 million.

II. Current Issues and Solutions

In 1992, the Guadalupe River Flood Protection Project began to provide flood protection to downtown San Jose's technology and commercial industries and established residential neighborhoods, to protect and improve the water quality of the river, to preserve and enhance the river's habitat, fish, and wildlife, and to provide recreational and open space benefits. The project was constructed by the US Army Corps of Engineers in phases along the Guadalupe River in downtown San Jose and extends from Interstate 880 to Interstate 280.

The finished flood protection work includes channel widening, bridge replacement, underground bypass box culverts, streambed erosion protection features, and terraces. The project includes on-site and off-site environmental mitigation work that will enhance steelhead trout and Chinook salmon runs and is an integral component of San Jose's downtown revitalization efforts.

Flood protection construction was completed by December 2004 with development of the river park, and recreation elements were completed in August 2005. On October 25, 2006, the Federal



Flooding in downtown San Jose at St. John Street near San Jose Arena March 1995

Source: Santa Clara Valley Water District

Emergency Management Agency (FEMA) issued a Final Letter of Map Amendment removing properties formerly in the Guadalupe River floodplain from flood insurance requirements.

III. Planning for the Future and Funding

The cost of the project's original design was estimated at \$183 million. However, in the original cost estimate there was no provision for the costs of implementing mitigation efforts to offset construction impacts to the environment and aquatic habitats. After completing the dispute resolution process, project estimates incorporating associated mitigation construction costs, including the bypass twin box culvert favored by all participants, were estimated to be \$226.8 million. In the Energy and Water Development Appropriations Act of 2002, language was included to authorize this revised project cost. Subsequent to the authorization, the project cost was raised to \$251 million.

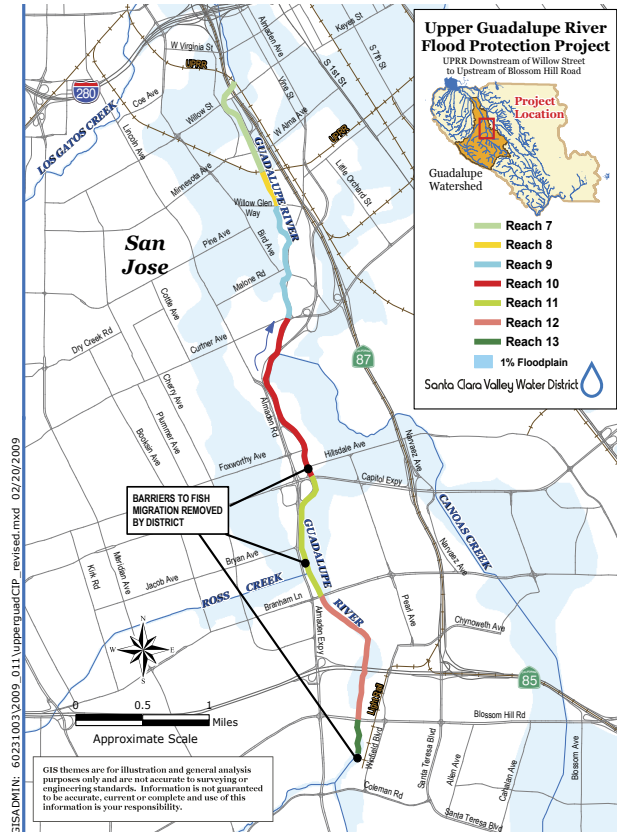
Because of the threat of significant flood damage, the local community has spent more than \$85.8 million in non-federal funds on planning, design, land purchases, and construction of Guadalupe River improvements. According to a 2001 US Army Corps of Engineers report, the completed project avoids 1-percent flood damages of over \$576 million and average annual damages of \$25.8 million, providing an overall benefit-to-cost ratio of 1.86 to 1.

For more information:

Guadalupe River Flood Protection Project, a project of the Santa Clara Valley Water District

<http://www.valleywater.org/Services/GuadalupeRiver.aspx>

Sara Duckler: sduckler@valleywater.org



Source: Santa Clara Valley Water District

SOUTH BAY AND PENINSULA

SAN FRANCISQUITO CREEK WATERSHED

I. History and Problem

Flood prone San Francisquito Creek is the dividing line between San Mateo and Santa Clara Counties and between the cities of East Palo Alto and Menlo Park on the north and Palo Alto on the south. While the creek's watershed or drainage basin is 46 square miles beginning in the Santa Cruz Mountains west of Interstate 280, the floodplain resulting from this creek is about 5 square miles near San Francisco Bay. The projects described here address the part of the creek floodplain between San Francisco Bay and Highway 101 as well as the entire Bay shoreline of East Palo Alto and Menlo Park north of the creek.

History and Summary

Following a major flood in 1998 that damaged 1,700 properties in Palo Alto, East Palo Alto and Menlo Park, these cities and two countywide flood-related agencies in San Mateo and Santa Clara Counties formed the San Francisquito Creek Joint Powers Authority (SFCJPA). While for decades these cities were well aware of the flood threat, until they formed this independent regional government agency in 1999, they had never organized themselves to collectively solve this complex challenge.

II. Current Issues and Solutions

Initially, the SFCJPA looked to the federal government for help. In 2009, with a US Army Corps of Engineers study to find a feasible solution incomplete, the SFCJPA decided to pursue on its own a project in the downstream reach that is influenced by Bay tides. Here the risk to life and property is greatest, with levee tops above rooftops of homes that suffered damage from flooding numerous times, most recently in December 2012.

This initial effort, the San Francisquito Creek Bay-Highway 101 project, will provide protection against a 100-year creek flow occurring during a 10-year tide with over two feet of sea-level rise and freeboard, to eventually get properties out of the flood insurance program. Preliminary construction has begun, while major construction activities await regulatory permits.

Because so many of the properties affected by previous creek flooding are also in the San Francisco Bay floodplain, the SFCJPA is also leading an adjacent project to design and complete an Environmental Impact Report (EIR) to protect the area between the Bay and Highway 101 against a 100-year tide following a similar rise in sea level.

Many jurisdictions must work with their neighbors to address flooding concerns. These projects of the SFCJPA make plain the enormous complexities and great opportunities created when public and private agencies work together to plan, design, permit and fund major water-related capital projects that benefit multiple communities.

III. Planning for the Future and Funding

Projects

The Bay-Highway 101 project will protect people and property against a 100-year flow during a 10-year tide with over two feet of sea-level rise. The SFCJPA anticipates completing construction by the end of 2016. As indicated in the image, golf course land will be used to widen the creek channel and floodwalls will be installed in an area constrained by homes and important infrastructure. Specifically, the project will

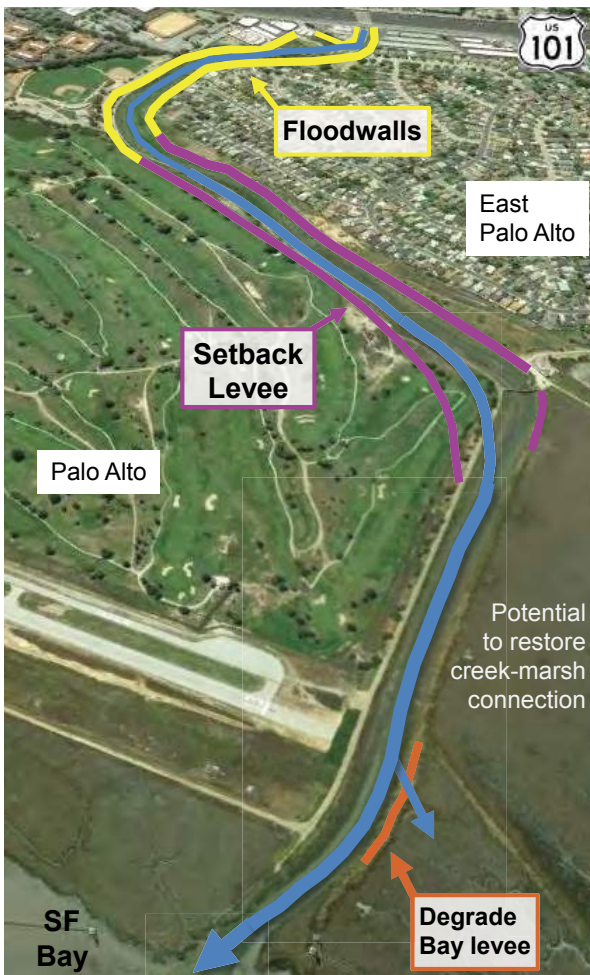
- protect over 1,000 parcels from water that currently overtops and seeps through substandard levees during a 15-year storm,
- create 15 acres of new marsh habitat,
- recreate the historic connection between the creek and marsh to the north,
- construct needed flood protection projects upstream,
- provide a modernized PG&E gas pipeline, and
- improve water quality by keeping flows to the Bay within the creek channel instead of through streets and homes.

Planning and design of the Bay-Highway 101 project was funded by the Santa Clara Valley Water District (SCVWD) and the San Mateo County Flood Control District, and construction is funded by the SCVWD,

the SFCJPA through a grant from the California Department of Water Resources (DWR), the City of East Palo Alto, and San Mateo County.

Approximately 40% of properties in the creek 100-year floodplain are also in the tidal floodplain of San Francisco Bay. Thus, the SFCJPA decided in 2011 that it needed to address the issue of tidal flooding in the cities it serves, starting with the two cities north of the creek in San Mateo County where no agency has responsibility for this issue.

In 2012, the SFCJPA received a grant from the DWR to design and complete an EIR for a new flood protection system from San Francisquito Creek to Marsh Road near the Redwood City border. This grant to develop the SAFER Bay project was matched by East Palo Alto and then Menlo Park, Facebook, Inc., the California State Coastal Conservancy, and the US Fish and Wildlife Service.



Source: San Francisquito Creek Joint Powers Authority

The flood protection system will likely combine traditional levees and floodwalls with innovative designs that achieve multiple benefits. For example, the SFCJPA intends to include levees with ecosystem transition zones, where broad levee slopes rising from Bay marshes accommodate varied habitats and reduce wave energy, thus reducing levee height and cost. Another example is the use of floodwalls that are hidden below the ground and raise as a result of hydrostatic pressure during flood events, thus reducing aesthetic impacts along the Bay.

