MISSION CREEK

SEA LEVEL RISE ADAPTATION STUDY

WATERFRONT STRATEGIES FOR LONG TERM URBAN RESILIENCY | SEPTEMBER 2016

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PREPARED FOR:

SPUR

Port of San Francisco

San Francisco Bay Conservation and Development Commission

Delta Alliance

San Francisco Public Utilities Commission

San Francisco Public Works

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SAN FRANCISCO ALREADY EXPERIENCES ANNUAL DISRUPTIONS FROM EXTREME TIDE AND RAIN EVENTS, AND INUNDATION MAPS CLEARLY SHOW THERE IS POTENTIAL FOR FUTURE FLOODING.

San Francisco is a city that is vulnerable to the impacts of sea level rise. One of the lowest lying parts of the city is the area surrounding Mission Creek on the eastern waterfront. To imagine what its future might look like with sea level rise, and to consider options to make the waterfront more resilient, multiple City and County of San Francisco (City) agencies teamed up with experts from the Netherlands, SPUR, the San Francisco Bay Conservation and Development Commission, and other stakeholders in an iterative design process. Using Mission Creek and the Mission Bay shoreline as a test case, the team sought to consider ways the shoreline could be modified to provide resilience for a rapidly growing mixed-use neighborhood. The team also sought to develop a model for interagency collaboration and knowledge-sharing the City can use in future work to address sea level rise along its entire shoreline.

The landscape of the Mission Bay and Mission Creek area has long been a stage for the story of our relationship to water in the Bay. Where neighborhood redevelopment is occurring now, there were once wetlands and tidal basins 100 years ago. Over the decades, developable lands were created by infill that resulted in a low lying district that needs a long term sea level rise strategy.

We used the latest guidance on sea level rise from the City and the San Francisco Public Utilities Commission to understand the Mission Creek area's vulnerabilities to future flooding. These maps show the impact of potential flooding using most-likely sea level rise scenarios of 11-inches for 2050 and 36-inches for 2100 in combination with 100-year storm water levels on the bay. In both scenarios there is quite significant inundation in Mission Bay and the South of Market Area (SOMA), ranging from 0 to 3 feet for 2050 and 0 to 5 feet for 2100. However, in the 2050 scenario inundation can be mitigated by raising some low spots along the shoreline to cut off pathways of inundation. In the 2100 scenario, the entire shoreline needs to be raised to keep the city dry. We evaluated the vulnerability of critical transportation and water infrastructure to flooding, and the potential citywide impacts of their disruption.

We used the following principles to guide the development of different concepts for both the Mission Creek Channel shoreline and the Mission Bay shoreline:

1. Focus on the development of a range of concepts without selecting one preferred alternative.

2. Nothing is off the table – despite concepts that may seem radical, difficult to implement, or hard to permit; this is a creative exercise.

3. Strive for multipurpose solutions that integrate flood protection into the urban fabric for an attractive and economically viable city.

Mission Bay (left) and its Mission Creek channel (right) are major features of the San Francisco landscape.

4. Seek opportunities for natural ecosystem and habitat development.

5. All design concepts should be able to cope with at least 36 inches of sea level rise.

6. Consider future adaptability as a criteria.

One of the key questions for San Francisco in adaptation planning is where to put the line of defense – or in other words what is allowed to flood and what is not. Will the new shoreline protection be along the shore, and will new infrastructure be built further out, or could some portions of the city be given back to the bay? Considering these questions, we developed seven different adaptation concepts - three for the creek, four for the bay shoreline - that explore various alignments for protecting the shoreline, including:

- Creek Concept 1 – Perimeter Shoreline Protection: Raise the perimeter of the Mission Creek shoreline to address vulnerable low spots. Adaptation measures would include a mix of levees and seawalls.
- Creek Concept 2 – Tidal Control: Construct a tidal barrier at the mouth of the creek that can be closed during high tides and storm surge.
- Creek Concept 3 – Mission Lake: Close Mission Creek off from San Francisco Bay at the mouth of the creek with a levee or dam.
- Bay Concept 1 – Perimeter Shoreline Protection: Build a levee and/or sea wall along the existing shoreline that will protect Mission Bay.
- Bay Concept 2 – City Levee: Create a wide multipurpose levee along the existing shoreline that provides opportunities for open space integrated with commercial and residential development.
- Bay Concept 3 – Elevated Third Street: Use Third Street as the main line of protection by connecting buildings, roads and elevated land to create a line of protection. Residential and commercial property on the bayward side would have to be modified to cope with temporary inundation.
- Bay Concept 4 – New Waterfront: Create a continuous landmass in the Bay outboard of the piers, parallel to the existing shoreline, to be used for new commercial and residential development, recreation and habitat development. The existing shoreline would not be modified.

Separate adaptation concepts were developed for San Francisco's iconic and historic piers in the area; only one of the adaptation concepts provide a way to preserve them from the impacts. The concepts include:

- Retrofit to flood proof the piers physically and functionally
- Raise and rebuild them out of the flood zone
- Use the piers for as long as practically possible and safe, but accept that ultimately they will need to be removed.

This study is a first step in trying to imagine what a future with sea level rise could look like for San Francisco. Developing technical engineering solutions will likely to be the easiest part; arranging funding, regulatory compliance, and community and political support will be much more challenging.

The slow pace of sea level rise does not communicate a sense of impending threat; however, that danger could materialize in this community. It is urgent that work on solutions begins now because major developments in the inundation zone are currently being planned or built. It can take years or decades to conceptualize, design, earn public support, fund, permit and construct major capital shoreline projects. We don't have 5-10 years before this process can begin. The catastrophic events of Katrina and Sandy show that disasters with unimaginable impacts can happen tomorrow.

In order to maintain the enthusiasm around this project, it is recommended that work begin towards a Citywide Adaptation Plan, consistent with the recently published San Francisco Sea Level Rise Adaptation Plan. This plan would encompass the entire bay shoreline, but also develop near-term adaptation plans for high-risk shoreline assets and geographic areas. Such a plan should encourage and integrate innovative, interdisciplinary design thinking and solutions for adaptation. The choice is clear, Bay Area citizens and leaders cannot afford not to take action. Building resilience in San Francisco is not just about the flood hazard or about the direct economic damages; it is about maintaining San Francisco's competitive edge as a global financial center, and preserving one of the world's finest places to live.

CHAPTER 1

INTRODUCTION

Coastal cities around the world are grappling with the question of how to cope with the challenges posed by climate change and sea level rise.

Coastal cities around the world are grappling with the question of how to cope with the challenges posed by climate change and in particular sea level rise. With a growing world population and continued migration of people from rural areas to cities, it is estimated that over half of the world's population will live in coastal cities by the year 2050 (UN, 2014). Coastal cities are attractive as they offer a more moderate climate, diverse natural ecosystems, access to water for commerce (ports) and recreation and an entryway to the hinterland through rivers that connect with oceans. Because many coastal cities are low lying and prone to land subsidence, they are vulnerable to coastal flooding and will only become more vulnerable in the face of rising seas and more frequent storms. Recent examples of this in the US are New Orleans with Hurricanes Katrina and Rita in 2005 and the New York-New Jersey coastline during Superstorm Sandy. Many other global cities facing similar challenges include London, Miami, Amsterdam, Rotterdam, Ho Chi Minh City, Shanghai, Singapore and, of course, San Francisco.

San Francisco's location on the coast - one of its finest attributes- makes it vulnerable already to annual flooding events like king tides, heavy rain, or large storms sometimes known as atmospheric rivers. The City by the Bay now faces rising sea levels, which will increase the frequency and intensity with which our transit service may be disrupted, sewer and stormwater systems backed up, neighborhood businesses closed, public safety imperiled and travel interrupted.

San Francisco is no stranger to risk or disasters. Evidence of the devastating 1906 earthquake and fire remains in photographs, and looms large in our cultural memory; the more recent 1989 Loma Prieta earthquake is still vivid for many. Robust hazard mitigation plans and the City's efforts to build earthquake resilience remind us of the importance of learning from the past when building our future. Updated building codes, a new eastern span of the Bay Bridge, the new Doyle Drive, and redundant power transmission to the City are just a few ways that San Francisco has become more resilient to earthquakes. We can do

Mission Creek includes parkland along its south shore (on the left), some existing abandoned piers, and SOMA housing (on the right).

5.5FT

SOME SCENARIOS INDICATE EVERYDAY SEA LEVEL MAY RISE UP MORE THAN FIVE FEET BY THE YEAR 2100. SUCH A FUTURE IMPLIES MUCH MORE FREQUENT INUNDATION, ESPECIALLY IN LOW LYING AREAS OF THE CITY.

the same for the challenge that lies ahead of us with climate change and sea level rise.

As a city, we must begin to understand the likelihood and impacts of high water, and consider whether those impacts are acceptable. The best available science today indicates that sea level will likely rise by 3 feet by 2100, though it may rise by as much as 5.5 feet (NRC, 2012). Such a future implies much more frequent and severe inundation and losses, especially in low lying areas of the city. If consequences from this flooding are not acceptable, then we must develop plans to reduce the frequency or the impacts of flooding.

WHY ADAPT?

While it is impossible to ever fully eliminate risks from flooding, there are many tools available to help us manage and adapt to those risks. With careful analysis, planning, and public engagement, we can develop adaptation strategies for San Francisco that not only keep us dry, but make our city a more attractive place to visit and live. The challenge in making San Francisco truly resilient, however, will be in getting out ahead of the disaster and planning for adaptation to reduce the risks associated with climate change, and not simply waiting for the waters to rise.

There will not be a one-size fits all solution for San Francisco's waterfront as it begins to manage sea level rise. Fully 4 miles of San Francisco's waterfront consists of an engineered seawall – built in segments over one hundred years ago – and adjacent fill areas that are low-lying, coupled with development and major City infrastructure within a few hundred feet of the water's edge. Flood protection in this area will be a different undertaking than in many other areas of the City.

This is a pilot study to imagine a future of San Francisco with higher waters, and to provide a vision for the City in adaptation so that San Francisco can remain the vibrant 'City by the Bay' it has always been. As San Francisco is situated within an entire region that is susceptible to sea level rise, this study and the solutions we explore may be broadly applicable to other parts of the Bay Area.

THE MISSION CREEK PROJECT AREA

The area surrounding Mission Creek on the east side of the city was selected as a pilot study location as it is one of the city's lowest-lying areas and is vulnerable to present day flooding from the Bay and the creek, urban stormwater runoff, and future sea level rise.

This part of the city is a growing residential, institutional and commercial redevelopment area, rich in public spaces, historic resources, and transit infrastructure, among other regionally-significant assets such as AT&T ballpark. Piloting adaptation planning here could thus serve as a model for advancing adaptation in the future, around the city and around the Bay Area. Ideas developed for Mission Creek and the Mission Bay neighborhood could be replicated in terms of both the design response to flooding, but also the processes of adapting to multiple land uses and working with stakeholders.

Mission Creek was once a tidal creek flowing through the Mission District out into then-Mission Bay. Today the Creek is a short navigation channel in what was Mission Bay, which no longer exists as an open water body as it was filled in the earlier part of the 20th century for industrial development. Today Mission Bay is changing again with one of the largest redevelopment project in the city; it is rapidly transforming from a former rail yard and port-related industries into a vibrant neighborhood with a new University of California, San Francisco (UCSF) Medical Center, the city's new Public Safety Building, over 6000 new housing units and millions of square feet of commercial office space, two light-rail lines and the Caltrain terminus, parks and open spaces and commercial retail areas, as well as the proposed home of the Golden State Warriors Event Center and mixed-use redevelopment.

A shoreline park, a large parking lot and large finger pier facility anchor the south shore of Mission Creek. A subsidiary of the San Francisco Giants is planning a mixed-use development project for the parking lot (Seawall Lot 337) and pier facility (Pier 48), which would extend the urban and open space character of the Mission Bay project to the northeast corner of the Project area. A San Francisco Public Utilities Commission (SFPUC) sewer and storm water pumping plant called Channel Pump Station anchors the west end of the creek. The Mission Bay streetscape plan included raising grades of streets to accommodate for future settlement and allow stormwater overflow to flow into Mission Creek and the Bay.

The Port of San Francisco (Port) owns and manages much of the waterfront property on the east side of San Francisco. It is responsible for the seven and one-half miles of San Francisco waterfront adjacent to San Francisco Bay, which the Port develops, markets, leases, administers, manages, and maintains. Its jurisdiction stretches along the waterfront from Hyde Street Pier on the north to India Basin on the south, including Mission Creek and the Mission Bay shoreline.

The Mission Creek south shore presents the most recent redevelopment opportunities - highlighting the importance of protection solutions.

NETHERLANDS-CALIFORNIA COLLABORATION

Many coastal cities have begun to address the challenges of sea level rise, and there is a great interest in learning from each other. This project is part of such an international collaboration to do the same.

In 2008 the Dutch national government initiated the Knowledge for Climate Research Program[1]. This program is aimed at conducting research and development of adaptation strategies to make the Netherlands climate proof for the future. One of the program objectives is to engage with other coastal areas around the world to share the outcomes of the research program, learn how these other regions are adapting to climate change and build a network of organizations that are involved in adaptation planning. Stichting Delta Alliance was created as a non-profit to administer and manage the international projects.

In California, the Netherlands' collaboration with BCDC began in 2009 with the joint production of 'San Francisco Bay: Preparing for the Next Level'[2].One of the major outcomes of this project was a simple and effective Strategy Development Method (SDM) for adaptation planning. This method used an analysis of ecological and economic growth opportunities by shoreline type to develop a preferred sea level rise adaptation approach.

CITY AND REGIONAL SEA LEVEL RISE GUIDANCE AND ADAPTATION INITIATIVES

In addition to the above mentioned experience, this pilot study leverages other work by the city and BCDC.

In 2014, the City adopted 'Guidance for Incorporating Sea level Rise into Capital Planning in San Francisco: Assessing Vulnerability, Risk, and Adaptation'[3]. The Guidance was prepared by the City and County's Sea Level Rise Committee and adopted by the San Francisco Capital Planning Committee. The guidance presents a framework and a process for considering and preparing for sea level rise from a site and project-specific perspective. The guidance provides direction to all city departments on best available science on sea level rise and how to incorporate sea level rise into new construction, capital improvement, and

The 3rd Street bridge and promenade outside the ballpark present unique challenges in maintaining asset value while protecting them.

maintenance projects. More information about the guidance and its use in this project is in Chapter 3.

BCDC leads the Adapting to Rising Tides (ART) Program in partnership with the National Oceanic and Atmospheric Administration and the Metropolitan Transportation Commission. The ART Program is a collaborative planning effort to help San Francisco Bay Area communities adapt to sea level rise and storm event flooding. The ART Program has engaged local, regional, state and federal agencies and organizations, as well as non-profit and private associations in building capacity to address the challenges of sea level rise. While their original pilot project focused on Alameda County, many other cities and counties are adopting all or parts of the ART process for sea level rise adaptation planning, including the City of Benicia and Marin and Contra Costa Counties. Through collaboration with BCDC, this project is also incorporating lessons learned from the ART process and contributing to what ultimately will be a regional Bay Area sea level rise adaptation strategy.

PROJECT GOALS AND PROCESS

This project has two main goals: 1) provide conceptual design solutions to reduce flood risks to a neighborhood based on a high-level vulnerability assessment, and 2) build capacity in San Francisco to understand and manage these risks in the long term. Our approach includes mapping the hazard and consequences of flooding from storms and sea level rise, developing adaptation alternatives to reduce risk in the Mission Creek area, continuing the exchange of knowledge and information between the San Francisco and regional entities, and furthering the exchange of expertise between the Netherlands and California.

CONTENTS OF THE REPORT

The chapters that follow present the outcome of the process to develop adaptation alternatives to reduce current and future flood risk for the Mission Creek area. The first section explains the broader context and history of Mission Creek and Mission Bay. Next, we explain the climate science and data to inform the two sea level rise scenarios that we used to generate inundation maps. In the vulnerability assessment, we use inundation maps to identify public and private assets that are exposed to flooding today and in the future, and we provide a detailed description of the impact of flooding to both the project area and to specific assets. Lessons learned from sea level rise adaptation around the world are shared to inform the adaptation strategies recommended for the project area. In the last section, we consider a variety of tools to reduce current and future flood risk including sea level rise. We explore a number of adaptation alternatives in further detail for the Mission Creek and Bay shorelines and for the Port's finger piers.