The SAFER Bay project also affords exciting opportunities to benefit regional projects related to environmental restoration, recreation and community connectivity. New levees between Highway 84 and areas to the north may allow the state-federal partnership known as the Salt Pond Restoration Project to open significant sections of the Ravenswood Ponds to tidal action. An important gap in the Bay Trail south of Highway 84 may be closed by a new levee that protects homes adjacent to that gap.

The figure below shows the extent of the SFCJPA's creek and Bay projects east of Highway 101. (Other SFCJPA projects address flooding in neighborhoods upstream of Highway 101).

Estimated Costs

San Francisquito Creek (SF Bay-Highway 101) design, EIR, construction and mitigation: \$39 million.

SAFER Bay feasibility, design and EIR: \$2.2 million; (there is no construction estimate at this time).

For more information:

San Francisquito Creek Joint Powers Authority: <http://www.sfcjpa.org/>
 Len Materman: len@sfcjpa.org



Source: San Francisquito Creek Joint Powers Authority

SOUTH BAY AND PENINSULA

SOUTH SAN FRANCISCO BAY SHORELINE

I. History and Problem

Santa Clara County's shoreline is now at great risk from flooding due to extreme storm events combined with high tides, and in the future due to sea-level rise. Portions of Santa Clara County nearest the Bay are significantly below sea level, and many high-tech companies are located along the shoreline, along with residents and the largest Water Pollution Control Plant in the Bay Area, which serves over 1 million people.

II. Current Issues and Solutions

To identify and recommend flood protection projects in Santa Clara County for federal funding, a congressionally authorized South San Francisco Bay Shoreline Study is being performed by the US Army Corps of Engineers together with the Santa Clara Valley Water District and the California State Coastal Conservancy. The Corps is considering projects that will reduce flood risk, restore ecosystems and provide related benefits like recreation and public access.

The study assessed flood risk damages for all Santa Clara County Baylands, from Palo Alto to Southern Alameda County, in addition to the restoration of former salt-production ponds within the Alviso Pond complex and adjacent properties such as areas around Moffett Field.

The project is being conducted in phases. The current phase of the Shoreline Study focuses on the most flood-prone section of the Santa Clara County

shoreline: the north San Jose shoreline area between Alviso Slough and Coyote Creek, which includes the Alviso community and the San Jose/Santa Clara Water Pollution Control Plant, as well as several high-tech businesses and the new Silicon Valley Advanced Water Purification Center. This area includes homes and commercial and industrial facilities, generally located below sea level, and over 2,000 acres of former commercial salt ponds now part of the Don Edwards San Francisco Bay National Wildlife Refuge. Implementation of the project will provide tidal flood protection for northern San Jose residents, businesses, and infrastructure and allow for the restoration of the former salt ponds into tidal wetland habitats for wildlife.

In a phased approach, the portions of Santa Clara County's shoreline with the highest potential damages from flooding will be protected using a combination of flood protection levees and wetlands. The multi-objective approach using natural infrastructure provides for increased flood protection, restored Bay habitats, and a flood protection system that can evolve in the future. The study recommends a flood protection project that meets the following goals:

- Protect from flooding from a 1% event (100-year high-tide event) for low-lying areas of San Jose and Alviso.
- Protect the area from just over 2 feet of sea-level rise.
- Protect urban areas next to north San Jose and Alviso from tidal flooding, including the city and county wastewater treatment plant.



- Restore up to 3.5 square miles of wetland habitat.
- Contribute to creation of the West Coast’s largest restored wetland with extensive habitat for endangered species, fish, and migratory birds.
- Provide enhanced public access trails and recreation, including completion of the Bay Trail through the project area.

III. Planning for the Future and Funding

The study is due for completion at the end of 2015. Construction will begin as soon as Congress authorizes the project and appropriates funds, which would happen in 2017 at the earliest. The total project cost is approximately \$140 million for the final design and construction of flood protection levees and associated flood protection features, large-scale wetland restoration, hiking and biking trails, and monitoring and adaptive management. The Santa Clara Valley Water District’s Safe Clean Water measure, passed in 2012, includes \$15 million to cost share construction of the project and leverage federal and state funding.

The Santa Clara Valley Water District’s Safe Clean Water measure also includes \$5 million to cost share studies with the Corps of Engineers to study additional shoreline areas starting potentially in 2015. Other shoreline areas with economic impacts include portions of Palo Alto, Sunnyvale, and Mountain View.



Sunset over the South Bay wetlands

Source: South San Francisco Bay Shoreline Study

For more information:

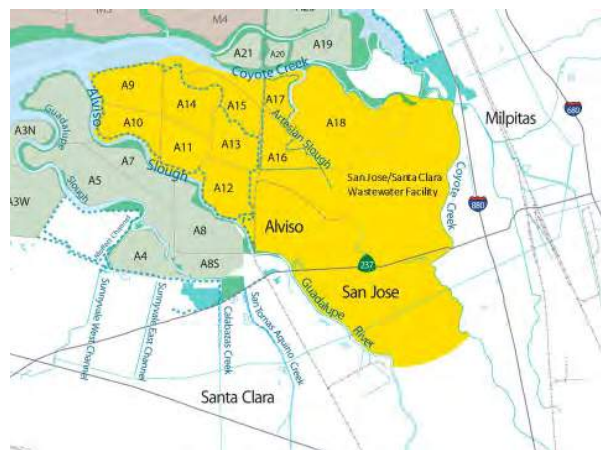
California State Coastal Conservancy: www.southbayshoreline.org

Brenda Buxton: Brenda.Buxton@scc.ca.gov



Aerial view of the South Bay Salt Ponds

Source: South San Francisco Bay Shoreline Study



This image shows the north San Jose shoreline area between Alviso Slough and Coyote Creek, which includes the Alviso community and the San Jose/Santa Clara Water Pollution Control Plant.

Source: South San Francisco Bay Shoreline Study

SOUTH BAY AND PENINSULA

SAN FRANCISCO INTERNATIONAL AIRPORT (SFO)

I. History and Problem

Economic Importance

SFO is the largest airport in the San Francisco Bay Area, the seventh largest in the United States, and 22nd in the world in terms of air passenger traffic. In 2013, SFO set an all-time record for passenger traffic with 45 million passengers, representing the third consecutive year of record-breaking traffic levels, capturing 66.1% of domestic and 95.5% of international market share in the Bay Area. In 2012, SFO directly accounted for \$5.4 billion in business activity supporting 33,580 jobs at the airport. Off-site business activities that depend directly on local air service for staff movements, cargo deliveries, or customer visits (visitor spending) together raise the direct airport economic contribution to the Bay Area to \$31.2 billion in business sales with 153,000 jobs. Including indirect impacts related to suppliers of goods and services, the total economic footprint of SFO in the Bay Area is almost \$55.8 billion in business sales, including \$19.6 billion in total payroll and more than 288,000 jobs in the region.

Flood Impacts and Sea-Level Rise

With San Francisco's recent participation in the Federal Emergency Management Agency's (FEMA) National Flood Insurance Program (NFIP), FEMA has been updating their Flood Insurance Rate Map (FIRM) for San Francisco to identify Special Flood Hazard Areas (SFHA) for a 100-year flood. The published draft FIRM shows SFO to be vulnerable to today's base floods. With sea-level rise, the number and intensity of these flood events is likely to increase.

Using the ranges of sea-level rise presented in the June 2012 National Research Council report on Sea-Level Rise for the Coasts of California, Oregon, and Washington, the Coastal and Ocean Working Group of the California Climate Action Team estimates that there will be 5 to 24 inches of sea-level rise by 2050 and 17 to 66 inches by 2100. The San Francisco Bay

Conservation and Development Commission (BCDC) estimates 10 to 17 inches of sea-level rise by 2050 and a high end scenario of 43 to 69 inches of sea-level rise by 2100. SFO's plans anticipate these changes.

II. Current Issues and Solutions

Sea-Level Rise Adaptation: Existing Seawalls

SFO has built approximately 30,000 feet of shoreline protection measures, consisting of earth berms, concrete seawalls, and vinyl sheet piles constructed between 1983 and 2006. These structures were built for erosion control and protection against tidal flooding. Existing gaps of various lengths between seawall sections would allow inundation of the airfield and the terminal areas during extreme flood events such as a 100-year flood.

Sea-Level Rise Adaptation: Adaptation Feasibility Study

In January 2013, the airport commissioned a two-year shoreline protection feasibility study specifically to address the threats of base floods and sea-level rise. This study, conducted by Moffatt & Nichol + AGS Joint Venture, is analyzing the airport's vulnerability to flooding from sea-level rise and extreme weather events, determining deficiencies in the airport's existing seawall systems, and developing shoreline protection improvement alternatives with cost estimates, and it will make recommendations to the airport on projects and/or a program to be incorporated into the airport's capital planning. The recommendations will help guide the airport on the best approach for extreme weather events accompanied by sea-level rise.

Sf Adapt

The City and County of San Francisco (CCSF) initiated its resilience program, SF Adapt, in September 2013. A Sea-Level Rise Committee was formed to draft the Guidance for Incorporating Sea-Level Rise into CCSF's Capital Planning. The Guidance provides methods and

tools for selecting sea-level rise scenarios. It identifies and describes key steps for assessing and adapting to the effects of sea-level rise in capital planning.

III. Planning for the Future and Funding

Collaborative Efforts with San Mateo County

SFO and San Mateo County jointly applied and were awarded a Climate Change Grant of \$200,000 from the State Coastal Conservancy to assess sea-level rise vulnerabilities at San Bruno Creek and Colma Creek. The Grant will provide funding to form a working group with stakeholders from SFO, San Mateo County, South San Francisco, San Bruno, Caltrans, and BART to work collaboratively and come up with adaptation strategies for the two creeks. This study will serve as a pilot study for other areas in San Mateo County.

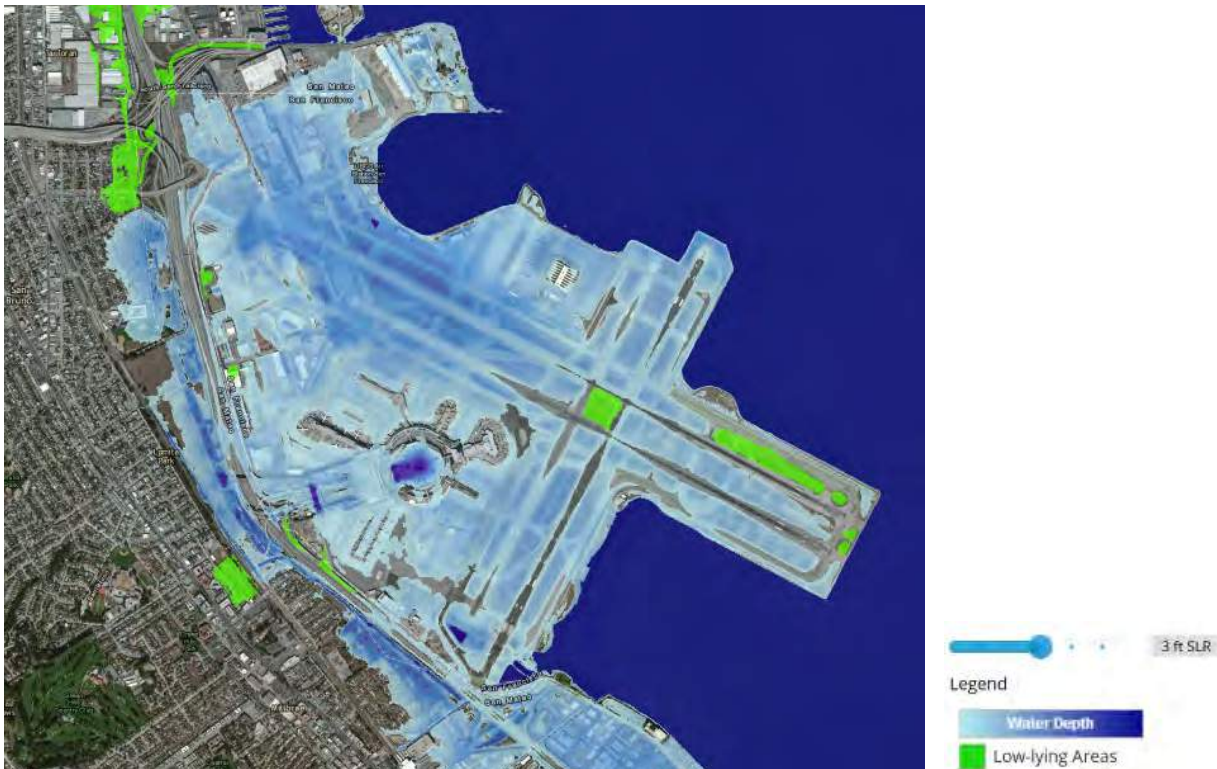
Engaging The Us Army Corps Of Engineers

SFO has requested the US Army Corps of Engineers (Corps) to start a Reconnaissance study which is the first phase of a General Investigation (GI) program to assess sea-level rise vulnerabilities at SFO. The GI program will require congressional authority to study the problem and a second authority to fund and construct the required physical facilities included in the program. Alternatively, the Corps' District office can utilize their Continuing Authorization Program (CAP), authorized by Section 205 of the 1948 Flood Control Act, to achieve protection against flooding from sea-level rise.

For more information:

San Francisco International Airport: www.flysfo.com

Rosalyn Yu: Rosalyn.Yu@flysfo.com



Sea-Level Rise Impact at SFO

Source: NOAA, <http://csc.noaa.gov/fig/viewer/>

SOUTH BAY AND PENINSULA

SAN FRANCISCO'S URBAN WATERSHED

I. History and Problem

Wastewater Infrastructure and Flooding

During heavy rains and storm events, aging wastewater infrastructure can become overwhelmed and contribute to flooding. Currently, over 80% of San Francisco's pipes are over 100 years old.

II. Current Issues and Solutions

The San Francisco Public Utilities Commission (SFPUC) is addressing wastewater infrastructure and flooding issues as a part of its Sewer System Improvement Program (SSIP) and the Urban Watershed Assessment. As part of SSIP, the SFPUC is planning wastewater infrastructure improvements on both the Bayside and the Westside of San Francisco in each of the eight distinct urban watersheds within the City and County of San Francisco. The Urban Watershed Assessment is a watershed-based planning process that the SFPUC is using to plan the City's collection system improvement projects over the next 20 years. These investments will include both traditional "grey" infrastructure such as pipes and tunnels, and "green" infrastructure such as rain gardens, creek daylighting and green streets to address such challenges as localized flooding, aging infrastructure, seismic safety and reliability, and water quality in the bay and ocean.

Vulnerabilities Addressed

To ensure that the SSIP's investments would address the major vulnerabilities of San Francisco's aging wastewater infrastructure, the SFPUC has committed to the following:

Provide a Compliant, Reliable, Resilient, and Flexible System that can respond to Catastrophic Events: The SSIP will ensure treatment of flows within 72 hours of a major earthquake.

Integrate Green and Grey Infrastructure to Manage Stormwater and Minimize Flooding: The use of green stormwater projects together with upgrades to sewer pipelines will minimize flooding impacts on neighborhoods and the sewer system.

Provide Benefits to Impacted Communities: Projects will provide both economic and job benefits to the communities they serve.

- **Modify the System to Adapt to Climate Change:** New facilities will be built using design criteria that will accommodate rising sea levels and other impacts.
- **Achieve Economic and Environmental Sustainability:** The SFPUC will beneficially reuse and conserve the by-products of wastewater and stormwater treatment systems.
- **Maintain Ratepayer Affordability:** Through the multi-phased SSIP implementation approach, the SFPUC will keep customer bills less than 2.5% of an average household income for a single-family residence.

III. Planning for the Future and Funding

The Urban Watershed Assessment

The Urban Watershed Assessment is part of the SFPUC's Sewer System Improvement Program (SSIP), San Francisco's 20-year program to plan, identify, and build investment priorities for the city's sewer system. The Urban Watershed Assessment will shape the next generation of collection system

projects to improve seismic reliability, manage stormwater, reduce odors, protect water quality, and reduce flooding. It is based on the premise that addressing challenges now will be more cost effective than deferring them to when the system fails and poses a critical threat to the city. The project team is conducting a rigorous analysis of each watershed's unique topography, hydrology, and built conditions to identify and recommend the best mix of grey and green projects, programs and policies to optimize the performance and cost-effectiveness of SSIP projects.

Sewer System Improvement Program Phase I Projects

In addition to creating a long term plan for investment, the Commission designated \$57 million for eight green infrastructure demonstration projects. Each project will be monitored to learn about the technology's effectiveness in local conditions. Information gathered through these eight demonstration projects will be used to program an additional \$400 million in funding for green infrastructure for future phases of the SSIP. The majority of the green infrastructure concepts were identified through a series of participatory planning workshops held by the SFPUC in 2007 and 2009 as part of the Urban Watershed Assessment.

Current improvement projects in the planning phase include the following:

- The **Mission & Valencia Green Gateway** project: Flow-through planters and permeable paving that will enhance bicycle and pedestrian safety.
- The **Chinatown Green Alley** project: A redesign of two alleys to provide green open space and improve infiltration in a dense urban neighborhood.
- The **Wiggle Neighborhood Green Corridor** project: Integration of permeable paving and bioretention into a famous San Francisco bike route.
- The **Sunset Boulevard Greenway** project: Rain gardens.
- The **Holloway Green Street** project: Bioretention, street trees and permeable paving.
- The **Yosemite Creek Daylighting** project: Opening a historical creek and integrating it into the surrounding neighborhood.
- The **Visitacion Valley Green Nodes** project: Bioretention and green streets.
- The **Baker Beach Green Street** project: Better management of stormwater in the Richmond and Sea Cliff neighborhoods with the goal of improving water quality at Baker Beach.

Planning is also underway for the Central Bayside System Improvement Project, a major tunnel project to provide sewer system reliability and redundancy and future regulatory compliance.

The estimated cost of the SFPUC's Sewer System Improvement Program (SSIP) is \$6.9 billion. The Urban Watershed Assessment is anticipated to be complete in December 2015.

For more information:

Sewer System Improvement Program, San Francisco Public Utilities Commission

<http://www.sfwater.org/index.aspx?page=116>

ssip@sfwater.org (415) 554-3289

RECOMMENDATIONS



While atmospheric conditions in California differ from the East and Gulf Coasts, New York's experience with Hurricane Sandy and the impact of Hurricane Katrina on New Orleans point to the importance of preparing for potentially catastrophic events. The good news is that comparatively small investments can provide large returns by preparing the region for these events and protecting its economy from crippling damage. Furthermore, many of these same investments can also improve the health of the Bay ecosystem. This study offers several recommendations at the local, regional, state and federal levels.

LOCAL LEVEL RECOMMENDATIONS

Support the work of local flood protection agencies to plan and implement flood risk management projects on creeks and rivers and on the Bay's shoreline.

- Develop and support local measures and benefit assessment districts that create stable funding streams for local flood risk solutions. Consider a rate-payer model for flood protection, similar to water supply and sewer, both of which benefit from steadier funding.

Emphasize the role of cities and counties in conducting vulnerability analyses, approving development, and supporting hazard mitigation strategies that take extreme storm events and sea level rise into account.

- Incorporate methods for increasing community resilience to extreme storms into General Plans.

BAY AREA REGIONAL RECOMMENDATIONS

Regularly evaluate regional flood risk and communicate findings, including the cost of doing nothing and the cost of improving readiness, to Bay Area residents, business leaders, and elected officials.

- Develop regional flood risk reduction goals and acceptable levels of residual risk.
- Consider regional economic resilience to extreme storms on flood protection plans.

Support the identification of regional interdependencies and vulnerabilities that elevate particular flood risks beyond the local level to a level of regional significance; develop regional strategies for flood protection.

- Focus on the interdependence of transportation corridors, including transit, regional rail, and air traffic.
- Focus on the resilience/continuity of critical regional services, including power, water supply, wastewater treatment, and telecommunications.
- Evaluate and address the continuity of emergency services (flood response, fire, EMT, provisioning) during and after severe events.
- Evaluate populations and communities particularly at risk (such as the elderly, infirm, and non-English-speaking) in a major regional event.
- Evaluate and address particular land uses at risk, including landfills and hazardous waste sites.
- Assess overlaps and conflicts in needs and resources with Delta and Central Valley communities that could be concurrently affected.

Develop regional funding strategies for flood protection, including measures that provide for flood protection through wetlands restoration.