PROJECT GOALS

G1 Provide conceptual design solutions to reduce flood risks to a neighborhood, based on a high-level vulnerability assessment

G2 Build capacity in San Francisco to understand and manage these risks in the long term

PROJECT APPROACH

A1 Mapping the hazard and consequences of flooding

A2 Developing adaptation alternatives to reduce risk in the Mission Creek area

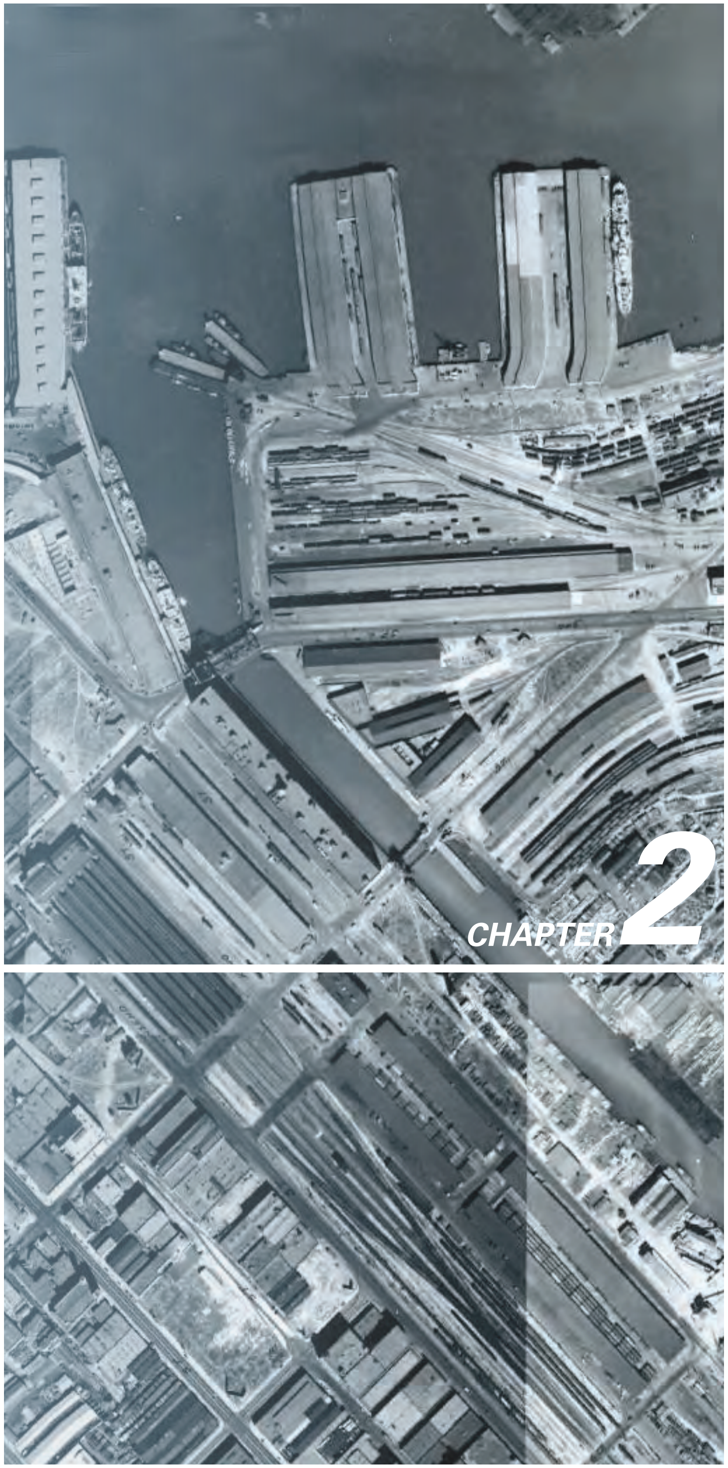
A3 Continuing the exchange of knowledge and information between the Netherlands and California

1 http://www.climateresearchnetherlands.nl/

2 http://www.bcdc.ca.gov/planning/climate_change/deltaAlliance.shtml

3 http://www.acfloodcontrol.org/SFBayCHARG/pdf/sf_slr_guidance.pdf

4 http://www.adaptingtorisingtides.org/



CHAPTER 2

THE EVOLUTION OF MISSION CREEK

What started as salt marsh and shallow bay transitioned to a dredged channel with an active port and industrial uses that fueled a growing city. The rich history of Mission Creek cannot be forgotten in planning for sea level rise adaption.

The Mission Creek watershed extends from San Francisco's Mission neighborhood to Mission Bay in Southeastern San Francisco. It has experienced a dramatic physical and economic transformation in the last two hundred years. Industrial and economic development have changed the once shallow and wild embayment into a bustling and vibrant part of San Francisco that we must now again adapt to a future influenced by coastal and tidal processes.

What started as salt marsh and shallow bay transitioned to a dredged channel with an active port and industrial engine that fueled a growing city. Fill placed in Mission Bay enabled the neighborhood to transition to a residential and commercial neighborhood starting in the late 1990s — making room for housing, office space, neighborhood-serving retail, sports and entertainment (AT&T Park), and a medical research campus (UCSF), to create a growing mixed-use neighborhood. While the historical landscape may be much altered, it is still subject to hydrological and geological phenomena, including rainwater ponding, subsiding lands, and exposure to high tides.

DEVELOPMENT OF MISSION CREEK AND ITS WATERSHED

Historically, Mission Creek meandered above ground from its headwaters around 19th street and Folsom, heading north and then east until it opened up into tidal marsh near today's Interstate 280; transitioning to tidal flats around 8th street, what we call Mission Bay, a small embayment of San Francisco Bay. It was said that in the late 1700s, it was possible to paddle a canoe from Mission Bay all the way to Mission Dolores, where the creek supported many bird species, as well as deer, elk, rabbit, fox, and bear. Historically, Mission Bay was characterized by calm large tidal marsh and tidal flats, which separated and buffered high ground in the city from San Francisco Bay. The marsh and flats were home to a variety of bird and other species, including ducks, geese, herons, egrets, osprey, and gulls, hawks, owls, and falcons, all likely attracted by a thriving population of smelt, along with mice, shrews, and rabbits. Prior to Spanish settlements and missions, the area was occupied by Sitlintac and Chutchui villages until the late 1850s'.

MISSION CREEK IN THE PRESENT

Today's Mission Creek and Mission Bay are considerably different from what European settlers encountered. Mission Creek was channelized and diverted to provide drainage, and marshes, flats, and the Bay were filled in to accommodate growth and development in San Francisco over the last 150 years. A railroad yard was built on the fill to support the region's growth. Mission Bay's transformation began around 1848 when development was fueled by the gold rush, and eventually shipbuilding, railroad, and cargo industries demanded the construction of wharves, bulkheads and pylons. Filling the mudflats and marshes made it easier for ships to reach the city, and construction of the railroad supported regional industry, well known sugar refineries and petroleum storage.

Lastly, construction of a now 4-mile long sea wall from the Aquatic Park to Pier 50 from 1878-1915 provided the much-needed infrastructure to support the demands of a growing city and port economy, drastically altering the shoreline of City of San Francisco. The new seawall and companion marginal wharf built out into the bay served as a bulkhead for new finger piers. The area in between the existing shoreline and the new seawall was filled and developed, including part of Mission Bay up to Pier 50. This 4 mile long sea wall provides the primary protection for 800 acres of city land and forms the hard edge supporting public access, below grade infrastructure, transportation facilities and maritime uses. Today, the bulkhead buildings and piers from Pier 45 in Fisherman's Wharf to Pier 48 in Mission Bay comprise the Embarcadero Historic District listed on the National Register of Historic Places. As the seawall was built before the advent of modern engineering to address seismic risks, there are concerns about the sea wall's overall performance in an earthquake. The Port is evaluating these risks.

What we now refer to as Mission Creek, the visible part that is the waterway, is a manmade channel in the unfilled portion of Mission Bay connected to San Francisco Bay. This channel was used to provide mooring space to load and unload ships and barges.

The area's importance in military logistics during World War II further bolstered industrial uses in the area. However, years of fill, land reclamation, and industry converted Mission Creek and

Figure 2–1: Until the late 19th century, Mission Bay was a geographic feature - a shallow wetland at the Mission Creek estuary.

FIG 2–2: THE LONG BRIDGE SEAWALL SERVED AS MULTI-FUNCTIONAL INFRASTRUCTURE

Top Photo: Mission Creek looking west from 3rd Street bridge, early 20th century, Photo: Bancroft Library (brk00012271_24a). Middle Photo: Two-master steams under 4th Street drawbridge, lumber yard still occupying south edge of Mission Creek, Photo: Bancroft Library (brk00012268_24a); Bottom Photo: Fourth Street draw bridge near Channel Street 1927, San Francisco History Center, San Francisco Public Library (aad-0683)

Bay from a once thriving embayment to a toxic landscape. After World War II, the region lost most of its cornerstone industries, such as shipping which moved to the East Bay. As a result, economic demand for the rail yards and warehouses in Mission Bay diminished, leaving an underutilized industrial neighborhood.

A houseboat community relocated from Islais Creek to Mission Creek around 1960[4], but otherwise the area remained underutilized in subsequent decades. In 2000, the San Francisco Giants constructed a ballpark at the former site of Pier 46 which opened in 2000 and is now known as AT&T Park. The city approved a redevelopment plan for Mission Bay in 1998. This plan, which is under construction and is nearly complete, includes 6,400 new residential units, 3.4 million square feet of commercial and medical office space, and 49 acres of new parks and publicly accessible open space, much of which adjoin the waterfront. The area is also the site of UCSF Medical Research Campus and UCSF Medical Center, and the potential future location of the

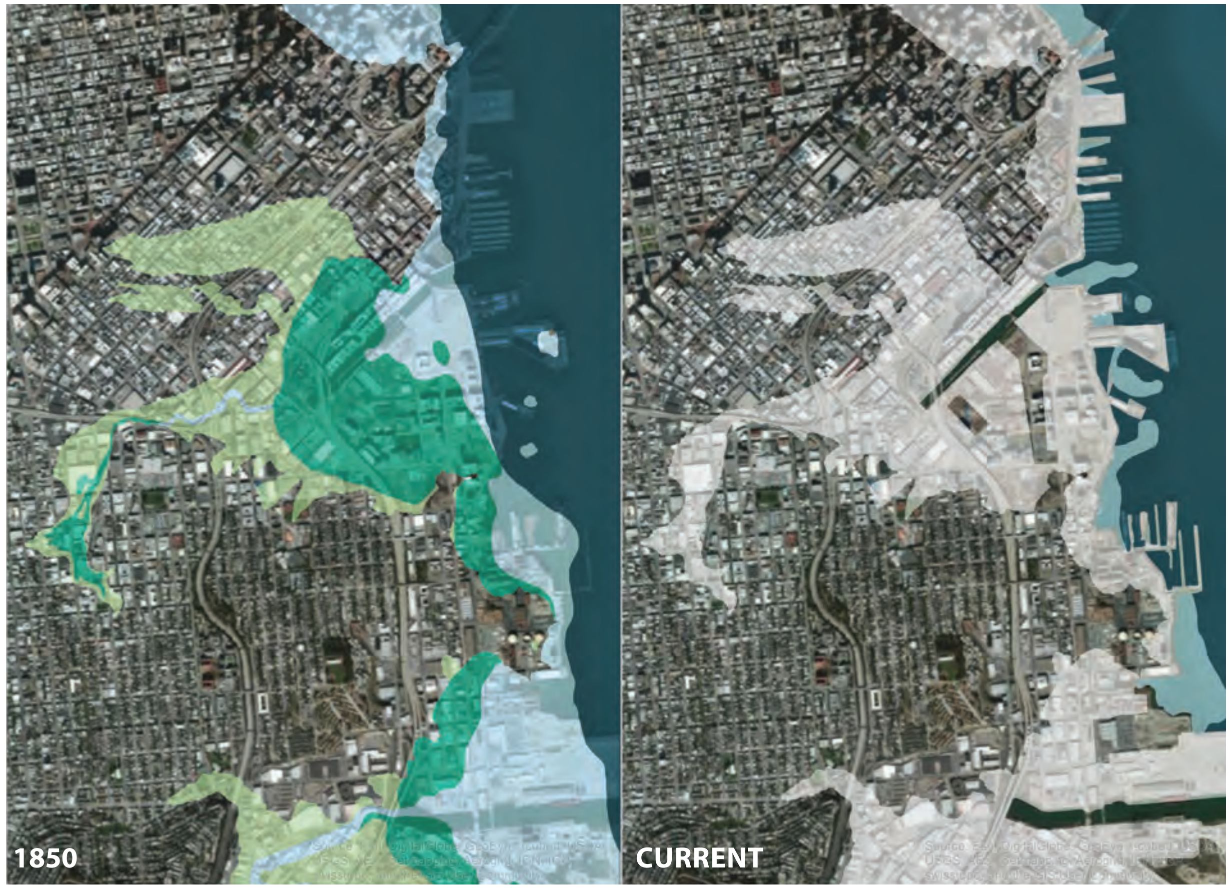
4 SFGate, 2014, and 7x7

Golden State Warriors professional basketball team and the new Mission Rock mixed use development proposed by the San Francisco Giants and the Port.

CHALLENGES IN WATER MANAGEMENT AND CONSIDERATIONS FOR ADAPTATION

The local area's geographic history as a bay and estuary complicate the hydrologic and water management challenges today. Though designated a navigable waterway in 1874, Mission Creek today can only be seen above ground in two places in San Francisco; one section of it runs above ground

FIG 2–3: HISTORICAL CREEK, TIDAL FLATS, AND BAY IN 1850 AS COMPARED TO CURRENT INFILL AND DEVELOPMENT



LEGEND

- Deep Bay / Channel
- Shallow Bay / Channel
- Tidal Flat
- Tidal Marsh
- Urban Development

through the National Guard Armory (not open to the public) on 14th and Mission Street, and the other is where it sometimes emerges at the Channel Pump Station at 7th Street. Typically, the inlet basin at Mission Creek does not have any freshwater flows from the Creek under dry conditions. Mission Creek usually empties into the sewer system, the central artery of which runs through this Channel Pump station. Backups during rain events flood higher up in the Missions Creek sewer/watershed through that sewer system, and, under such conditions, the basin can become a combined-sewer system outfall area.

Parts of San Francisco built on top of the creek bed experience regular flooding during rain storms. Development has altered the Mission Creek watershed hydrology, removing any natural ability to drain. Other stormwater outfalls cannot discharge into the creek during extreme high tide, which can cause or exacerbate a backup. Stormwater drainage, capture, and holding strategies must be considered in any sea level rise protection scheme.

Today, areas behind the seawall are prone to wave over-topping during king tides and stormwater ponding can occur during rains due to poor drainage. This occurs mostly because these low lying filled lands are relatively flat. The build-out of Mission Bay not only removed the wave height-attenuating buffering once provided by tidal flats, but moved the city's edge immediately adjacent to the deeper waters of San Francisco Bay, exposing it to more extreme tides and storms. The neighborhood, like all of San Francisco, is in a seismically active area making the ground prone to subsidence and liquefaction, although stringent building codes adopted prior to the development of Mission Bay parcels are protective of buildings and their occupants.

The Mission Bay development does not have a combined sewer system like most of the city, but instead has separated storm and sanitary systems. The grading and stormwater drainage system of Mission Bay is designed such that stormwater either drains directly into the Mission Creek Channel or the bay or is collected at a low point and pumped to the bay or creek. The streets of Mission Bay are designed to convey excess stormwater that may overwhelm the stormwater pumping system in a larger, lower probability storm.

All of these considerations are critical for sea level rise adaptation planning as measures intended to prevent flooding from the bay, such as levees or floodwalls that raise the height of the shoreline, may prevent the area from draining naturally and create more ponding of rain water.

SEA LEVEL RISE BACKGROUND UNDERSTANDING

Knowledge about sea level rise and its risks as well as actions that can be taken has grown in the region over the last ten years.

Reducing current and future flood risk in the San Francisco Bay region requires understanding both the potential for exposure of the area to inundation and how likely inundation is to occur.

The state of knowledge about sea level rise and what actions can address the risks associated with it has been growing substantially in the San Francisco Bay region over the last ten years. This section provides an overview of current local and regional guidance on sea level rise, a summary of how the San Francisco Bay-specific sea level rise maps were developed, and the project team's process in utilizing sea level rise projections to inform inundation mapping, vulnerability assessments, and conceptualizing adaptation measures to reduce flood risk in Mission Bay.

BACKGROUND AND CURRENT GUIDANCE

In 2013, the California Ocean Protection Council issued sea level rise guidance[1] for the state based on a 2012 National Research Council Report, *Sea Level Rise for the Coasts of California, Oregon, and Washington: Past, Present and Future.*

Because sea level rise adaptation measures require site and project specific information, and because San Francisco has so many vulnerable shoreline assets that will become more exposed over time, the City initiated an effort to adapt the OPC's guidance to support city capital planning, decision making, and sea level rise adaptation. In 2014, the City's Sea Level Rise Committee prepared a report, Guidance for Incorporating Sea Level Rise into Capital Planning in San Francisco: Assessing Vulnerability, Risk, and Adaptation (San Francisco Guidance)[2] for the San Francisco Capital Planning Committee. The document is intended to "guide the evaluation of projects considered for funding through the City and County of San Francisco capital planning process." While the Guidance states that the range of sea level rise projections from the OPC are appropriate, it offers additional considerations for sea level rise mapping and planning and recommends use of the ranges of sea level rise levels in Table 2.1 below.

TABLE 2–1: RECOMMENDED SEA LEVEL RISE ESTIMATES FOR SAN FRANCISCO RELATIVE TO THE YEAR 2000

Year	Projections	Upper End of Range
2030	6 in	12 in
2050	11 in	24 in
2100	36 in	66 in

Source: NRC (2012)

1 http://www.opc.ca.gov/2013/04/update-to-the-sea-level-rise-guidance-document

2 http://onesanfrancisco.org/staff-resources/sea-level-rise-guidance

The San Francisco Guidance also highlights the importance of incorporating storm surge, storm waves, and wave run up along the shoreline to more accurately project water levels and better understand vulnerability of assets to inundation. The range of the additional factors that should be considered in capital planning are shown in Table 3-2 below.

In addition, the Guidance recommends considering the adaptive capacity (i.e. the ability to adaptively manage protection measures) of an asset or shoreline area in selecting sea level rise scenarios.

SEA LEVEL RISE PROJECTIONS AND MAP DEVELOPMENT

Inundation maps of the Mission Creek area have recently been prepared by the San Francisco Public Utilities Commission (SFPUC)[4] in conjunction with the Sewer System Improvement Program (SSIP 2014). These maps represent state of the art sea level rise mapping in the city and provide the highest resolution and most comprehensive inundation mapping to date for the City and County of San Francisco shoreline.