- Include regional strategies being developed to address anticipated sea-level rise, such as the Bay Conservation and Development Commission's Adapting to Rising Tides (ART) project.
- Support funding for the San Francisco Bay Restoration Authority to restore wetlands and provide associated flood protection.

APPENDIX



7

FOOTNOTES

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- 25–27. Ibid.
28. Richard Halstead, "San Anselmo Residents Raise Concerns about Memorial Park Flood Plan," Marin Independent Journal, July 10, 2013. http://www.marinij.com/ci_23636339/san-anselmo-residents-raise-concerns-about-memorial-park

IMAGE SOURCES

Cover: Photo by Michael Macor/San Francisco Chronicle/Polaris

Inside Cover: McIDAS, Dec 11, 2014

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MAPS (following pages)

Map Source: Bay Area Flood Protection Agencies



Flood Protection Agency Facilities Bay Area

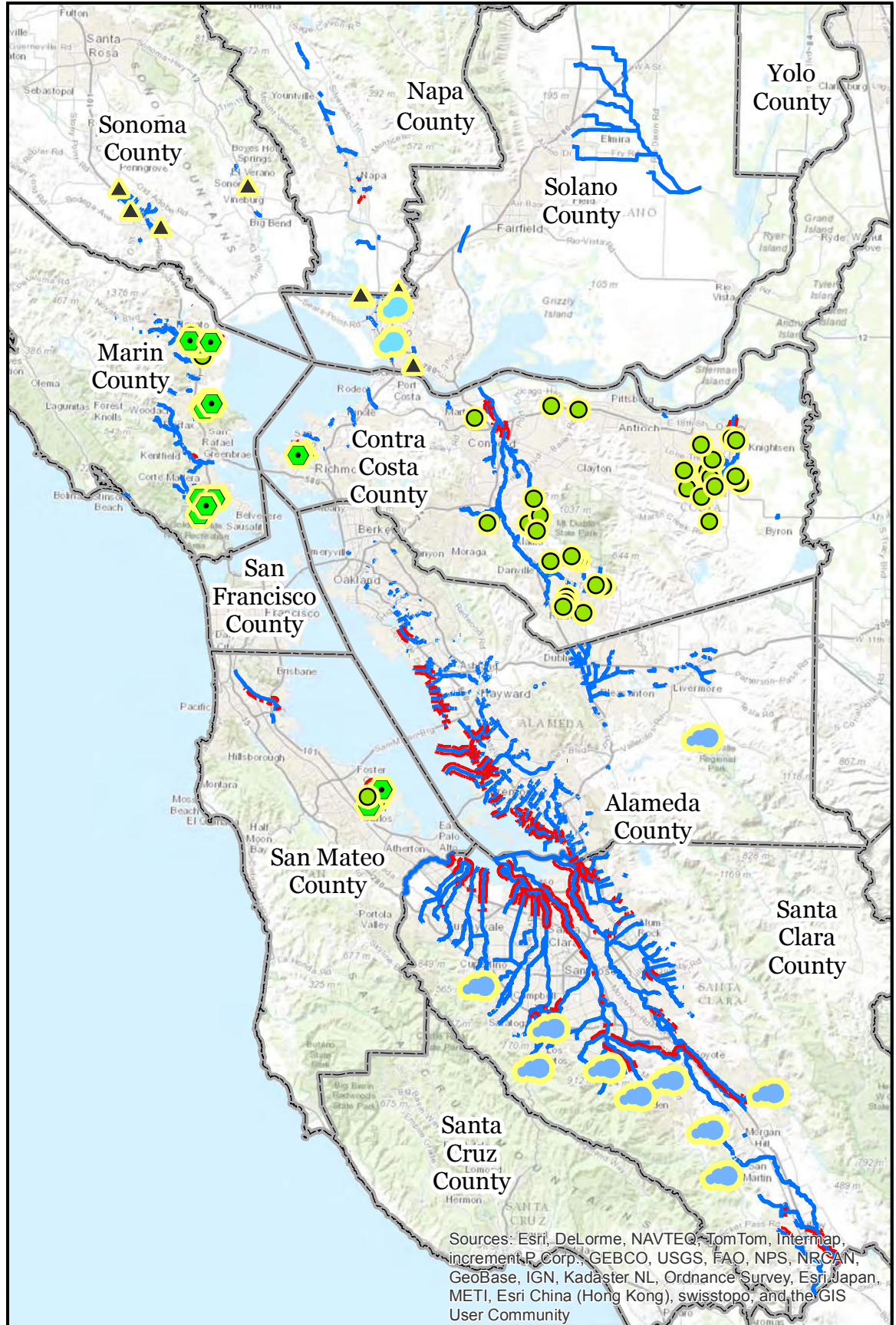


Location Map

Data Source: Bay Area Flood Protection Agencies Association members. All data should be considered draft.

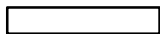
- Channels
- Levees*
- Reservoir
- Detention Basin
- Sediment Basin
- Lake
- Pump Station

* Levees may be offset from actual position for clarity.



1:800,000

10



Miles

Sources: Esri, DeLorme, NAVTEQ, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, and the GIS User Community

Flood Protection Agency Facilities Marin, Sonoma



Location Map

Data Source: Bay Area Flood Protection Agencies Association members. All data should be considered draft.

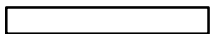
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- Reservoir
- Detention Basin
- Sediment Basin
- Lake
- Pump Station

* Levees may be offset from actual position for clarity.

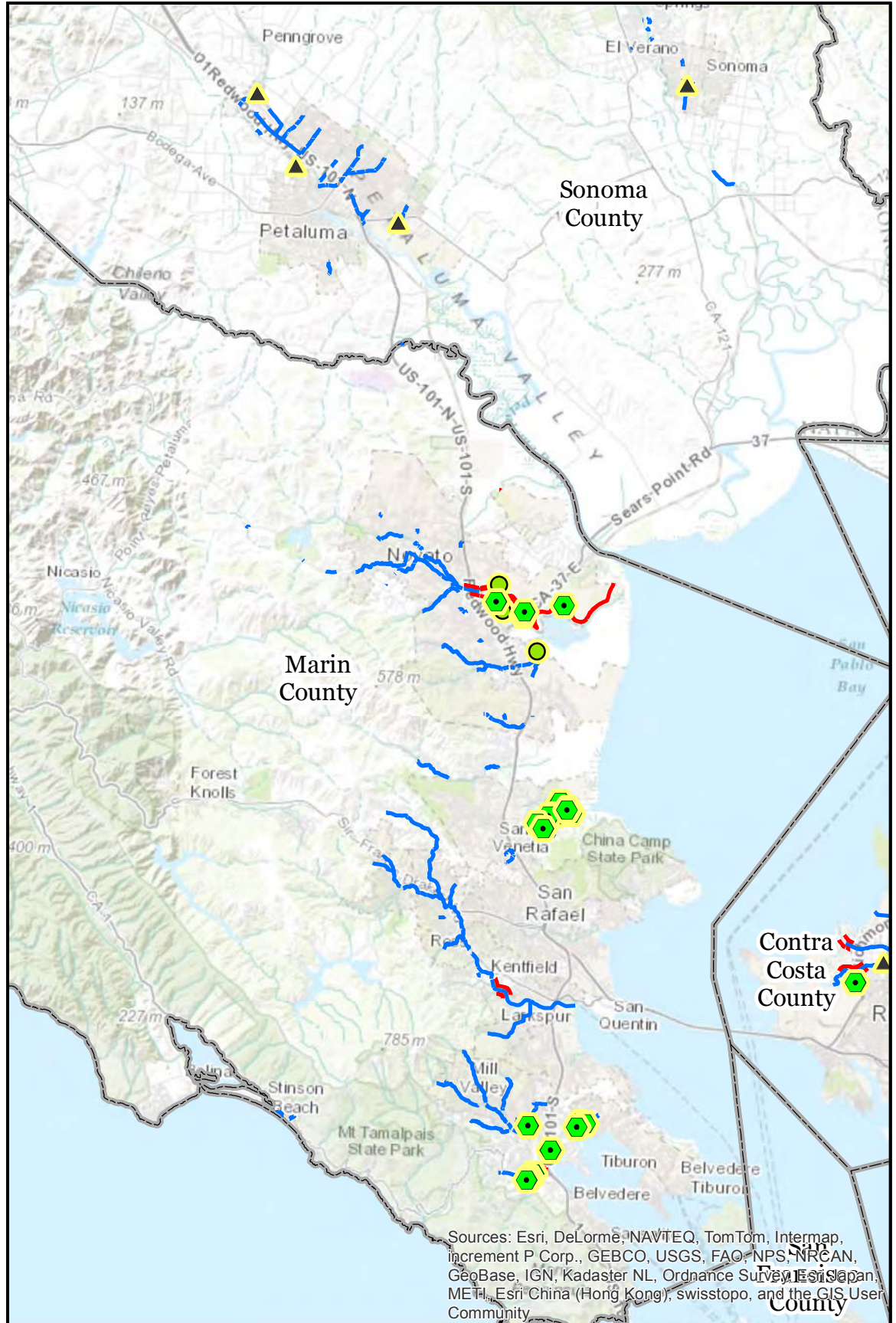


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4



Miles



Sources: Esri, DeLorme, NAVTEQ, TomTom, Intermap, Increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, and the GIS User Community