TABLE 3–1: FACTORS THAT INFLUENCE LOCAL WATER LEVEL CONDITIONS IN ADDITION TO SEA LEVEL RISE[3]

Factors Affecting Water Level	Typical Range CCSF Bay Shoreline	Period of Influence	Frequency
Tides	5 to 7 ft	Hours	Twice daily
Storm Surge	0.5 to 3 ft	Days	Several times
Storm Waves	1 to 4 ft	Hours	Several times
El Niños (within the ENSO cycle)	0.5 to 3 ft	Months to Years	Every 2 to 7 years

3 Sources: a) Typical ranges for tides, storm surge, and storm waves for the CCSF Pacific Coast: BakerAECOM 2012. Intermediate Data Submittal #1. Scoping and Data Review. San Francisco County, California. California Coastal Analysis and Mapping Project / Open Pacific Coast Study. Submitted to FEMA Region IX. February 13, 2012. b) Typical ranges for tides, storm surge, and storm waves for the CCSF Bay shoreline: DHI. 2010. Regional Coastal Hazard Modeling Study for North and Central Bay. Prepared for FEMA. September 2010.

The maps utilize a 1-meter horizontal grid resolution digital elevation model (DEM) based on the 2010/2011 California Coastal Mapping Program LiDAR, and surface water elevations (SWELs) based on data from FEMA's San Francisco Bay Area Coastal Study[5] (FEMA 2013), which is based on a 31-year simulation of hydrodynamics and storm surge. In addition to static sea level rise levels, the inundation maps also consider high tide events (mean higher high water, MHHW) and a range of storm events, from 1-year to 100-year events.

Based on information in the city's Guidance, our project team selected two sea level rise scenarios from the range of options provided by the SFPUC maps. We utilized the OPC's and the Guidance's "most likely" scenarios of 11 inches of sea level rise for mid-century, and 36 inches of sea level rise for the end-of-century. Because the Guidance also suggests considering water level increases due to storm surge and wave run-up, the SWELs used for planning will also account for the 1% annual chance (or 100-year) storm surge SWELs, which equals roughly an additional 41 inches above static water levels. The result is that this project's two inundation mapping scenarios correspond to 52 inches for the mid-century scenario and 77 inches for the end-of-century scenario. The inundation mapping did not include additional water level elevation due to wind wave effects, which could raise water levels by an additional 3-4 feet.

While the surface water elevations of the flooded areas could be taken from prior studies, recent development in the Mission Creek area included street level grade improvements and raising of a park on the south side of the creek. Furthermore, the existing DEM does not include the piers at Mission Creek, specifically Piers 48, 50, and 54. As such, an assessment of inundation in the area required updating of the DEM using development drawings and pier elevations, and recalculation of the flooded depths based on these new elevations.

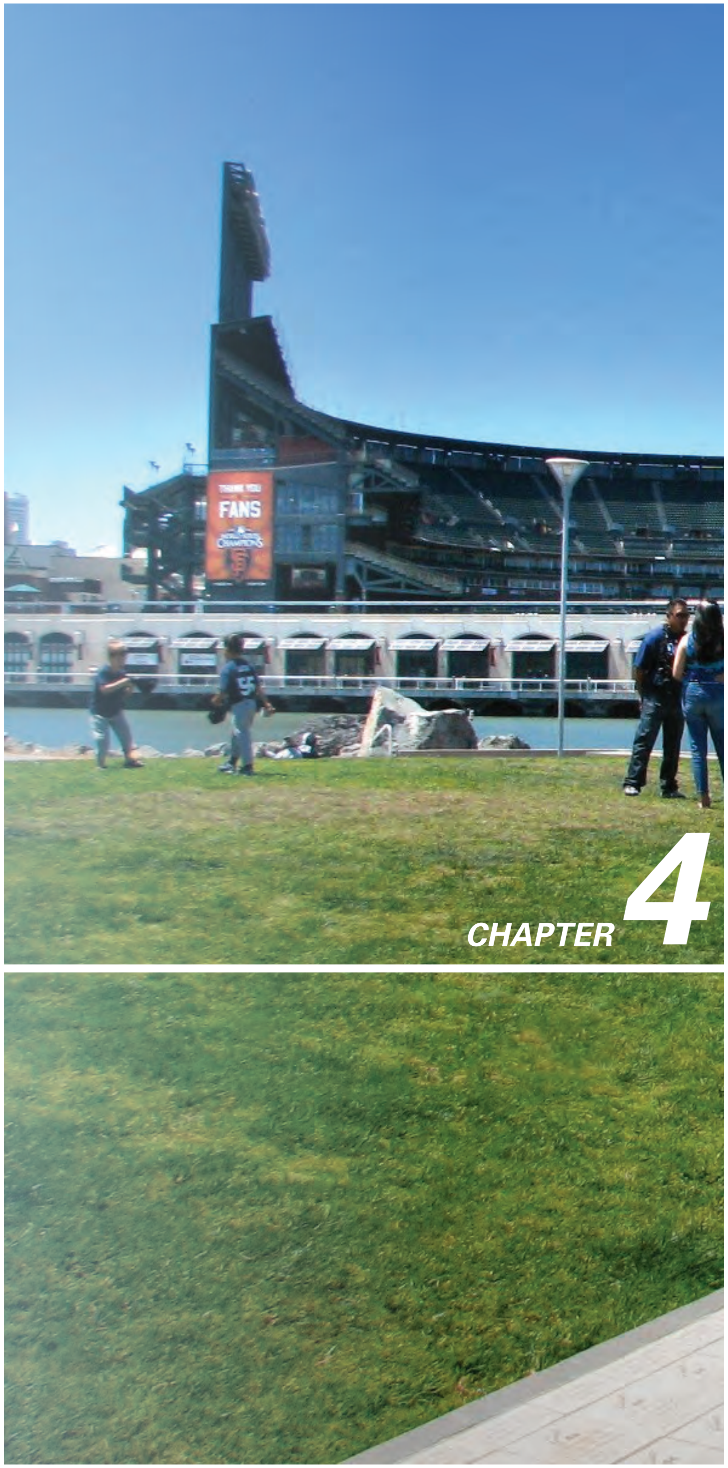
Since this study looks at future sea level rise, future grade levels were used to account for 50 year settlement in Mission Bay post-development (subsidence that was forecast at the outset of the Mission Bay Plan). More information about the development of the inundation maps used for this project may be found in Appendix 1.

TABLE 3–2: SEA LEVEL RISE INCREASES

Year	Water level above mean higher high water	Corresponding storm events resulting in the same water level
2050	52 inches	• 11 inches of SLR + 100 year storm, or • 24 inches of SLR + 10 year storm
2100	77 inches	• 36 inches of SLR + 100 year storm, or • 48 inches of SLR + 25 yr storm

4 SFPUC SSIP Program Management Consultant AECOM. 2014. Climate Stressors and Impact: Bayside Sea Level Rise Mapping.

5 Federal Emergency Management Agency (FEMA/AECOM). 2013. San Francisco Bay Area Coastal Study. FEMA Region 9, Oakland, CA. Available from: http://www.r9map.org/Pages/ProjectDetailsPage.aspx?choLoco=38&choProj=260



CHAPTER 4

VULNERABILITY + INUNDATION ASSESSMENT

The next step toward creating a resilient San Francisco Bay is to identify and evaluate the tools that are available to reduce floods and their impacts.

FUNDAMENTALS OF A SEA LEVEL RISE VULNERABILITY ASSESSMENT

This chapter examines the impact of sea level rise on the shoreline along Mission Creek and in Mission Bay. This high-level vulnerability assessment will inform identification of potential actions to adapt to future flooding and reduce flood risk.

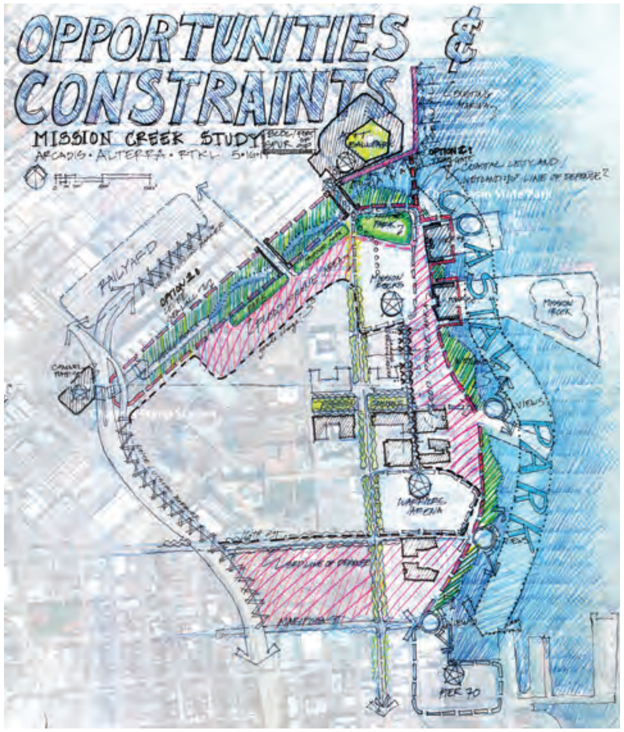
In a flood risk management and climate change context, the vulnerability of an asset is often assessed in terms of exposure, sensitivity, and adaptive capacity. For the Mission Creek sea level rise vulnerability assessment, the project team used definitions from the Intergovernmental Panel on Climate Change (IPCC 2007) for the following terms:

Vulnerability "is the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes." For this project we look solely at sea level rise as a climate change impact.

Exposure "is the nature and degree to which a system is exposed to significant climatic variations." For this project, we measure depth of inundation on the top of or surrounding an asset for projected midcentury and end of century sea level rise scenarios.

Sensitivity "is the degree to which a system is affected, either adversely or beneficially, by climate related stimuli." For this project, sensitivity includes the physical characteristics of the asset, including physical condition, age, level of use, operation and maintenance activities, etc. For assets in poor condition, we assume greater impacts from sea level rise.

Adaptive Capacity "is the ability of a system to adjust to climate change to moderate potential damages, to take advantage of opportunities or cope with the consequences." For example, if an inundated highway or waste water treatment plant (WWTP) were closed, the provision or existence of alternate roadways or backup WWTPs would mean these assets would have high adaptive capacity.



In the design charrettes for this project, participants sketched visions for protecting and enhancing Mission Bay.

APPROACH

This project includes a high-level vulnerability assessment for number of key assets in the study area surrounding Mission Creek. These include

- AT&T Park
- Sea Wall Lot 337
- Pier 48
- Pier 54
- Wetland in Mission Creek
- Channel Pump Station
- Third Street Bridge
- Fourth Street bridge
- Public Safety Building

To inform the vulnerability assessment, in addition to consulting available documentation, asset owners and managers were asked to provide information on the physical and functional characteristics of the assets. They were also asked to provide information related to asset operation, maintenance, and the history. This information was combined with the inundation maps to provide a qualitative description of the overall vulnerability for each asset.

INUNDATION EXPOSURE

The 2050 map suggests that under an 11-inch sea level rise scenario, a 1% annual chance (100-year) storm event would result in one to four feet of inundation in Mission Bay, and some flooding South of Market. More detailed analysis shows two low entry points along the shoreline (one along the creek and one along San Francisco Bay) will be over-topped in this scenario, which will create a flow path for water into Mission Bay.

36 inches of sea level rise with a 1% chance storm event would cause widespread inundation throughout Mission Bay, South of Market and into parts of the Mission. The depth of inundation ranges from 1 to 6 feet. The reason so much more land is inundated under this scenario compared to the 2050 scenario is because much of the low lying area is hydrologically connected in 2100, whereas in the 2050 scenario, water does not have a direct flow path from the shoreline to low-lying areas. In 2100, most of the shoreline is over-topped and there are no “quick wins” in terms of upgrading the shoreline protection to deal with this type of storm event.

FUTURE SEA LEVEL RISE VERSUS TODAY’S FLOOD RISK

Sometimes it can be difficult to think about and plan for future flooding due to sea level rise when today’s flooding is perceived by the public to be infrequent, unlikely, or insignificant. The challenge with discussions about sea level rise adaptation then becomes about when to start adapting. In Mission Creek, for example, King tides and daily high tides are not causing major inundation or disruption. Rather, it is the more extreme but less frequent events that could lead to flooding here.

The National Flood Insurance Program (NFIP) establishes a national standard of flood protection against a 100-year storm. The Federal Emergency Management Agency administers the NFIP by mapping flood risks around the country and designating special flood hazard areas using base

FIG 4–1: MISSION BAY NEIGHBORHOOD AND MAJOR LOCAL ASSETS

3rd Street Bridge during a high "King Tide"

flood elevations (BFEs) assuming flood impacts from 100-year storms. Federal law creates strong incentives for local communities to join the NFIP when FEMA maps a special flood hazard area within their jurisdiction. In participating communities, with few exceptions, the federal government requires property that is in federally-mapped floodplains to purchase flood insurance.

The mapping that was done by the SFPUC for the city shows that the water levels for a 500-year storm are only about 12-16 inches higher in the Mission Creek area, on average, than those of a 100 year storm - not an order of magnitude greater. This means that overall flood risk could be reduced significantly with only a marginal increase in the height of the flood protection features.

INDIVIDUAL ASSET VULNERABILITY

The table below shows the approximate inundation level for each of the assets that are part of this vulnerability assessment for both the 2050 and 2100 scenarios. The highest and lowest ground elevation levels near an asset were considered in determining the highest and lowest inundation levels around an asset. The result is a flood level relative to the base of each asset. Zero feet of inundation represents a situation where the local ground-level may not by inundated, but lower portions of assets such as bridge support structures, infrastructure, basements, and pier piles could be affected.

TABLE 4–1: POTENTIAL ASSET IMPACTS OF 2050 AND 2100 SEA LEVEL RISE SCENARIOS

	2050		2100	
Asset	Low (ft)	High (ft)	Low (ft)	High (ft)
Channel Pump Station	0	<1	<1	3
3rd Street Bridge	0	2	<1	3
4th Street Bridge	0	1	1	1
AT&T Park	0	0	<1	2
Seawall Lot 337	0	3	2	5
Pier 48	0	<1	1	3
Public Safety Building	TBD	TBD	TBD	TBD