Flood Protection Agency Facilities

Napa, Vallejo

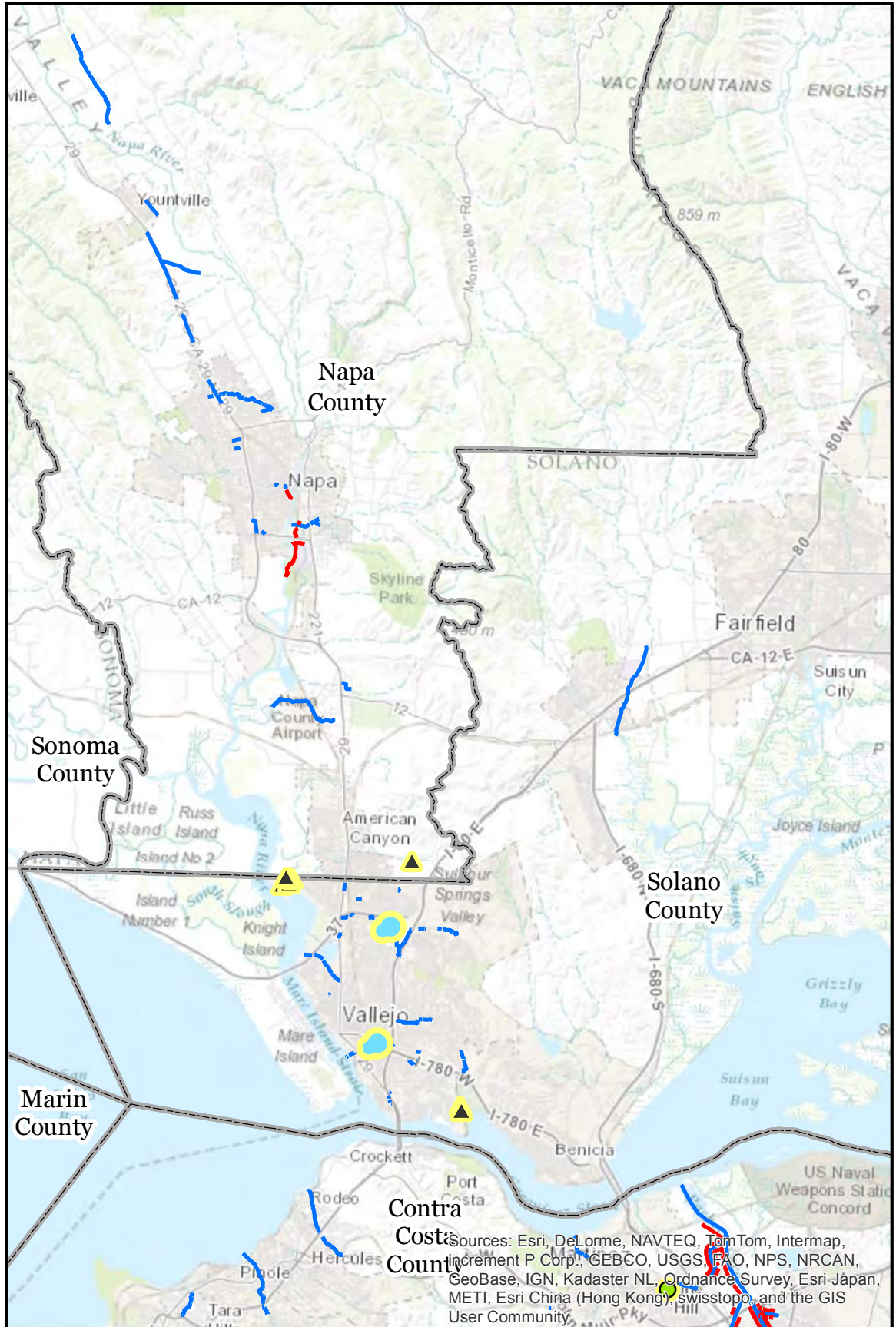


Location Map

Data Source: Bay Area Flood Protection Agencies Association members. All data should be considered draft.

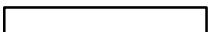
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- Reservoir
- Detention Basin
- Sediment Basin
- Lake
- Pump Station

* Levees may be offset from actual position for clarity.



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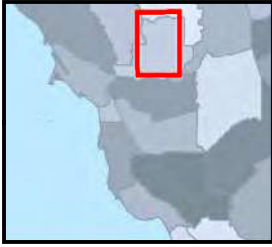
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Miles

Sources: Esri, DeLorme, NAVTEQ, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), Swisstopo, and the GIS User Community.

Flood Protection Agency Facilities Solano

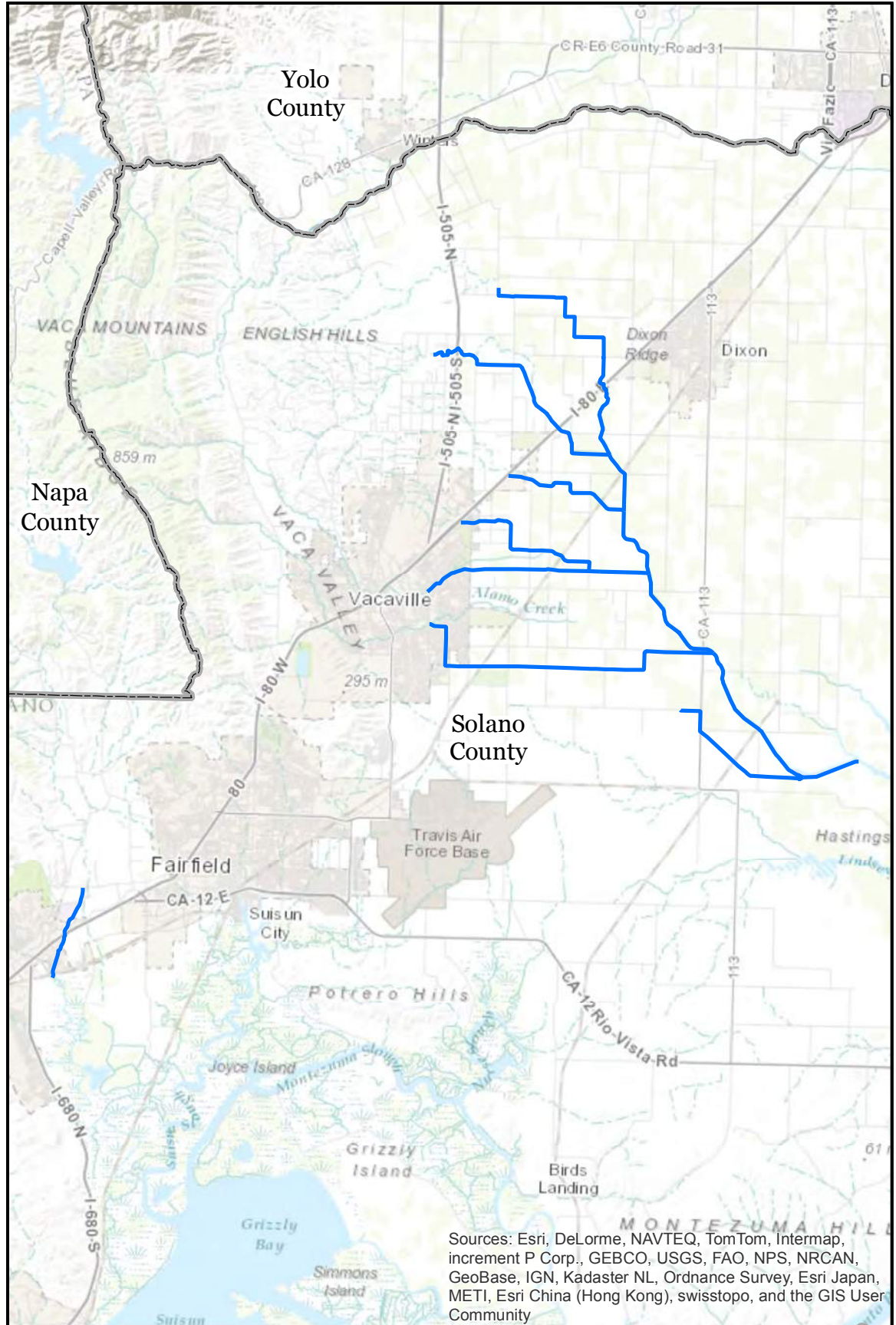


Location Map

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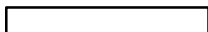
- Channels
- Levees*
- Reservoir
- Detention Basin
- Sediment Basin
- Lake
- Pump Station

* Levees may be offset from actual position for clarity.



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4



Miles

Flood Protection Agency Facilities Contra Costa - East, Zone 7

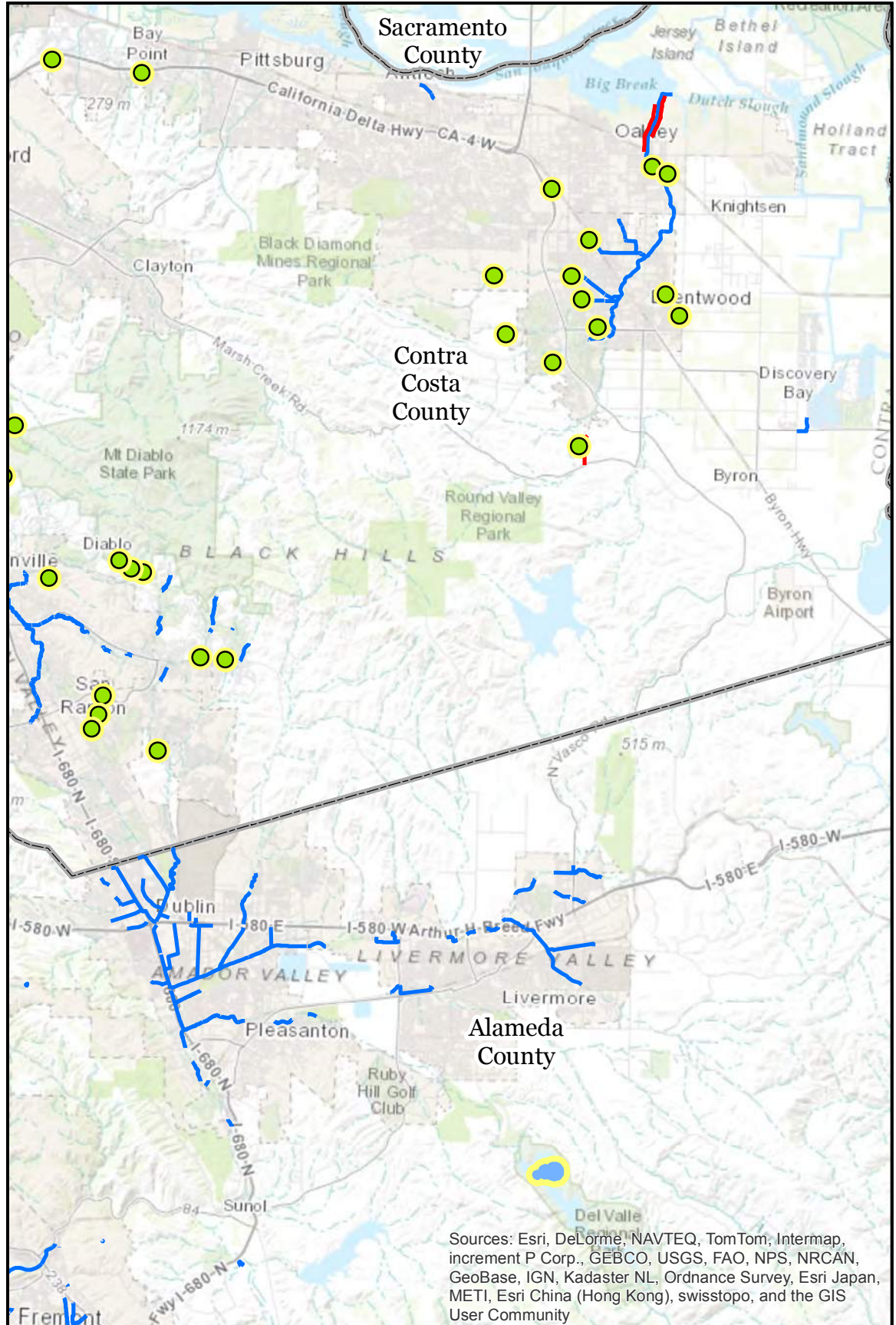


Location Map

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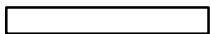
- Channels
- Levees*
- Reservoir
- Detention Basin
- Sediment Basin
- Lake
- Pump Station

* Levees may be offset from actual position for clarity.



1:240,000

4



Miles

Sources: Esri, DeLorme, NAVTEQ, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, and the GIS User Community

Flood Protection Agency Facilities Contra Costa - Central

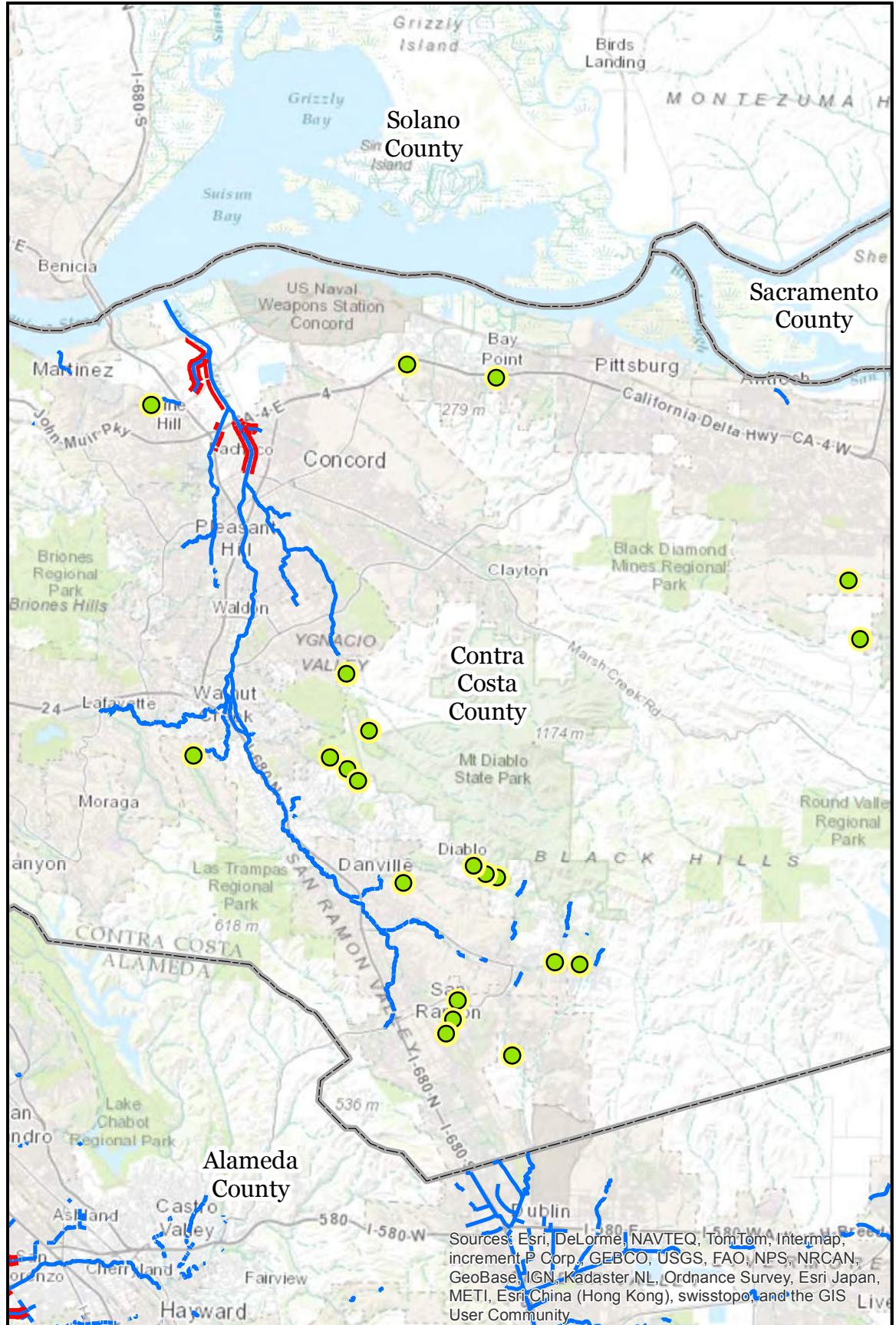


Location Map

Data Source: Bay Area Flood Protection Agencies Association members. All data should be considered draft.

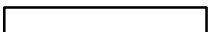
- Channels
- Levees*
- Reservoir
- Detention Basin
- Sediment Basin
- Lake
- Pump Station

* Levees may be offset from actual position for clarity.



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4



Miles

Flood Protection Agency Facilities Contra Costa - West, Alameda



Location Map

Data Source: Bay Area Flood Protection Agencies Association members. All data should be considered draft.

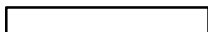
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- Reservoir
- Detention Basin
- Sediment Basin
- Lake
- Pump Station

* Levees may be offset from actual position for clarity.

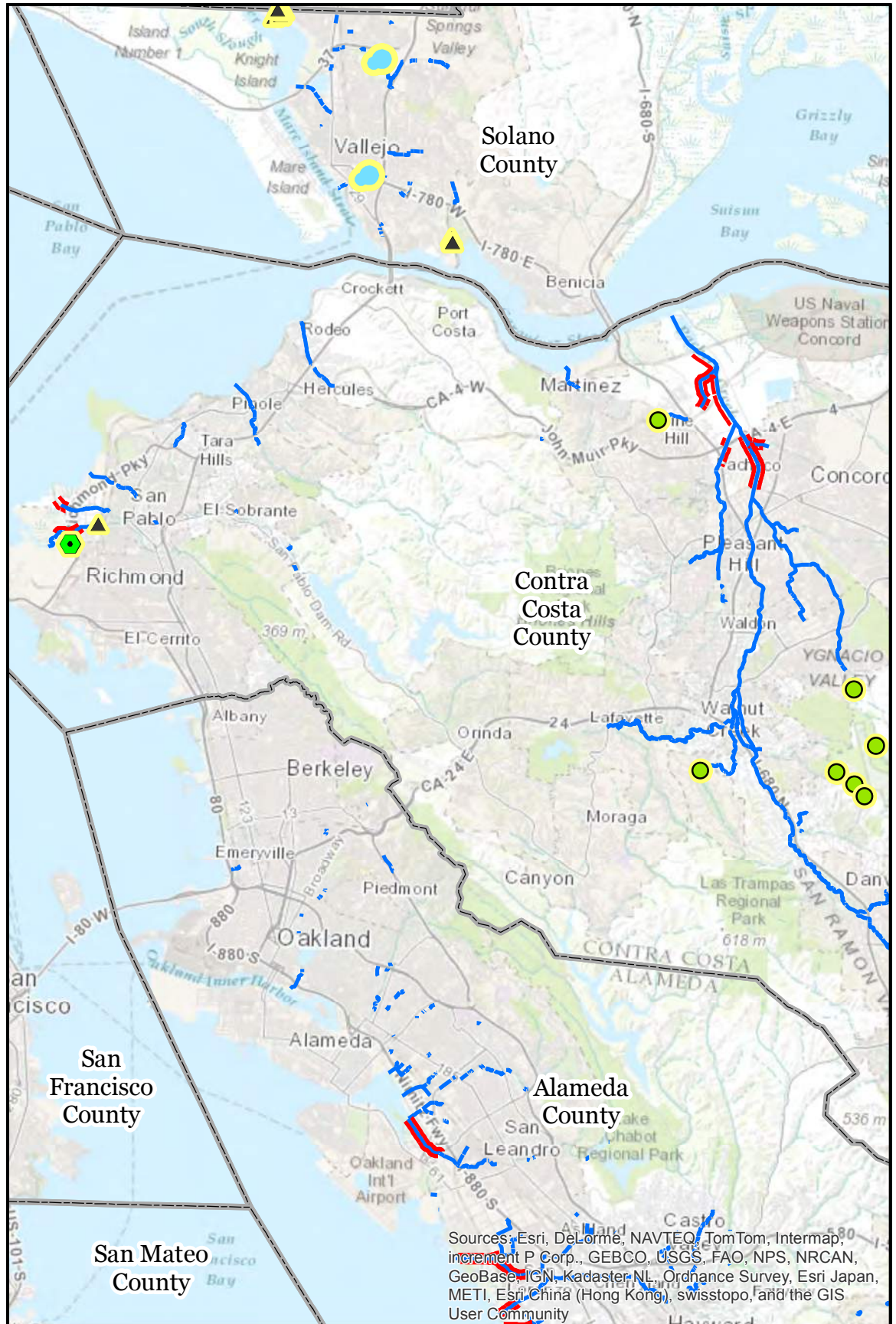


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4



Miles



Sources: Esri, DeLorme, NAVTEQ, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, and the GIS User Community