FIG 4–2: MISSION BAY NEIGHBORHOOD 2050 SEA LEVEL RISE & STORM IMPACTS WITHOUT ADDITIONAL FLOOD PROTECTION MEASURES

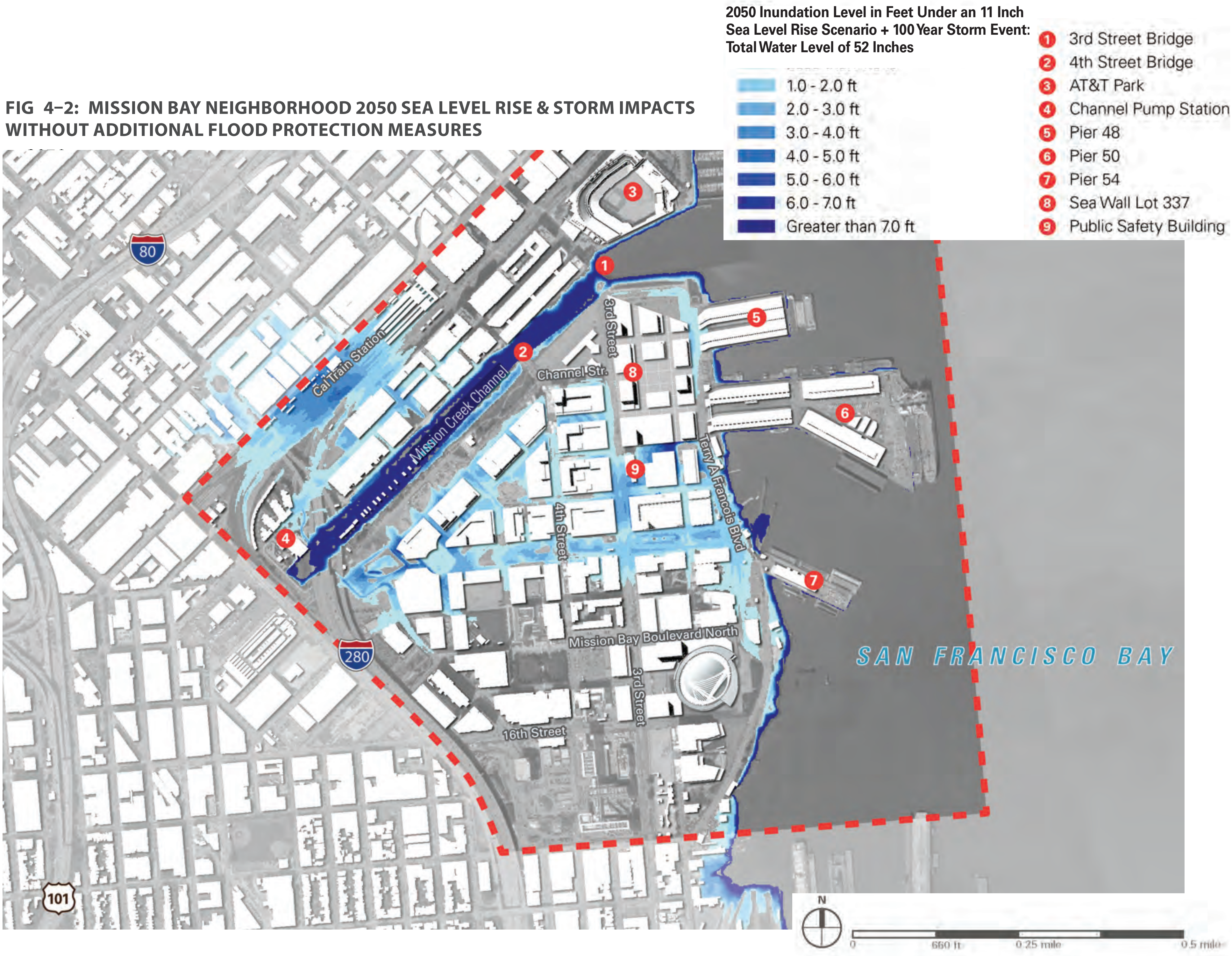
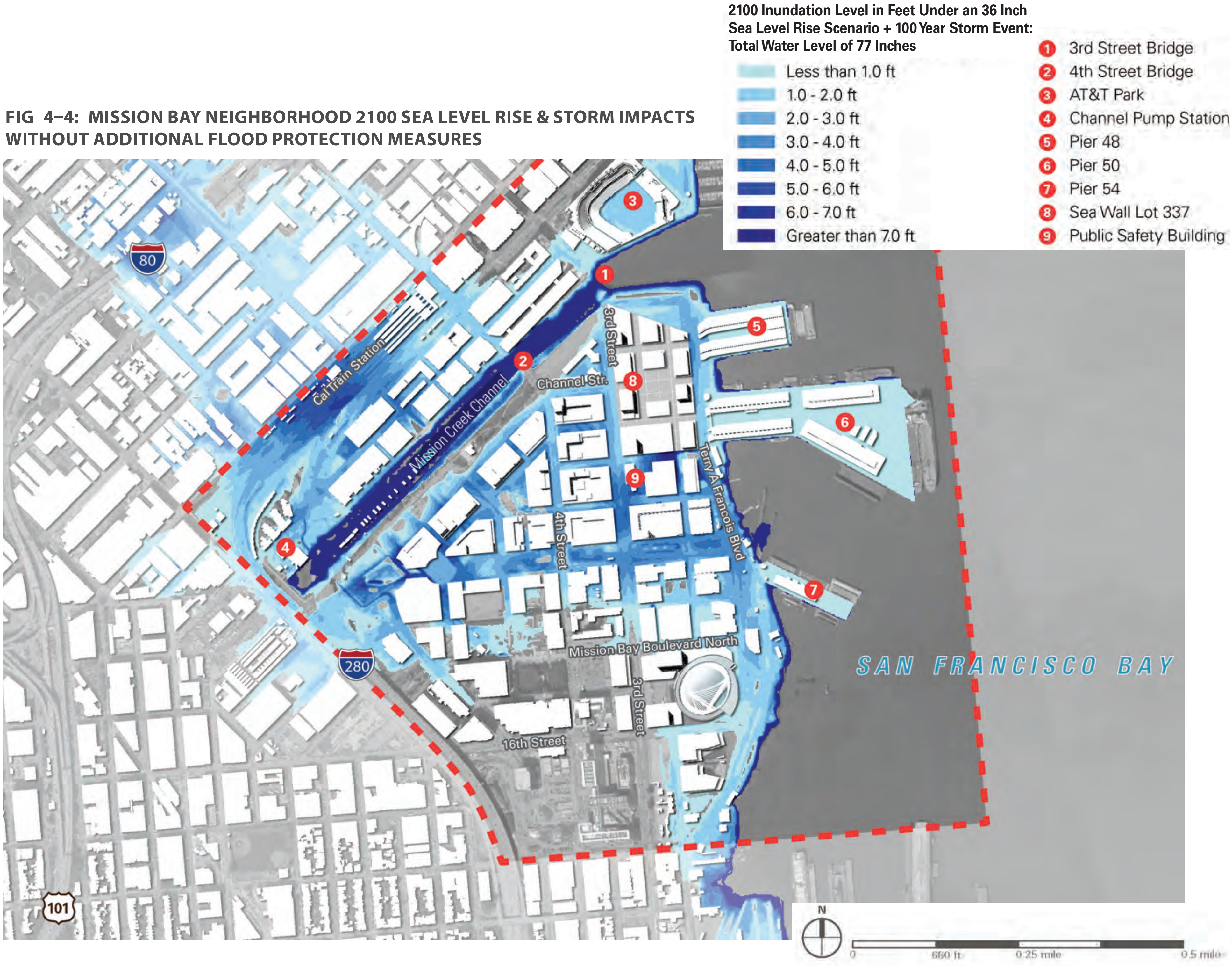


FIG 4–3: ILLUSTRATION OF 3RD STREET BRIDGE SEA LEVEL AND STORM IMPACTS

FIG 4–4: MISSION BAY NEIGHBORHOOD 2100 SEA LEVEL RISE & STORM IMPACTS WITHOUT ADDITIONAL FLOOD PROTECTION MEASURES



THIRD AND FOURTH STREET BRIDGES

37.776921, -122.390196 + 37.775047, -122.392492

Third and Fourth Street Bridge both cross the Mission Creek and form critical connections between South of Market and Mission Bay. Third Street Bridge, built in 1933 and Fourth Street Bridge in 1917, are historical landmarks. Both bridges were designed by Joseph B. Strauss and are owned by the City and County of San Francisco.

Third Street Bridge is located along Third Street between Terry Francois Blvd. and Berry Street. The bridge is a Heel trunnion bascule style bridge and is the only one of this type in the vicinity of San Francisco. The main span consists of a 143-foot steel bascule truss and is approximately 103 feet wide. The bridge is asymmetrical with three travel lanes between truss supports and a travel lane and walkway on the cantilevered west side of the bridge. Southwest of Third Street Bridge is Fourth Street Bridge which is a is a single-leaf bascule truss bridge and crosses the Mission Creek channel between Berry Street and China Basin Street. The 4th St. Bridge is 205 feet long and 40 feet wide and supports motor vehicle, bicycle, pedestrian and light rail (T-Line)

Both bridges are already vulnerable to inundation today. During King Tide events, the bottom part of the structures are inundated, increasing corrosion and maintenance cost. While the bridge deck will likely not be flooded during the 2050 11-inch sea level rise plus a 100-year storm event, the impact to the structure overall will increase. Roads that connect to the bridges, such as Third Street are partly inundated under this scenario and will impact access to the bridges. Under the 2100 scenario, the bridge decks would be flooded as well as more of the connecting roads, putting many out of service until water recedes. The challenge with the Fourth Street Bridge is that its counterweight is below grade and would be submerged during storm events making it impossible to operate and raise the bridge.

Plans have been developed to raise the historic bridges and its roadways; however, this cannot be done without affecting the egress of nearby buildings. If it were impossible to cross the bridges, Mission Bay could still be accessed from the West through Mission Bay Drive or 16th Street and 3rd Street from the south, though parts of these streets could be flooded as well. There would not be an alternative for the T-Line light rail connection.

SEA WALL LOT 337

37.776921, -122.390196 + 37.775047, -122.392492

Sea Wall Lot 337 is owned by the Port and is a sixteen-acre seawall lot bounded by Third Street to the west, Mission Rock Street to the south, and Terry Francois Boulevard to the west and north. The lot is currently used for day-use parking and heavily used during events at AT&T Park. It is also one of the lowest lying areas in Mission Bay without improvements. There is a potential of up to 2 feet of inundation under the mid-century scenario and 4-6 feet of inundation under the end of century scenarios.

Before development and associated improvements, inundation would lead to temporary closure of the parking lot and lead to reduced mobility and accessibility of Mission Bay overall.

The San Francisco Giants, who are negotiating an agreement with the Port and city to develop this site, have proposed a new neighborhood called Mission Rock at the site. The new development would include up to 3.5 million square feet of office, residential housing (including 40% affordable housing), retail, manufacturing uses, and a new parking structure. It would also include over 8 acres of public space and parks, which will include replanting of saline tolerant plants along the water's edge. The plan for redevelopment includes committments to raise the center of the site to significantly reduce the risk of flooding.

CHANNEL PUMP STATION

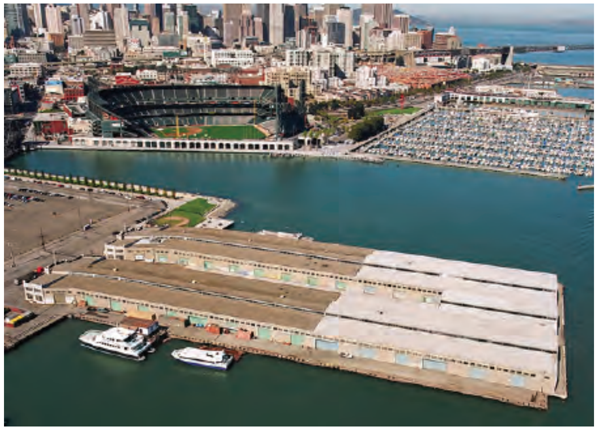
37.776921, -122.390196 + 37.775047, -122.392492

Channel Pump Station is a major wastewater pump station built in 1979 owned and operated by the SFPUC. It is the primary conveyance facility for wastewater from the Northeast quadrant of the City to the Southeast Wastewater Treatment Plant.

The pump station itself will likely not experience flooding under a 2050 scenario, except for some inundation on the nearby intersection of Berry and King Streets that is caused by the bioswale which could reduce accessibility to the pump station. Inundation under a 2100 scenario is much more severe, as the pump station could be surrounded by up to 3 feet of water. Further analysis should clarify if water would also enter the facility under this scenario. In that case, there could be significant damage to the facility and widespread impacts, the Channel system receives and transports wastewater pumped from the North Shore Pump Station and wastewater brought by gravity flow from the Channel drainage area sewers.

Most of the pumping equipment and electrical controls are below grade and cannot sustain any type of inundation. Failure of this pump station would mean that substantial amounts of San Francisco's wastewater could not be conveyed to the southeast treatment plant.

Inundation of critical facilities like pump stations or wastewater treatment plants is something that was experienced during Superstorm Sandy. From an adaptive capacity perspective, creating redundancy in the system (back up pump capacity) is important to minimize the impact. Alternatively pump stations can be flood-proofed so that while the facility might be surrounded by water during high water events, it cannot enter the facility and operations can continue as normal.



PIERS 48, 50 AND 54

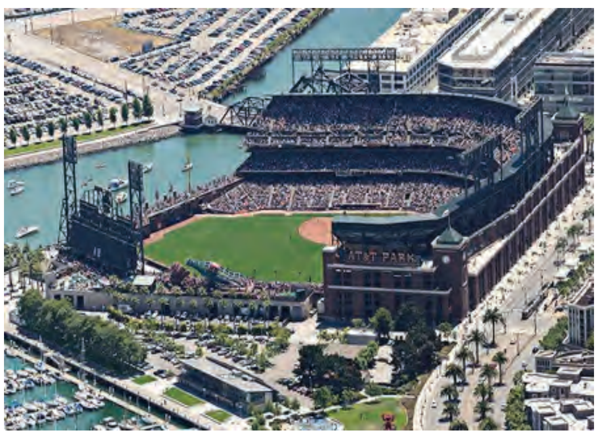
37.775607, -122.386699 + 37.773877, -122.385068 + 37.770086, -122.384714

Piers 48, 50 and 54 are facilities owned by the Port of San Francisco located along the bay shoreline on Terry Francois Boulevard in Mission Bay. Pier 48 was constructed in the 1920s and is a contributing resource to the Embarcadero Historic District and Piers 50 and 54 were constructed in the 1950s; together they are defining features of this area of the San Francisco waterfront. Today, the piers are used for special events, parking, a distillery, and warehouse storage. Pier 50 continues to be an active maritime hub, and is home to the Port's Maintenance Division.

From an exposure point of view the pier decks will only be inundated under the end of century scenario. However at the mid-century level sea level rise scenario they will also be significantly impacted. Much of the utility infrastructure of the piers is beneath the pier decks. In addition wave action underneath the piers can create uplift and jeopardize the structural integrity of the piers substructure. These impacts are exacerbated in the end of century scenario because parts of the pier decks are inundated impacting the sheds and business activities.

This impact could result in temporary closure of the piers. As the Port leases these facilities to tenants, the impact could result in reduction of revenues.

Pier 48 is part of the Mission Rock redevelopment and will be the future home of Anchor Brewing & Distilling. It will also include new manufacturing and public access components.



AT&T PARK

37.778151, -122.388962

AT&T Park is San Francisco's Major League Baseball facility, owned by the San Francisco Giants and located on the north side of the creek mouth. It was opened in 2000, and is built on land controlled by the Port of San Francisco that is held in public trust for the citizens of the State. With a capacity of approximately 41,000 people, the ballpark draws close to 4 million visitors per year. The Giants play 81 regular season home games per year, and host a range of special events and programming.

Given that the sea wall surrounding the ballpark is relatively new and built at higher elevation than most of the neighboring shoreline, there is no major flooding impact for the mid-century sea level rise scenario. For end-of-century there is a potential for 0 to 2 feet of inundation. This would impact the field, offices, entertainment and team facilities.

TIDAL SHORE HABITAT / SOFT EDGE

37.772190, -122.396491

While small, the tidal wetlands in Mission Creek form habitat for plant and animal species in the city. Despite many decades of pollution and filling under its former use, Mission Creek still has an abundance of wildlife and water quality has improved significantly over the years. This includes the reduction in combined sewer overflows. The wide variety of marine and coastal species that has been observed in the creek has an obvious direct link to the San Francisco Bay ecosystem. The real functioning of the creek as part of the SF Bay ecosystem is however unclear.

The challenge with sea level rise is whether the tidal wetland and shoreline habitat can keep up with the rate of sea level rise and whether this will have an impact on biodiversity here. In typical creek ecosystems, there is a sediment supply from upstream that provides capacity for wetland accretion; this natural system is not in place for Mission Creek. Likely, human intervention will be needed to maintain the existing habitat. Strategies to maintain a natural shoreline habitat in order to keep biodiversity intact should be incorporated into any future flood protection measures.

PUBLIC SAFETY BUILDING

37.772516, -122.388860

The Public Safety Building, completed in 2015, is located along 3rd Street between Mission Rock and China Basin Streets. It provides a replacement facility for the San Francisco Police Department (SFPD) Headquarters and the Southern District Police Station. The Public Safety Building also contains a fire station that serves Mission Bay. In the event of a major earthquake, the existing Police Headquarters on 850 Bryant Street is not expected to be operational. As it is essential that the police command structure remain fully operational immediately after a big earthquake, this new building provides the structural and operational resiliency to do so.

From a flood resiliency perspective, this building is vulnerable and could jeopardize the operations it houses. Under the mid-century scenario, this building could see between 0 to 2 feet of inundation and 2 to 4 feet for the end-of-century scenario.

Despite the resilient design, this critical facility could be found to be non-operational in the unlikely event that sea level rise, storm surge, and seismic activity present a compound threat. The city also operates an inland Emergency Operations Center at 1101 Turk Street.

CHAPTER 5 ADAPTATION GUIDANCE FOR MISSION CREEK AND MISSION BAY SHORELINE

In densely built urban areas, multi-purpose flood protection can provide additional value. These new concepts of infrastructure integrate flood protection with other functions.

Previous sections have identified the exposure of Mission Creek and Bay to current and future flooding, and have identified some of the vulnerabilities and impacts of flooding in the region. Since it is not possible to eliminate all future flood risk, a strategic adaptation plan informed by a thorough understanding of risks and clear evaluation of adaptation trade-offs can help reduce those greatest flood risks to ensure a resilient San Francisco future.

Experience in California and in other coastal cities around the world show us that there are many kinds of adaptation measures and strategies. Some measures will reduce the frequency of inundation, such as storm surge barriers, sea walls and levees; these are called structural flood risk management measures. Meanwhile, other measures can reduce the consequences of flooding; such as flood-proofing assets and buildings, buying flood insurance, or implementing more restrictive land use regulations; these are referred to as non-structural measures.

Adapting to sea level rise and managing flood risk in San Francisco Bay requires considering the full range of tools, some of which require significant investment in infrastructure, others a smaller investment, while some measures may be financial or regulatory tools such as insurance or zoning that address various components of the risk.

What is appropriate for one area along the waterfront in San Francisco may not necessarily be appropriate or feasible in other places in the city, and each measure has its benefits, as well as its costs. A careful exploration and analysis must evaluate adaptation alternatives and options to identify a strategy to make best use of limited resources in achieving goals and objectives.

For example, storm surge barriers around the world play an important and sometimes indispensable role in flood protection. In the Netherlands and London, they shorten the line of defense (miles of coastline to be protected) considerably, which reduces construction and maintenance costs. Storm surge barriers are flexible in that they allow for navigation and, if properly constructed, can be adapted to future conditions. However, storm surge barriers today are expensive, they can affect local sediment transport and other ecological processes, and they bear the additional risk of a closure failure.

Common questions when developing a flood management and adaptation strategy are “what level of protection” is appropriate, or, “how safe is safe enough” “and how high should it be?” Historically, emphasis in the United States has been on achieving a “100-year” level of protection. However, this was a standard for the National Flood Insurance Program and was not developed for safety or for what level of flooding and impacts would be considered tolerable. Rather, it was selected as the minimum threshold by which one not need to purchase federal flood insurance. Ongoing debates suggest that safety and design standards for managing flood risk be commensurate with the lives and value of the assets at risk.

For example, ultimately, the decision on “how safe is safe enough” needs to be made by the community and its stakeholders based on what frequency and impacts of flooding they consider tolerable. This understanding will then help inform the adaptation strategy that is developed.

BEYOND FLOOD CONTROL: MULTI-FUNCTIONAL INFRASTRUCTURE

Historically most infrastructure, including flood control infrastructure such as levees and flood control channels, has been built for one purpose only—to hold back floodwaters. Effective in places, many of these single-purpose flood control assets have also had detrimental impacts on ecosystems and water quality, in some cases increasing flood risk by sending flood waters elsewhere, and also encouraging development in unsafe areas.

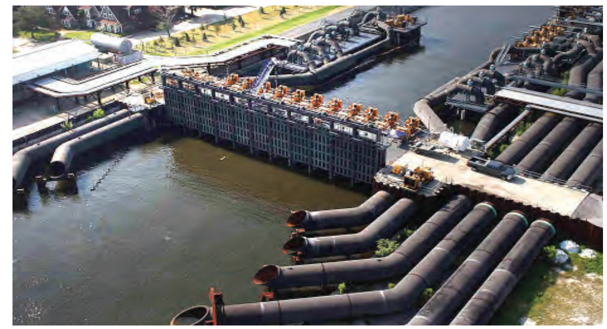
From an aesthetic perspective, traditional flood control features are usually made of concrete or dirt, are un- attractive, and can separate communities from their waterfront. This also prevents the public from understanding that they in fact 'live on and with water'. Most of this single-purpose infrastructure is financed by local, state, or federal governments—most of whom have seen an increase of people living in flood prone areas, while at the same time experiencing difficulty obtaining funding to build and maintain the infrastructure today and into the future.

100

EMPHASIS HAS BEEN ON ACHIEVING A "100-YEAR" LEVEL OF PROTECTION, THAT FACTORS SEA LEVEL RISE, TIDE IMPACTS. STORM SURGE AND WAVE ACTION THREATS

However, limited resources and rising sea levels mean that we will likely no longer be able to afford infrastructure that serves only one function. Ecological values have shifted and nearby projects, such as the Napa River Flood Control Project in the City of Napa, California, suggest the public is no longer satisfied with the opportunities afforded by concrete single purpose flood control infrastructure.

As such, the last few years have lent themselves to a new concept of multi-purpose infrastructure, which integrates flood protection with other functions. In densely built urban areas, multi-purpose flood protection can provide additional value by integrating flood protection with other urban functions, like transport, waste water management, housing, recreation, nature and tourism.



The New Orleans Tidal and Flood Barriers are examples of monofunctional infrastructure that limit our relationship with water.

Multi-purpose flood protection infrastructure can improve the urban ecosystem and enhance living conditions for local communities. For example, wetlands can provide ecosystem benefits, clean water, and recreational opportunities while reducing wind-wave run-up during high tides and storms. A pilot project of the Hybrid Levee[1], or a levee that employs ecological restoration and incorporates other open space and civic functions,

1 http://www.sfestuary.org/hybrid-levees/

is already underway in San Francisco Bay at the Oro Loma Sanitary District pilot project. Multi-functional dikes on the Dutch coastline hold back storm surge while creating new land and waterfront property to serve public spaces, parks, and recreational opportunities.

Multi-purpose flood protection can pool several existing revenue and capital investment streams, can also generate additional financial resources, and create opportunities for urban development. For example, after Hurricane Sandy, the New York City Economic Development Corporation (NYC EDC) is studying "Sea Port City" which is a landmass build out into the East river that serves as a levee and protects lower Manhattan, while providing new land on which to build high-value residential housing. In addition to meeting a need

Sea Port City exemplifies the approach to building secure shorelines using development driven financing.

in a city with a housing crisis, the Sea Port City multi-functional levees provide an opportunity for a unique public-private financing partnership for development and funding.

Or at a more modest scale, a recent example from Katwijk, the Netherlands, where a coastal dune restoration project included the construction of a parking garage within the dune to meet parking needs for beach visitors.

Katwijk coastline in the Netherlands provides transportation, recreational, ecological, and resiliency services to its community.

While attractive, however, these types of projects can also be complicated from a regulatory standpoint. New fill in San Francisco Bay is regulated by the USACE, BCDC and the Regional Water Quality Control Board and the type and amount of fill is strictly regulated. The Mission Creek Channel is designated as a navigable waterway under federal law - requiring approval for significant modifications at higher levels of administration.

PROJECT DESIGN OBJECTIVES

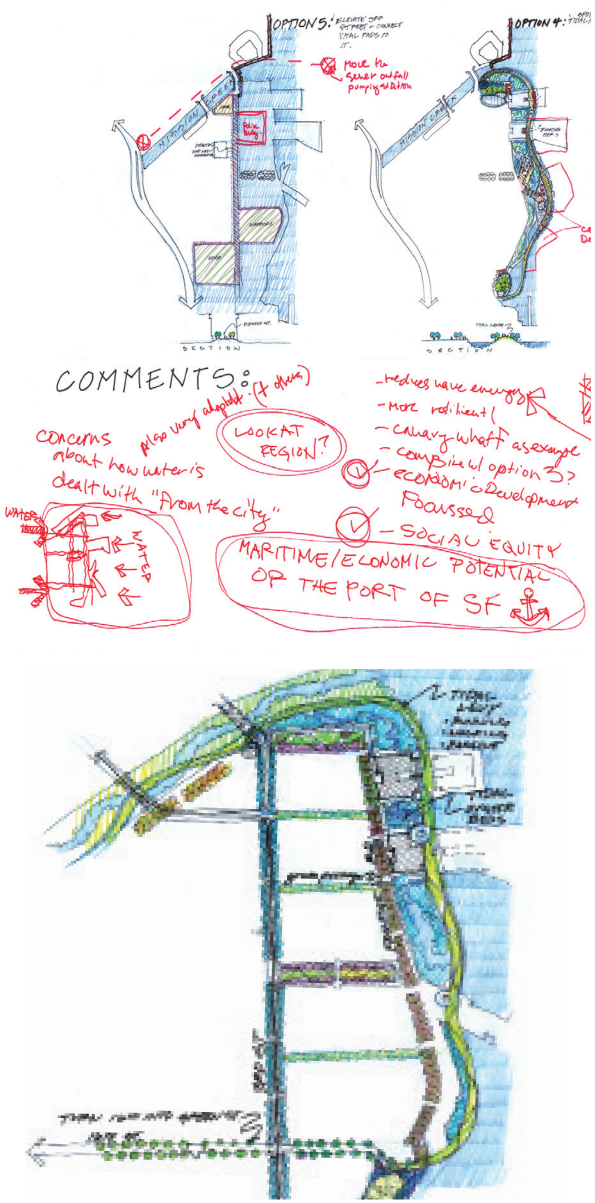
01 Focus on the development of a range of concepts for both the creek and the bay shoreline, without selecting a preferrred alternative.

02 Engage in an imaginative exercise envisioning what living with future sea level rise could look like.

03 Strive for multipurpose solutions that integrate flood protection into the urban fabric for an attractive and economically viable city.

04 Seek opportunities for natural ecosystem and habitat development to enhance the environmental qualities of the waterfront.

05 Consider future adaptability as criteria in adaptation measure selection.
All design concepts should be able to cope with at least 36 inches of sea level rise - in other words, suitable for 2100 water levels.



The design process for developing proposals included a workshop based and open-minded approach.

ADAPTATION DESIGN GUIDANCE

Through an interactive design process many stakeholders and experts from many different fields around the table participated in design charrettes and field visits.

Their work explored alternatives within the range mentioned above, and describes a few adaptation concepts in detail for the Mission Bay shoreline and Mission Creek. The discussion includes the type of measure, the flood protection benefits and trade-offs of that measure, and —whether it is a near-term or long-term flood risk management approach. Where appropriate, the discussion also mentions where certain approaches may accommodate multiple purposes.

As the design process commenced the following principles were used to guide the development of different concepts:

- Focus on the development of a range of concepts for both the creek and the bay shoreline. It was not the intention of this process to select one preferred approach.
- Nothing is off the table – meaning that while some concepts might be considered radical, difficult to implement, or hard to permit, this was meant to be an imaginative exercise envisioning what living with future sea level rise could look like.
- Strive for multipurpose solutions that integrate flood protection into the urban fabric for an attractive and economically viable city.
- Despite the urban and built nature of the waterfront, seek opportunities for natural ecosystem and habitat development to enhance the environmental qualities of the waterfront.
- All design concepts should be able to cope with at least 36 inches of sea level rise and potentially manage the threat from a 1% chance storm event (i.e. be suitable for 2100 water levels).
- Consider future adaptive capacity as criteria in adaptation measure selection.

INTRODUCTION TO ADAPTATION CONCEPTS

While any future adaptation planning needs to carefully evaluate the trade-offs across alternatives and specifically assess the long term flood risk reduction benefits for Mission Creek, a preliminary evaluation suggests that there are two flood risk scenarios that should be dealt with: one near term strategy to address current flood risk and one long term strategy to adapt to sea level rise.

In the near term, we recommend addressing the weak (or lowest) points in the current "line of defense" along the shore by permanently raising or closing off of the low spots along the shoreline of Mission Creek and the bay shoreline. This would reduce the likelihood that the shoreline will be over-topped by high water and the likelihood that the land, buildings, and assets will be inundated.

The Mission Creek research team developed ideas through collaboration with local experts, then proceeded with workshop and charette meetings, and then narrowed options to a focused set of viable solutions through presentation.

In the longer term, assuming a planning horizon until 2100, sea level rise planning and proper risk evaluation is key. As part of this project many different adaptation approaches were considered which after much deliberation, stakeholder input and research resulted into three specific adaptation concepts for the creek shore line and four specific adaptation approaches for the bay shoreline, all of which can accommodate and be designed for a 36 inch rise in sea level rise.

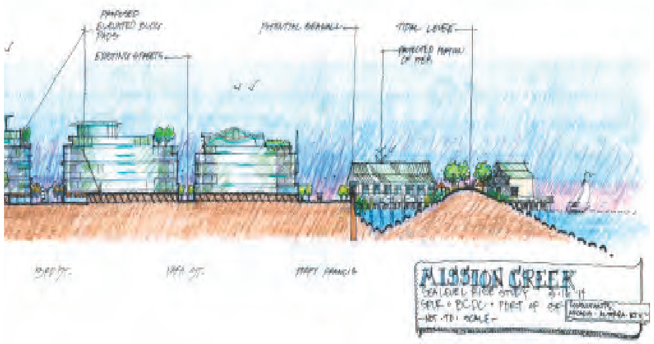
PROJECT DESIGN PROCESS STEPS

S1 Gather information and interview professionals and stakeholders with on-the-ground expertise in working in and around the mission bay neighborhood.

S2 Commence with a stakeholder-driven workshop that applies an open minded approach to the intersecting challenges of protecting mission creek and mission bay.

S3 Present, discuss, and refine a select set of individualized solutions that balance engineered resiliency systems with ideas that add full value for the district and its occupants.

S4 Collect comments from stakeholders, revise, and digitally develop conceptual and schematic designs for creek and shoreline protection alternatives. Assess lessons learned and propose implementation steps.



Preparing a resilient and adaptive city will require a layered and sophisticated approach - not simply a dike or wall.

ADAPTATION: MULTIPLE LAYERS AND MULTIPLE LINES OF DEFENSE

One of the key questions for San Francisco in adaptation planning is where to put the line of defense – or in other words what is allowed to flood and what not. Will the new shoreline protection be along the shore, will new infrastructure be build further out or could some portions be given back to the bay? Planning for flood risk in coastal cities typically happens through a multi-layered approach of integrated solutions each contributing to reduce overall flood risk. Below is a graphic that shows three layers of defense.

- Inner Layer – focuses on local solutions designed to protect critical infrastructure and integrate watershed management and urban planning in a city environment
- Middle Layer – is the typical transition zone from land to water and encompasses sustainable coastlines including waterways, barriers, beach fortification, marshes and multi-functional levees, etc.
- Outer Layer – is mostly water based with large engineered solutions such as sea gates, pump stations, barriers and offshore structures

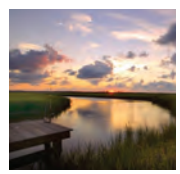
In the adaptation concepts for this study, all solutions fall in the first two categories: the inner and middle layer. Outer layer solutions would include, for example, the consideration of a barrier at the Golden Gate to keep high waters out, which is not part of this study. The complexity and cost of highly engineered "outer layer" solutions should remind us to first consider the more cost effective and multi-use inner and middle layer solutions.

Within a multi-layered safety approach one can still vary a lot with the actual line of defense that is chosen. This is shown in Figure 5-2 below. Each of the three creek concepts and each of the four bay concepts has a different footprint in the study area and also differs in length.

INNER LAYER

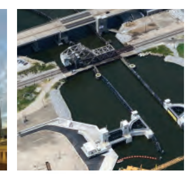

Watershed Management + Public Amenities

MIDDLE LAYER

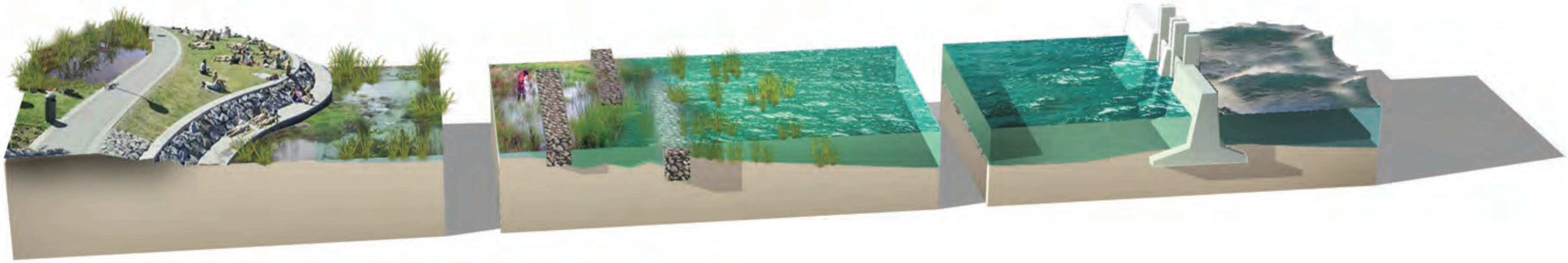



Living Breakwaters + Wetland Buffers

OUTER LAYER

Hard Infrastructure to Protect a Larger Region



It should be noted that both to the north and to the south of the project area these lines of defense should tie into either higher existing land or be continued to avoid 'back-door' flooding. Each of the lines of defense of the 3 creek concepts can be made compatible with and tie into each the lines of defense of the 4 bay concepts.

FIG 5-1: CREEK AND SHORELINE PROTECTION CONCEPTS

On the next pages the following adaptation concepts are described in detail:

CREEK CONCEPTS:

1. Perimeter Shoreline Protection
2. Tidal Barrier
3. Mission Lake

BAY CONCEPTS:

1. Perimeter Shoreline
2. City Levee
3. Elevated Third Street
4. New Waterfront

Finalized proposals were developed by hand with care towards contextual impacts and constructability.

Note: This image depicts a conceptual idea and is not intended to be authoritative regarding proposed intensity of development or preferred mitigations regarding sea level rise. Further study and coordination between interested parties will be required to further refine these concepts toward a viable proposal.

Creek Concept 1 builds along the existing edge of Mission Creek and China Basin

CREEK CONCEPT 1: PERIMETER SHORELINE PROTECTION

CREEK CONCEPT 1 OVERVIEW

THE CONCEPT:

Raise the perimeter of the Mission Creek shoreline to address vulnerable low spots. Adaptation measures would include a mix of levees and seawalls.

PROS:

- ✓ Maintains tidal flow
- ✓ Adaptable as sea level rises
- ✓ Channel remains navigable
- ✓ Sewer overflow system remains intact

CONS:

- ✗ Bridges will have to be raised or replaced in the longer term
- ✗ Long line of defense
- ✗ Need for modification of Mission Bay interior drainage
- ✗ Less able to meet "multipurpose objective"; potential visual barrier at AT&T Park

This adaptation concept (Figure 5-3) would raise the perimeter of the Mission Creek shoreline to reduce the frequency of floods over the long term as sea level rises.. The proposed structural adaptation measures would include a mix of levees and seawalls, depending on the space that is available on shore. For example, levees take up a larger footprint in the landscape than a seawall, so a sea wall may be more feasible where space is limited. The measures can be implemented over time as sea level rises or in advance of sea level rise to take advantage of current and future redevelopment and restoration activities in these locations. This is an approach that would allow the creek to continue to function much as we know it today, a tidal channel.

As stated in the vulnerability assessment, the shoreline along the ball park is higher than most of the rest of Mission Creek's shoreline. A thick glass wall could reduce both the impact of wind waves over-topping the shoreline and could hold back occasional high water at this location This measure would allow the city to maintain the waterfront aesthetics of the AT & T Park by continuing to provide unobstructed views. This measure is only suitable for wind wave impacts, not for permanent high water. Therefore, as sea level continues to rise and the year 2100, the glass wall would likely have to be replaced by a stronger material such as a concrete wall.

Along the north shoreline of the creek, a concrete wall could be installed to reduce the frequency of inundation due to high water. A sea wall would be preferable to a levee because there is limited space available between the shoreline and the existing buildings in China Basin. For the 2100 sea level rise scenario, the wall would need to be at least three to four feet high to hold back that amount of sea level rise.

FIG 5–2: CREEK CONCEPT 1 DEVELOPMENT VISION

Note: This image depicts a conceptual idea and is not intended to be authoritative regarding proposed intensity of development or preferred mitigations regarding sea level rise. Further study and coordination between interested parties will be required to further refine these concepts toward a viable proposal.

Top: Glass or acrylic over-topping walls provide strong and safe resistance to periodic stormwater surges while avoiding view disruption. Bottom: Roadways which must cross the levee or seawall will require operable gates for use during significant high water events.

This wall would still allow pedestrians to look over the wall, or in some places could be designed to serve as a staircase to maximize opportunities for the community to stay connected to the water. To further mitigate the disconnect with the water in some instances the wall could be as wide as the pedestrian path which would enable people to walk on it like a sidewalk, and would provide unobstructed views and access to the water as people know the creek today.

On the Mission Bay side of the creek, a levee would be a more appropriate measure. There is plenty of space along the shoreline and the levee could be integrated with the new shoreline park that is being developed along Mission Creek, and new recreational opportunities could be created by adding recreational features along the waterfront.