Flood Protection Agency Facilities Alameda

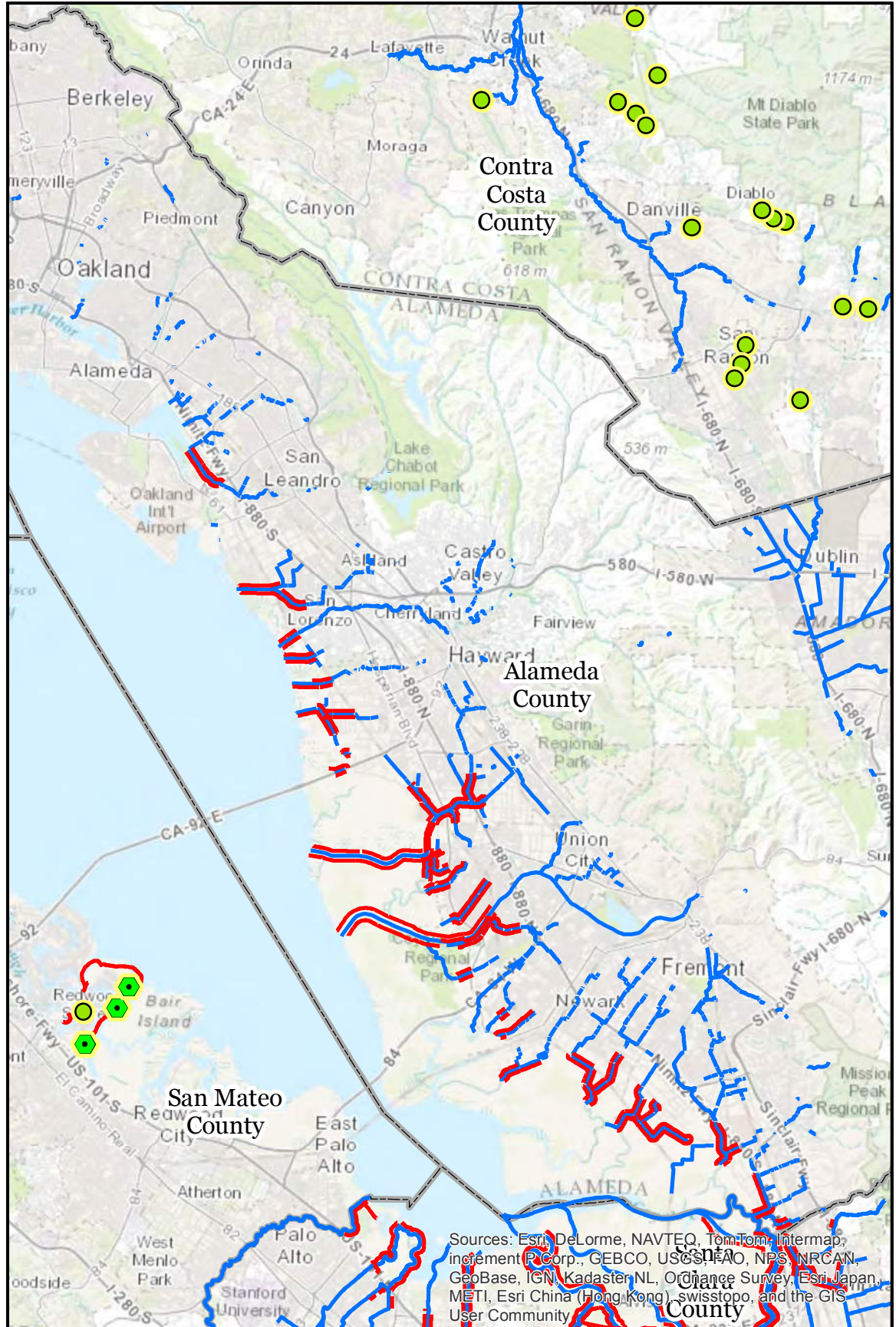


Location Map

Data Source: Bay Area Flood Protection Agencies Association members. All data should be considered draft.

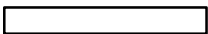
- Channels
- Levees*
- Reservoir
- Detention Basin
- Sediment Basin
- Lake
- Pump Station

* Levees may be offset from actual position for clarity.



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4



Miles

Flood Protection Agency Facilities Santa Clara - Central

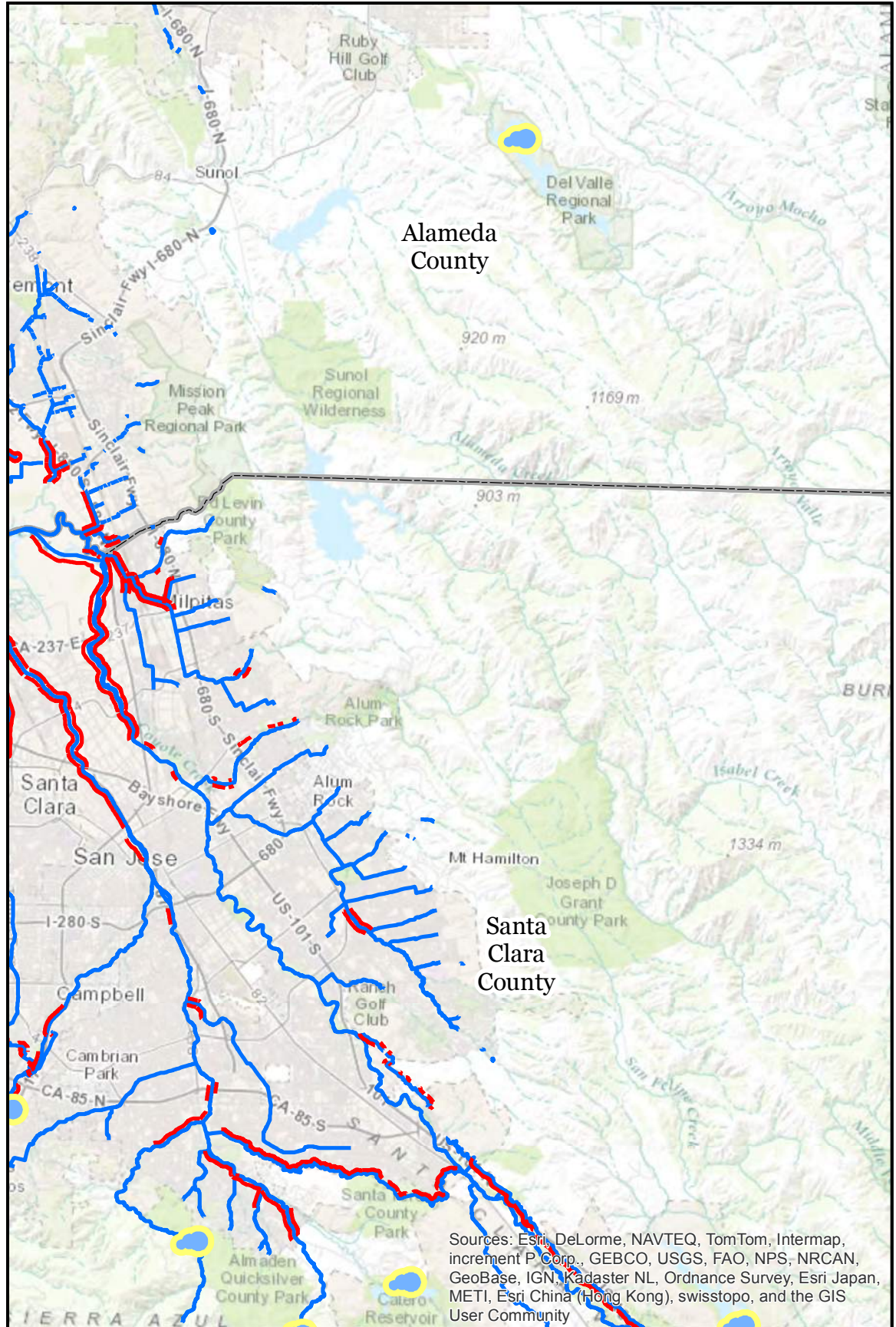
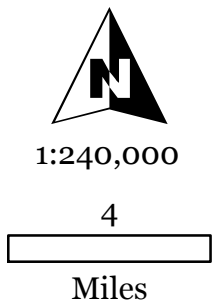


Location Map

Data Source: Bay Area Flood Protection Agencies Association members. All data should be considered draft.

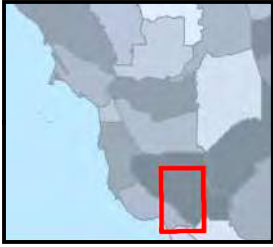
- Channels
- Levees*
- Reservoir
- Detention Basin
- Sediment Basin
- Lake
- Pump Station

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Sources: Esri, DeLorme, NAVTEQ, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, and the GIS User Community

Flood Protection Agency Facilities Santa Clara - South

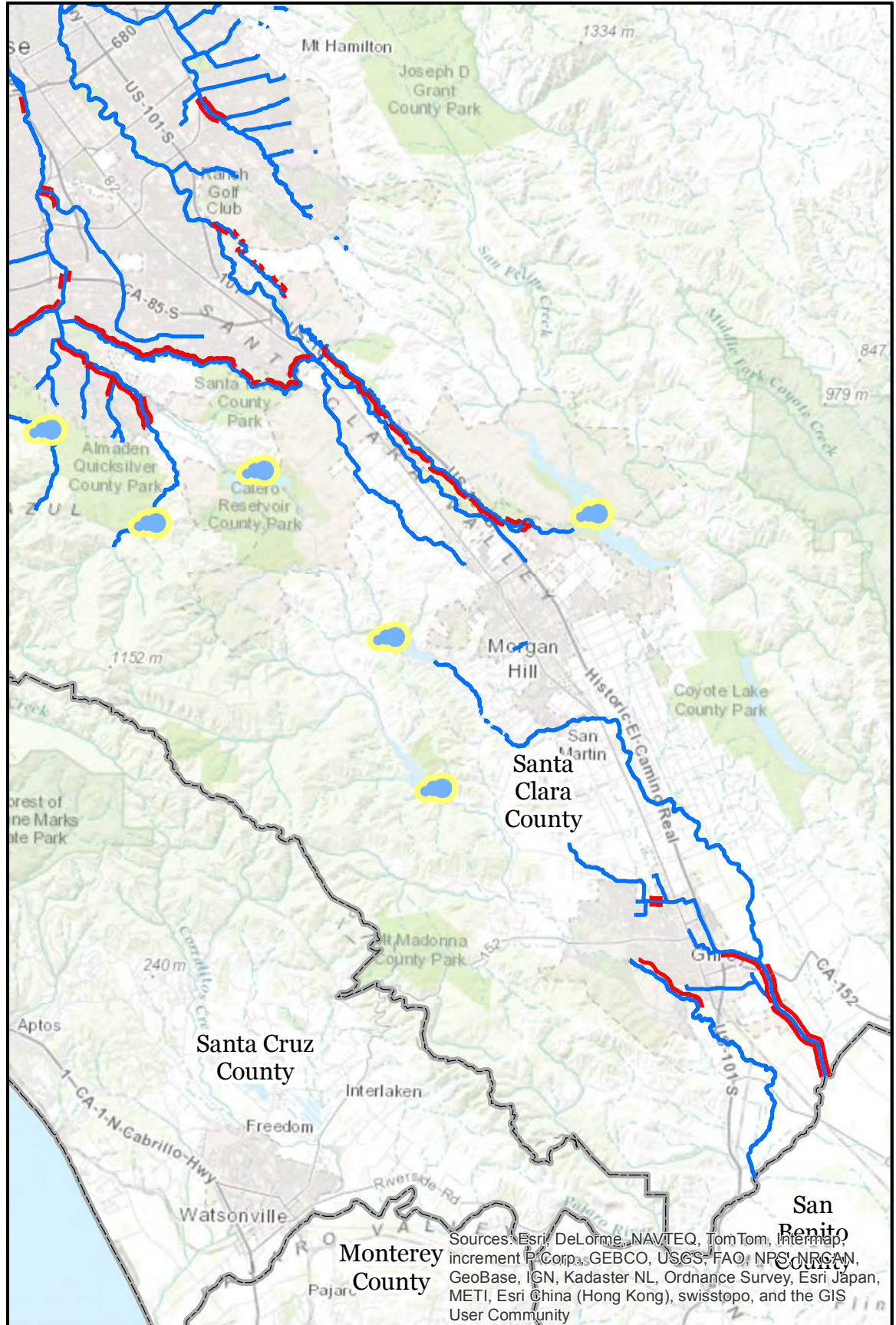


Location Map

Data Source: Bay Area Flood Protection Agencies Association members. All data should be considered draft.

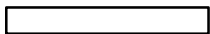
- Channels
- Levees*
- Reservoir
- Detention Basin
- Sediment Basin
- Lake
- Pump Station

* Levees may be offset from actual position for clarity.



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4



Miles

Flood Protection Agency Facilities Santa Clara - South West

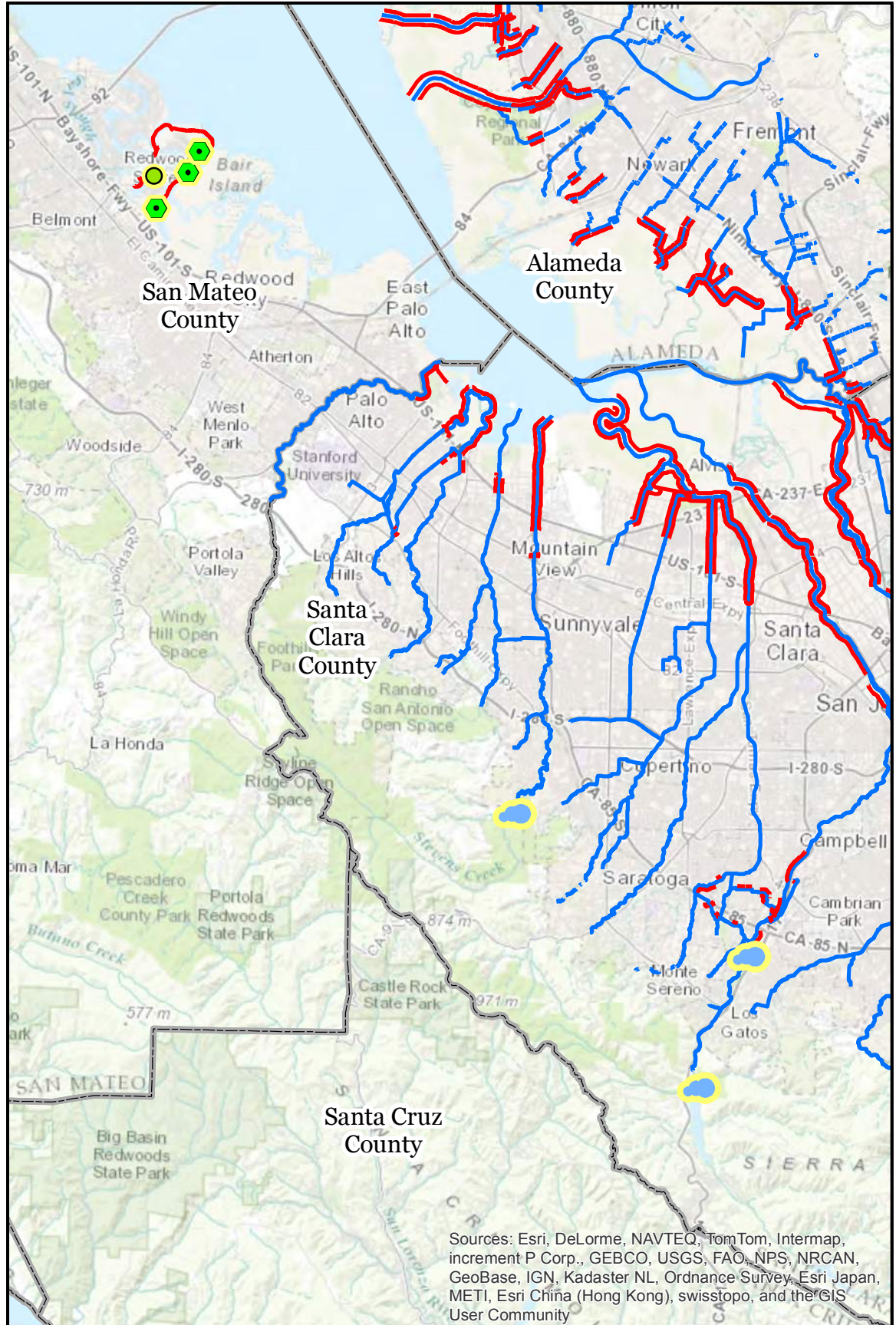


Location Map

Data Source: Bay Area Flood Protection Agencies Association members. All data should be considered draft.

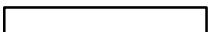
- Channels
- Levees*
- Reservoir
- Detention Basin
- Sediment Basin
- Lake
- Pump Station

* Levees may be offset from actual position for clarity.



1:240,000

4



Miles

Sources: Esri, DeLorme, NAVTEQ, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, and the GIS User Community

Flood Protection Agency Facilities San Mateo - San Francisco



Location Map

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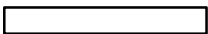
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- Detention Basin
- Sediment Basin
- Lake
- Pump Station

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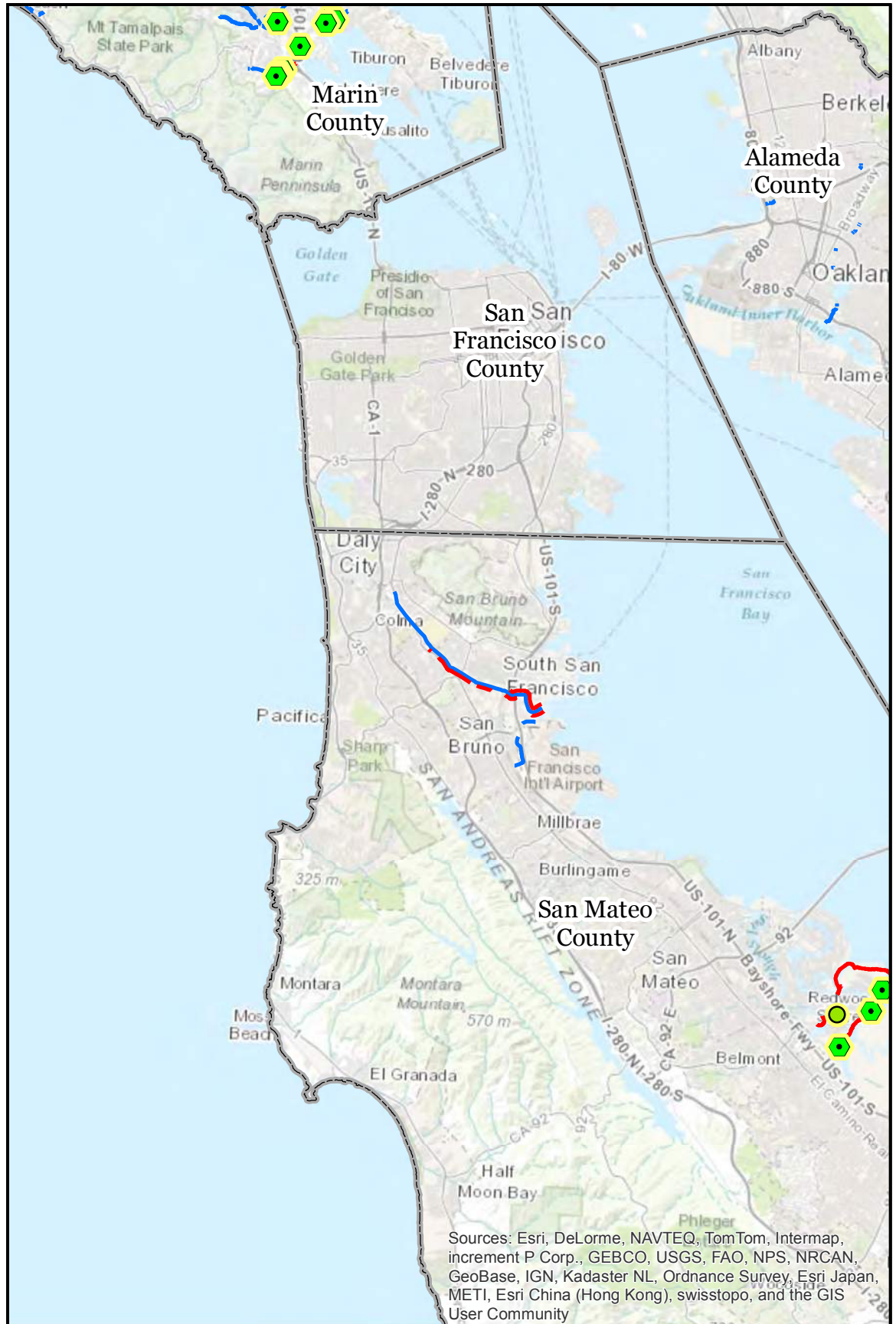


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4



Miles



Sources: Esri, DeLorme, NAVTEQ, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, and the GIS User Community



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