The perimeter shoreline protection concept would require that Third and Fourth Street Bridges be elevated to create a continuous flood protection system or line of defense with the rest of the shoreline. Alternatively, temporary barriers could be installed across the roadway on either end of the bridge. This cross-roadway gate at the bridge thresholds would effectively extend seawall protection across those bridge entries - preventing water from entering the Mission Bay and SOMA districts. This, of course, would not directly protect the bridge roadway decks where they are currently over the water. A temporary barrier could be as simple as laying down sandbags during a high water event, or alternately somewhat more complex like installing moveable doors or barriers that would lift out of the roadway (Figure 5-4). Flooding of either bridge deck, however, will impact the structural integrity of the bridge.

While this strategy would reduce inundation interior of Mission Creek, temporary barriers at the bridges would prevent use of the bridges during and in preparation for high tides. As such, it could create a significant nuisance for residents, commuters and businesses. Over time as sea level continues to rise the frequency of closure would increase.

A major advantage to the perimeter shoreline protection concept is that it generally preserves Mission Creek and its current functions. For example, the tidal regime of Mission Creek can be maintained and it can continue to serve as an outlet for stormwater and sewer system overflow to the Bay. Also, navigation on the creek would not be altered and houseboats can be moved in or out of the creek as needed. Related to stormwater drainage, given that Mission Bay has a separated sewer and stormwater system and stormwater flows into the bay by gravity, the new shoreline protection measures may create a barrier for water to flow into the bay and require more stormwater to be pumped out, or to be discharged only during low tide s. The other downside of this concept is that it creates a relatively long line of defense (compared to the other concepts) and consequently has a higher risk of failure due to potential breaching or overtopping.

The future adaptive capacity of this concept and the adaptation measures within it within a 100 year time span is fairly good. The glass wall can be replaced and the concrete wall and levee can be raised assuming that future increases in height are taken into account as part of the original design.

This measure would allow the city to maintain the waterfront aesthetics of (the) AT&T Park by continuing to provide unobstructed views. This measure is only suitable for wind wave impacts, not for permanent high water. Therefore, as sea level continues to rise and by the year 2100, the glass wall would likely have to be replaced by a stronger material such as a concrete wall.

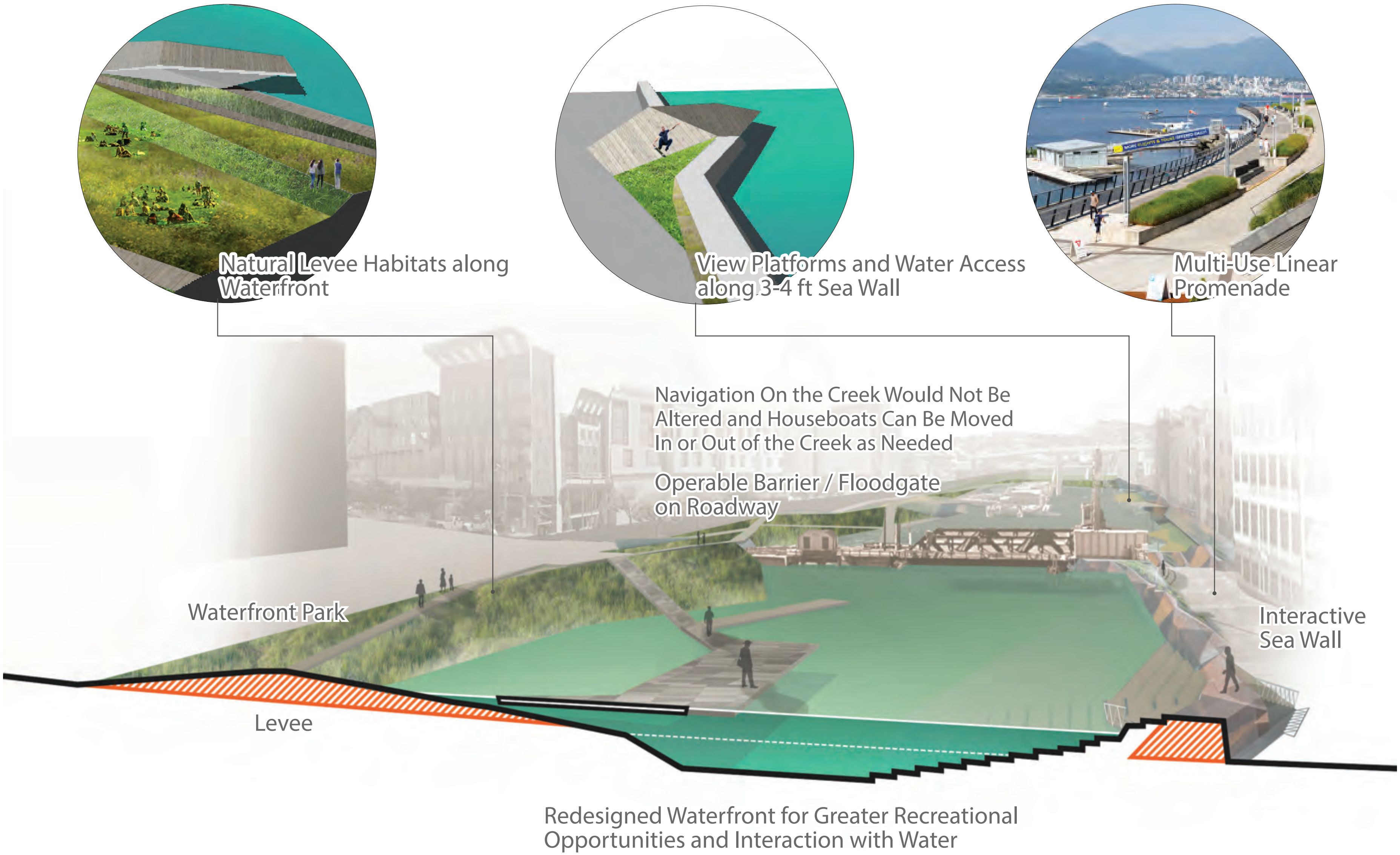


FIG 5–3: CREEK CONCEPT 1 OPPORTUNITIES AND DETAILS

Note: This image depicts a conceptual idea and is not intended to be authoritative regarding proposed intensity of development or preferred mitigations regarding sea level rise. Further study and coordination between interested parties will be required to further refine these concepts toward a viable proposal.

Creek Concept 2 places a tidal control line outside of China Basin; it would also require transitions to elevated adjacent parkland as well as modifications to the stormwater pump station at the end of the Mission Creek channel

CREEK CONCEPT 2: TIDAL CONTROL

CREEK CONCEPT 2 OVERVIEW

THE CONCEPT:

Construct a tidal barrier at the mouth of the creek that can be closed during high tides and storm surge.

PROS:

- ✓ No need to increase height of flood protection around the creek
- ✓ Maintains tidal flow most of the time
- ✓ Maintains channel navigability
- ✓ Bridges protected, no modifications needed

CONS:

- ✗ Will require more frequent operation as sea level rises, eventually leading to permanent closure.
- ✗ Risk of operational failure
- ✗ Conspicuous location out in waterway

Tidal Control would involve the construction of a tidal barrier at the mouth of Mission Creek in McCovey Cove. This adaptation concept involves shortening the line of defense in order to reduce maintenance and costs, as well as likelihood of system failure and flooding.

In contrast to preventing high water from overtopping the perimeter along Mission Creek as in Concept 1, Concept 2 suggests a tidal barrier to protect the shoreline inland of the barrier by preventing water from entering Mission Creek. During storm or high tides, the barrier would slide or lower into place to prevent water from entering the Mission Creek Channel, and it would stay closed until water levels have receded to safe levels. Typically this is connected to the tidal cycle and the duration of a storm event. As sea level rises, however, the barrier would close more because higher water levels will occur more frequently.

The Thames Barrier in London is an example of a tidal barrier; similar to the situation described above, while the Thames Barrier was designed to only close once every 10 years, it now closes multiple times a year in high tide situations because sea level rise causes the critical water surface elevation to be reached more frequently. The figure below shows the Thames Barrier[2], however different types of barriers could be appropriate at the mouth of the Creek.

2 http://www.sfestuary.org/hybrid-levees/

The Thames Barrier

FIG 5–4: CREEK CONCEPT 2 DEVELOPMENT VISION

Note: This image depicts a conceptual idea and is not intended to be authoritative regarding proposed intensity of development or preferred mitigations regarding sea level rise. Further study and coordination between interested parties will be required to further refine these concepts toward a viable proposal.

The Gulf Intracoastal Waterway West Closure Complex includes pumping mechanisms to maintain river flow during high water.

Marina Barrage is a stormwater retention and storm surge protection infrastructure which also serves as public open space amenity in central Singapore.

In this concept Third and Fourth Street Bridges would not have to be raised, as navigation remains possible. Similarly, stormwater and the sewer overflow systems do not have to be adapted. However, when a high tide coincides with extreme rainfall and the barrier is closed, Mission Creek would become a temporary water retention basin. This, with combined sewer overflow might lead to temporary poor water quality in the creek channel. If an extremely high water event coincides with a big rain event and the amount of stormwater flowing into the creek channel exceeds its retention capacity, it could result in interior flooding. Future studies should investigate whether additional pumping capacity would be necessary to pump out excess stormwater across the tidal barrier into the bay. This type of configuration is very common in New Orleans. After Hurricane Katrina, many storm surge barriers were built to close off canals and waterways, but each has a pump station alongside of it to keep the interior drainage system function properly.

The tidal barrier would consist of a fixed section connecting to the elevated banks on either side of the creek. The size of the movable portion of the barrier would be determined by navigation requirements and by the objectives for minimizing changes in tidal and sediment transport. The concept rendering shows a vertical lift gate (applied in the Netherlands), but many other designs a are possible. A sliding sector gate, for example is used in New Orleans, and a bottom hinged flap gate is used in Venice, Italy. The barrier could also serve as a new north-south pedestrian crossing with a walkway on top of the fixed portion and a bridge across the movable part. As an example, the Marina Barrage in Singapore prevents flooding in the city, created a giant fresh water lake, and acts as a new tourist attraction with a visitor center.

As with any moveable barrier around the world there is operational failure risk associated with this concept. If the barrier did not close during a high tide or storm situation it could lead to unexpected and possibly sudden flooding.

Given the sea level rise projections for 2100, and considering future sea level rise beyond that, it is likely that a tidal barrier would have to be permanently closed shut or replaced by a fixed barrier (see Creek concept 3) to account for much greater and more frequent water levels. Due to more frequent closure of the barrier over time the operation and maintenance costs will likely increase as well.

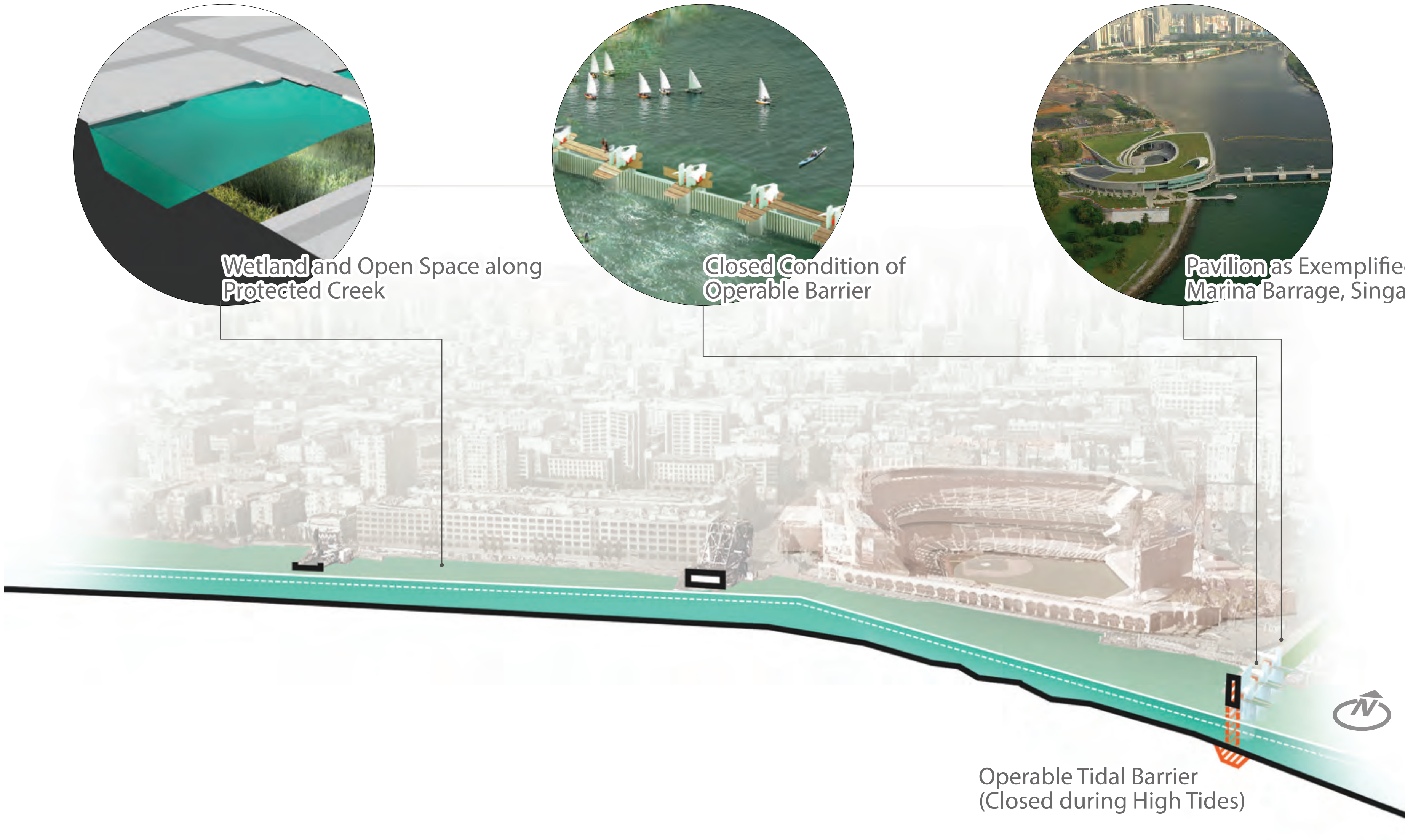


FIG 5–5: CREEK CONCEPT 2 OPPORTUNITIES AND DETAILS

Note: This image depicts a conceptual idea and is not intended to be authoritative regarding proposed intensity of development or preferred mitigations regarding sea level rise. Further study and coordination between interested parties will be required to further refine these concepts toward a viable proposal.

Creek Concept 3 builds level and wetland protection at the creek's mouth at China Basin; the remaining channel would become a freshwater runoff impoundment.

CREEK CONCEPT 3: MISSION LAKE

CREEK CONCEPT 3 OVERVIEW

THE CONCEPT:

Close Mission Creek off from San Francisco Bay at the mouth of the creek with a levee or dam.

PROS:

- ✓ Controlled water level in Mission Creek Channel
- ✓ New habitat, recreation and destination opportunities
- ✓ Robust and proven concept
- ✓ Short line of defense

CONS:

- ✗ Will alter tidal regime
- ✗ Uncertain water quality
- ✗ No navigation on Mission Creek Channel
- ✗ Major alterations to sewer system overflow needed
- ✗ Pumped Mission Bay drainage system

Creek Concept 3 is an evolution of Concept 2 and would permanently close off the Mission Creek Channel from San Francisco Bay with a levee or dam at the mouth of the creek. Similarly to Creek Concept 2 this dramatically shortens the line of defense and since it is a fixed structure rather than a movable barrier it reduces both the long term maintenance costs as well as likelihood of failure.

Closing off the creek channel would create a lake behind the dam or levee and the water level would be controlled. The lake could provide ample new opportunities for recreation and habitat development, by raising parts of the creek bottom, and could potentially serve as fresh water detention basin no longer impacted by sea level rise.

This concept has, however, significant downsides. The tidal nature of the creek would be lost, impacting water quality, salinity and sediment

Creek protection measures are opportunities to improve our relationship to water.

FIG 5–6: CREEK CONCEPT 3 DEVELOPMENT VISION

Note: This image depicts a conceptual idea and is not intended to be authoritative regarding proposed intensity of development or preferred mitigations regarding sea level rise. Further study and coordination between interested parties will be required to further refine these concepts toward a viable proposal.

Lake Merritt in Oakland exemplifies the value of closed freshwater runoff systems to communities in the Bay Area; efforts to reconnect it to the larger Bay Area ecosystem exemplify the challenge planners face in protecting these assets while enhancing their ecological value.

movement. Also navigation in and out of the creek would no longer be possible, impacting the mobility of the house boats and other boats on the creek.

It could potentially still be possible in this concept to keep the Mission Creek Channel connected to the Bay with a culverted channel (similar to Lake Merritt in Oakland or the Aquatic Park in Berkeley) to create a brackish water environment and allow for water circulation during low upstream inflow summer months. This alternative would allow much of the Creek shoreline to remain as it is today. However because “Mission Lake” would no longer have regular inflows and outflows, the sewer system would have to be reconfigured to prevent sewer overflow from spilling into the creek. The overflow structure would have to be moved to the mouth of the creek closer to the bay. This may require a new large diameter pipeline to be built from the existing pump station or the storage bunkers into the bay. All excess stormwater in the creek would have to be pumped out or released under low tide conditions.

Although this concept will change the present ecosystem , it may provide options for new habitat and recreation opportunities in the creek, provided that sewer overflow bypasses the lake.

The optimum location for the levee or dam would be at the shortest distance from one side to the other in order to minimize the length (and maintenance costs) of a levee or dam.

Stormwater treatment wetlands slow down runoff, clean the water, and provide wave and storm surge buffers during over-topping events and king tides. Equally important is their value as habitat matrix to threatened Bay Area shorebirds.

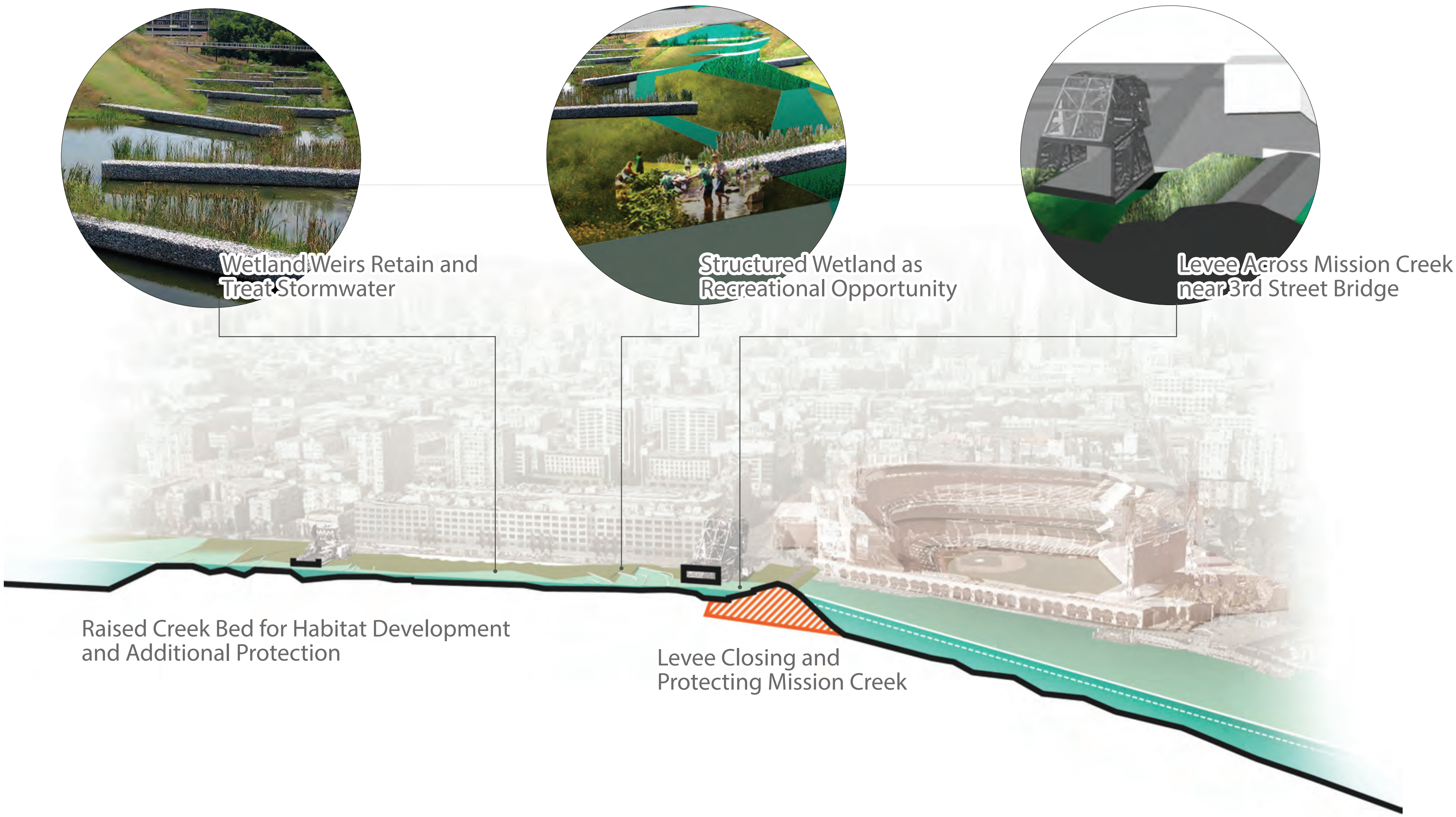


FIG 5–7: CREEK CONCEPT 3 OPPORTUNITIES AND DETAILS

Note: This image depicts a conceptual idea and is not intended to be authoritative regarding proposed intensity of development or preferred mitigations regarding sea level rise. Further study and coordination between interested parties will be required to further refine these concepts toward a viable proposal.

Bay Shoreline Concept 1 is a straightforward earthen levee proposal along the existing waterfront

BAY SHORELINE CONCEPT 1: PERIMETER SHORELINE PROTECTION

BAY SHORELINE CONCEPT 1 OVERVIEW

THE CONCEPT:

Build a levee and/or sea wall along the existing shoreline that will protect Mission Bay

PROS:

- ✓ Comparatively low cost alternative
- ✓ Limited space requirements
- ✓ Easy to fit in existing infrastructure
- ✓ Robust: Limited failure risk

CONS:

- ✗ Visual barrier along the waterfront
- ✗ Piers not protected
- ✗ Sets Mission Bay up for a future below sea level

The first bay shoreline concept builds on Creek Shoreline Concept 1 by building a levee along the perimeter of the shoreline to reduce the chance of inundation to Mission Bay. Perimeter protection is very common around the world, including along much of the San Francisco Bay shoreline, so this experience can easily be leveraged into the design of such a levee in Mission Bay, resulting in a robust solution.

This concept requires very little area to accommodate the project footprint, and the levee could be widened at locations where more space is available.

As with any of the proposed measures land subsidence and seismic activity will affect the performance of this concept, as levees can be susceptible to liquefaction during an earthquake, as such this must be accounted for and appropriately mitigated in project design. If, for example, the levees are designed to accommodate three feet of sea level rise by 2100, they would need to be four to seven feet high, depending on the elevation of the existing shoreline and on the target "level of protection." The target level of protection that accounts for a 1% storm will indicate a levee that is markedly higher.

Levees become de-facto platforms for engaging with the body of water - they are landscape design and public amenity opportunities with a view.

Utilizing sloped and stepped plazas and boardwalks turns hard shorelines into urban destinations.

This adaptation strategy is preparing Mission Bay for a future below sea level as bay water levels continue to rise. Given the high value of real estate and critical infrastructure present (e.g. the hospital and the main connection via Third Street), failure or overtopping of the levee or sea wall would have severe consequences with potentially significant losses. Stormwater in Mission Bay will no longer be able to flow under gravity to the bay and would have to pumped out.

As the intervention of new perimeter protection would all happen on land, this measure does not provide protection for the piers, in fact with a raised shoreline and no adaptation to the piers accessibility could be impeded.

Beyond single purpose flood protection, a levee could be used to enhance recreation, acting as a green corridor that connects Pier 48 to Pier 70 on which people could walk, run, skate close to the shore and away from regular road traffic.

Depending on the design this new levee along the shoreline could still provide an opportunity for new small wetland development. This can be done by changing the gradient to have a gentler slope creating a terraced slope. However due to the high flow velocities of the bay along the Mission Bay shoreline, protective measures would be required to reduce erosion and keep a newly created greener shoreline in place.

Although there is an opportunity for new shoreline recreation the new levee would create a visual barrier for open views to the water and the 'water experience' will be less than in the existing situation.

Traditional levees can be positioned as game-changing social infrastructure that reinvests in our waterfronts.

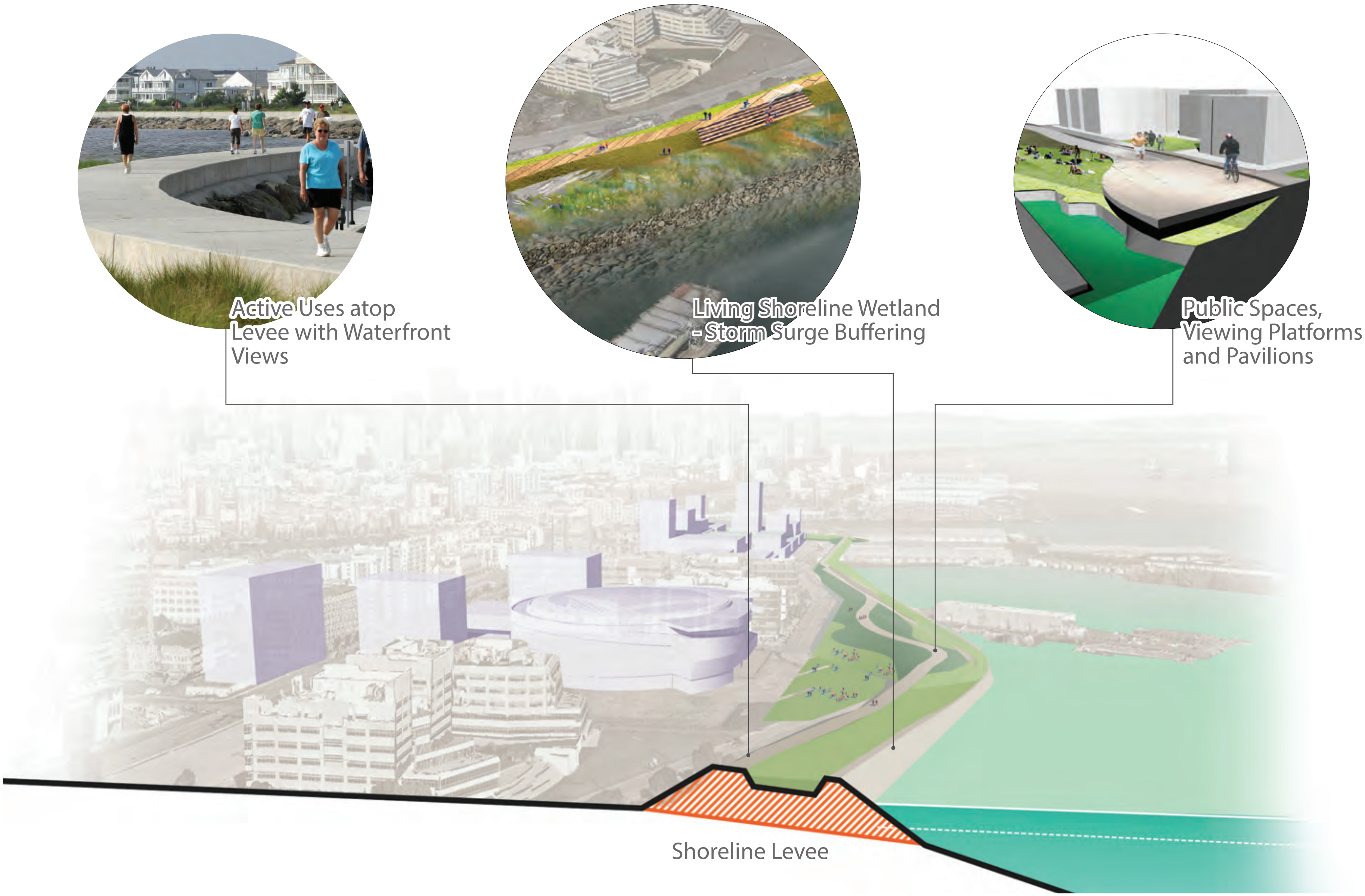


FIG 5–8: BAY SHORELINE CONCEPT 1 OPPORTUNITIES AND DETAILS

Note: This image depicts a conceptual idea and is not intended to be authoritative regarding proposed intensity of development or preferred mitigations regarding sea level rise. Further study and coordination between interested parties will be required to further refine these concepts toward a viable proposal.

Bay Shoreline Concept 2 involves landform and infrastructure changes deeper into the cityscape

BAY SHORELINE CONCEPT 2: CITY LEVEE

BAY SHORELINE CONCEPT 2 OVERVIEW

THE CONCEPT:

Create a wide multipurpose levee along the existing shoreline that provides opportunities for integrated commercial and residential development.

PROS:

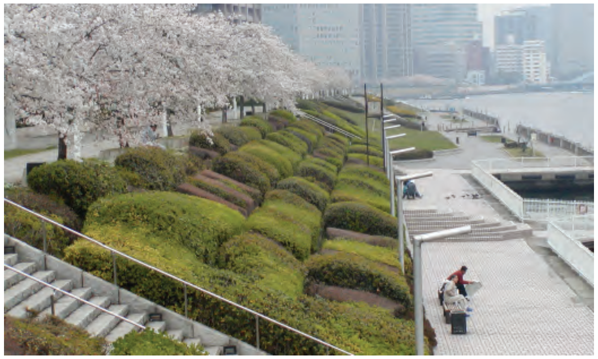
- ✓ Fail safe
- ✓ Creates opportunities for return on investment for dual functions (development and protection)
- ✓ New Bayfront residential development possible

CONS:

- ✗ Expensive to implement
- ✗ Piers not protected
- ✗ Need to integrate with existing buildings

The City Levee concept would create a wide multipurpose levee along the existing shoreline designed to accommodate sea level rise, and reduce inundation from storms and storm surge well beyond 2100. The measure would be a continuous raised landmass along the waterfront that serves as a levee. However, because the levee would be so wide, it would also support opportunities for development on top of the levee, including residential and commercial buildings, and could be integrated into the natural and urban fabric of the existing shoreline. The proposed Mission Rock development is intended to be 55” higher than the current land elevation, creating a land mass that would connect well to the concept of a multi-purpose levee.

While dubbed City Levee in this study in other parts of the world this concept is often referred to as super levee. The image below shows a super levee along a river in Tokyo in Japan.



The Super Levee concept was first tested (with success) in Tokyo Japan. The elevated cityscale integrated with existing buildings and provided a richly textured public environment.

Proposed waterfront resiliency measures in Amsterdam offer multi-use strategies that add further value along narrow coastline real estate.

As new buildings would be on top of this new elevated land, the new City Levee must be designed and built high enough to deal with significant rates of sea level rise, well beyond 2100. Already existing buildings in Mission Bay would have to be integrated into the design of the city levee. This could be done through changes in the way lower levels of buildings are used or in some instances the city levee could be less wide (e.g. the width of Terry Francois Boulevard) to accommodate existing development.

The multipurpose levee requires larger investment to elevate the entire land area between the shoreline and Third Street. However, this type of measure would reduce flood risk considerably, is considered robust, and ensures opportunities to develop on top of the levee. This could provide additional opportunities for a public-private partnership to finance flood protection for the city. For example, residential, commercial, recreational, and infrastructural projects can be better integrated in this muncipial landform. This, in turn, can yield programming opportunities and partnerships with the city that may be able to generate revenue and enhance streetlife. The vulnerability of the piers is not addressed in this approach, so these would need to be adapted with additional measures.

As in concept 1 (the perimeter shoreline protection) the city levee provides opportunities to develop a tidal ecosystem with a gradually sloping gradient on the bayshore side. The open space between and in front of the buildings on top of the urban flood protection infrastructure could be transformed into a high quality park.

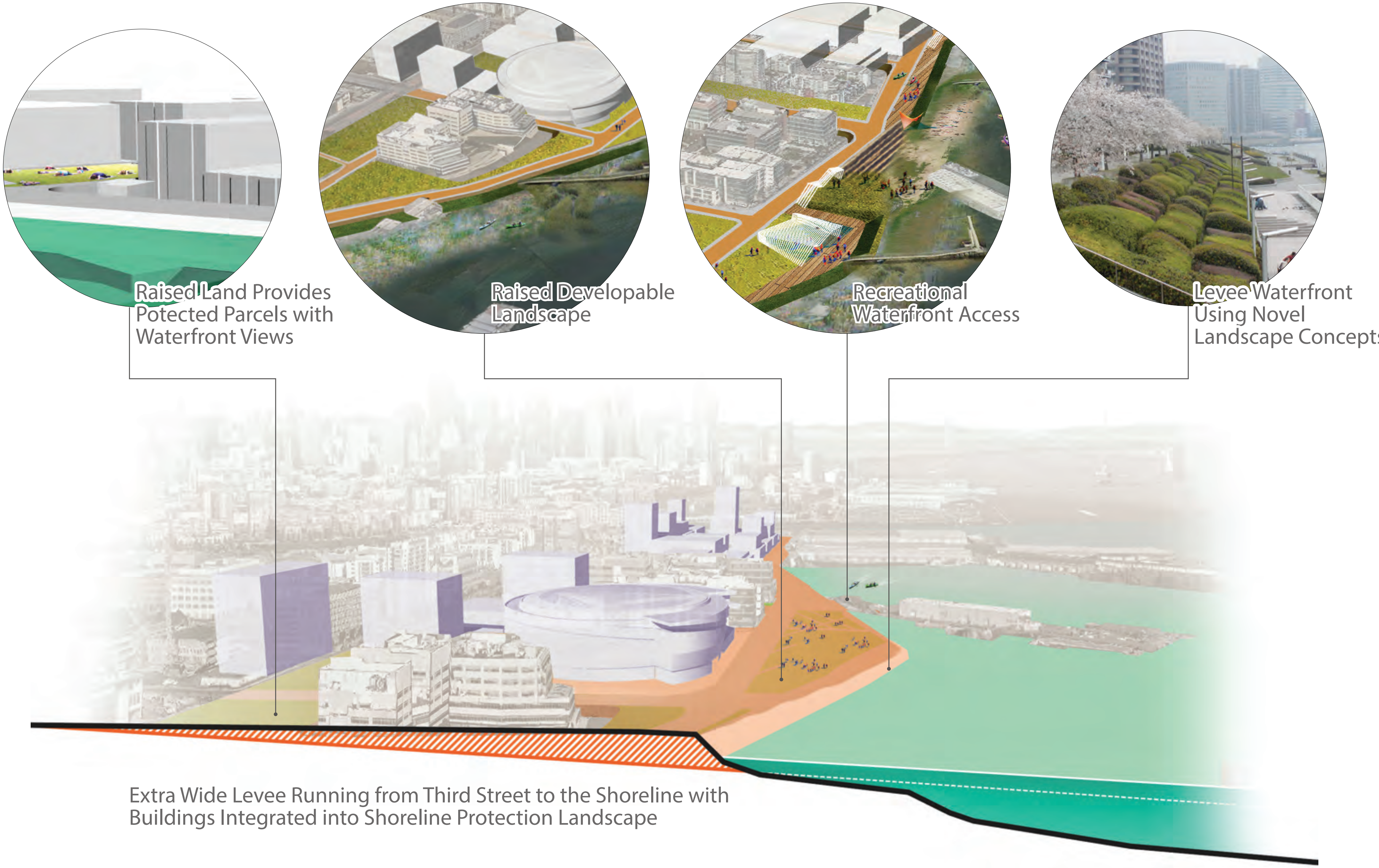
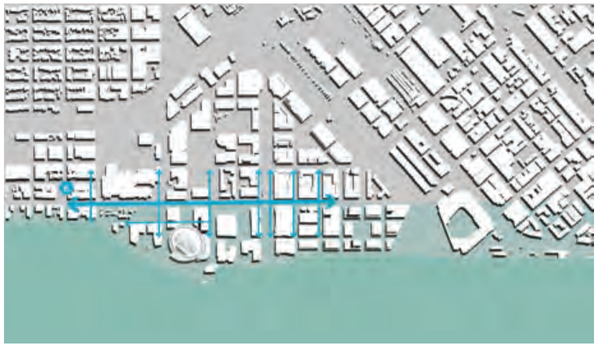


FIG 5–9: BAY SHORELINE CONCEPT 2 OPPORTUNITIES AND DETAILS

Note: This image depicts a conceptual idea and is not intended to be authoritative regarding proposed intensity of development or preferred mitigations regarding sea level rise. Further study and coordination between interested parties will be required to further refine these concepts toward a viable proposal.



Bay Shoreline Concept 3 positions water protection at 3rd street as it is elevated and converted to the primary line of defense as a dike

BAY SHORELINE CONCEPT 3: ELEVATED THIRD STREET

BAY SHORELINE CONCEPT 3 OVERVIEW

THE CONCEPT:

Use Third Street as the main line of protection by connecting buildings, roads and elevated land to create a line of protection. Residential and commercial property on the bayward side would have to be modified to cope with temporary inundation.

PROS:

- ✓ Precedent for 'living with water'
- ✓ Unique residential and commercial waterfront development opportunities
- ✓ Third Street transit lines can be embedded within elevated roadway-barrier.

CONS:

- ✗ Bridges will have to be raised or replaced in the longer term
- ✗ Long line of defense
- ✗ Need for modification of Mission Bay interior drainage
- ✗ Expensive and complicated to implement

This adaptation concept will embrace how Mission Bay and San Francisco could be "living with water" by integrating structural and non-structural adaptation measures along Third Street. Third Street itself would be the main line of flood protection by connecting buildings, roads and elevated land to create a line of defense. Meanwhile, the residential and commercial development on the bayward side of Third Street could be "flood-proofed" or modified to deal with temporary inundation. Existing light rail on Third Street could be integrated within an elevated roadway-barrier.

This approach minimizes the scope and scale of sea level rise impacts - as opposed to entirely suspending them. Some buildings should be retrofitted with materials and uses in mind that could adapt to potential flooding. More specifically, buildings would permit flooding from high water levels on the ground floor; most activity and transportation would occur on the second floor,

Haffen City in Hamburg, Germany exemplifies how new urban development can growth in close relationship to water.

above King Tides. This would prevent major damages and business interruption during floods. Building access and evacuation would also be on the second floor.

Pedestrian walkways could connect buildings on the second floor and will ensure that business can continue as usual in high tide situations. The current streets running from Third Street to the Bay Shoreline would be gradually sloping.

Top: The west side of an elevated Third St can provide a unique retail and pedestrian setting. Bottom: Floodproof buildings can be novel and architecturally charismatic.

Modern water-resilient architecture in Venice has positioned that community for a secure and vibrant 21st century.

This concept is modeled after Hafen City in Germany, which functions similarly as described above and is inundated a few times a year.

While creating the opportunity for a real 'living with water' experience the implementation of this approach will be complex and time consuming. It does however allow for the city to communicate that living with rising sea levels might not mean that water is stopped at the shoreline, but can enter the city in a controlled and safe way. On the bayward side available land near the shoreline can be configured for more tidal habitat and other areas can be raised depending on acceptable flood frequencies. It can enable the development of salt marsh habitat that mimics conditions of tidal marshes. It can also help maintain tidal flats and open water habitat. Like the Port's Pier 94 wetlands, small patches of tidal marsh can be ecologically important and may provide especially valuable habitat to certain plant and animal species. As satellite habitats, small wetlands may be very important in maintaining populations of wetland-associated animals; this way, they can serve an educational purpose for the general public for larger bay area ecosystem restoration activities.

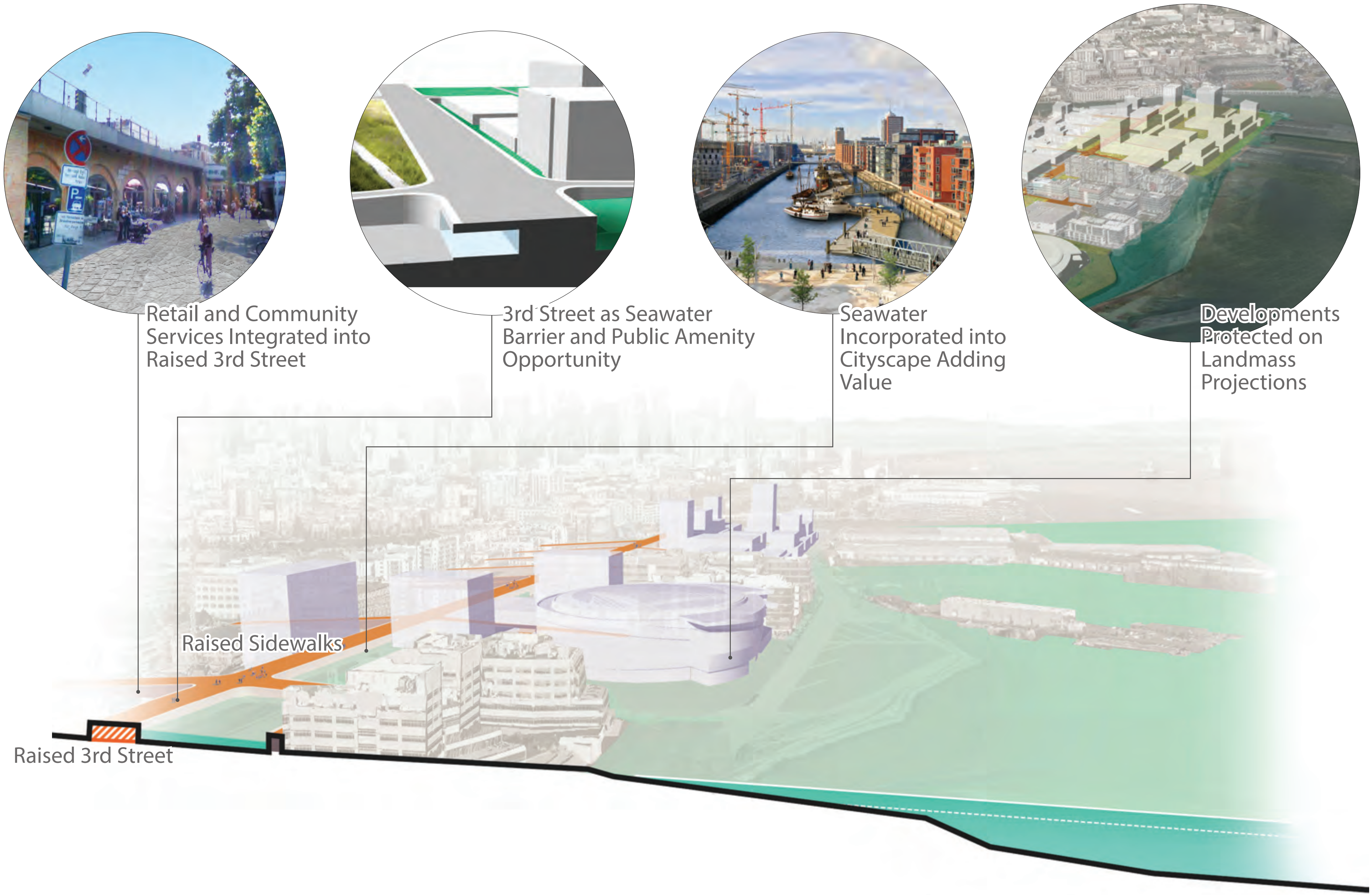


FIG 5–10: BAY SHORELINE CONCEPT 3 OPPORTUNITIES AND DETAILS

Note: This image depicts a conceptual idea and is not intended to be authoritative regarding proposed intensity of development or preferred mitigations regarding sea level rise. Further study and coordination between interested parties will be required to further refine these concepts toward a viable proposal.

Bay Shoreline Concept 4 is a bold proposal to build an outlying levee as a second waterfront ready for use as open space and development opportunity

BAY SHORELINE CONCEPT 4: NEW WATERFRONT

BAY SHORELINE CONCEPT 4 OVERVIEW

THE CONCEPT:

Create a continuous landmass in the Bay outboard of the piers, parallel to the existing shoreline, to be used for new commercial and residential development, recreation and habitat development. The existing shoreline will not be modified.

PROS:

- New ecological transition zone
- Opportunity for public private partnerships for funding of sea level rise adaptation
- New waterfront commercial and residential development opportunities
- Could provide protection to the piers
- Limited failure risk

CONS:

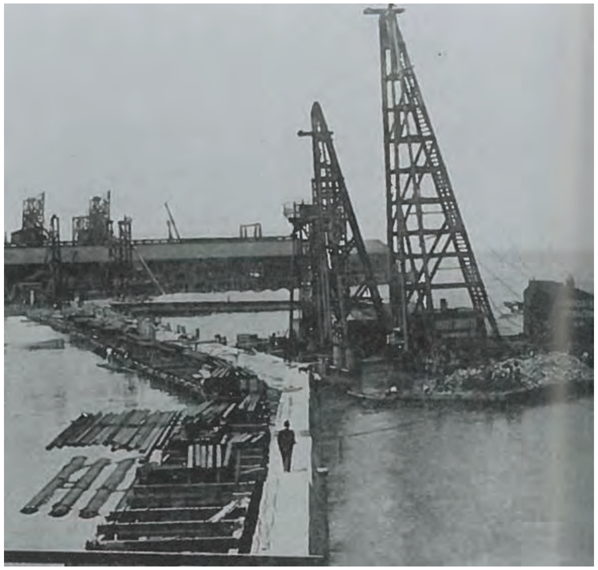
- Expensive and complicated to implement
- Requires filling of the Bay

This concept utilizes a multi-purpose-levee to build new land outboard of the piers that prevents high water from inundating Mission Bay, while providing opportunities for new commercial and residential development, recreation and habitat. The existing shoreline does not necessarily have to be modified, but can be changed to become part of the larger development.

Similar to the other adaptation measures, this type of approach could be designed to accommodate sea level rise into and beyond 2100. And while this might sound like a radical approach, this concept is in a way very similar to how San Francisco's current sea wall was built with the exception that it would not be the intention to fill in all the land between the existing and the new shoreline.

Developing the multi-purpose levee would create an artificial lagoon, open water between the newly created landmass and the current bay shoreline. Storage of fresh water after intensive rain is possible and could be let into the bay through gravity flow or pumped out. As discussed before

The San Francisco waterfront was reconfigured in layers that began with an outlying breakwater serving shipping and development.



The construction of the original San Francisco Embarcadero was a bold endeavor that serves as a model for future urban resiliency measures.

this water storage function is important as parts of the city will be below sea level at some point in the future and it will require massive pumps to pump out rainwater at the same pace with which it is falling out of the sky.

Instead of a fresh water basin the water body in between the existing and new shoreline could also be developed as a tidal lagoon with a controlled and potentially brackish water environment to provide tidal ecosystem benefits similar to other Bay Area ecosystems with opportunities for public access and recreation.

Sea Port City utilizes new waterfront development to help fund shoreline hardening and protection strategies while reforming an underutilized coast as new open space.

Dutch housing examples suggest ways to create value and place atop any new waterfront development.

Among all the concepts presented this will be by far the most challenging concept to implement and permit. This concept however also provides opportunity for new public-private partnership for financing and development, similar to the concept for Lower Manhattan that was discussed earlier.

Among all concepts presented, Concepts 3 and 4 are among the most complex to implement. This Concept allows the City to preserve the relationship between current waterfront development and the water's edge (via the interior lagoons), while creating a new shoreline that effectively protects the City from flooding. It is designed from scratch to fully integrate development, open space, natural habitat, and water access. In essence, it offers San Francisco the most flexibility to create a shoreline that is more than a defensive fortification.

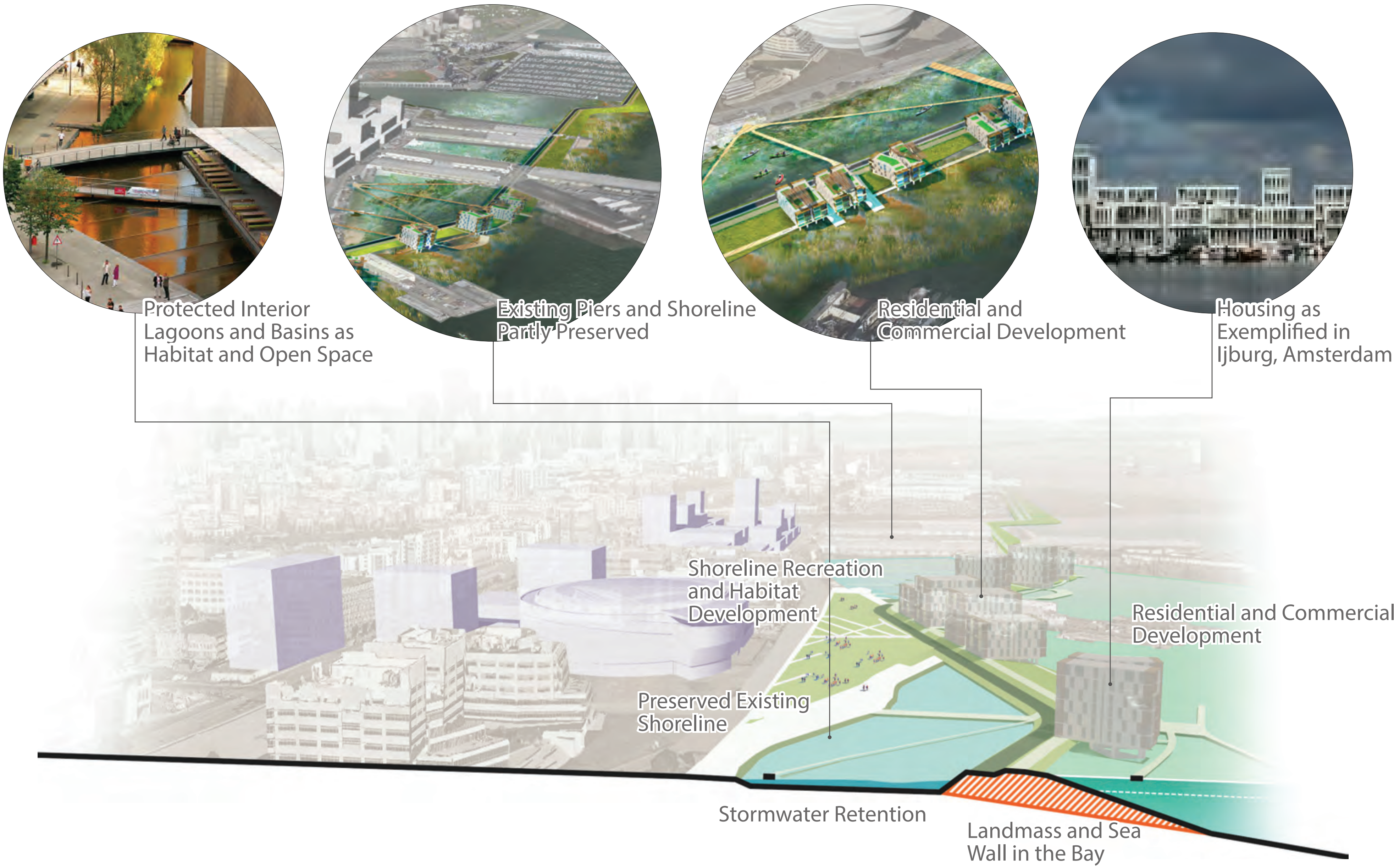


FIG 5–11: NEW WATERFRONT CONCEPT 4 OPPORTUNITIES AND DETAILS

Note: This image depicts a conceptual idea and is not intended to be authoritative regarding proposed intensity of development or preferred mitigations regarding sea level rise. Further study and coordination between interested parties will be required to further refine these concepts toward a viable proposal.

Images of the historic Pier 48 - among three that are threatened by sea level rise in this neighborhood.

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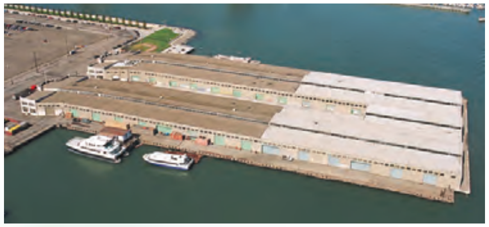
PREPARING A RESILIENT PIER

THE PIERS: MANAGING A UNIQUE LOCAL ASSET

The vulnerability assessment showed that San Francisco's piers are vulnerable to high water. At present, high water impacts below-deck utilities and the structural integrity of the piers. In the longer term, under a scenario that combines a 36-inch sea level rise with a 100 hundred year storm, the pier decks themselves could be inundated.

In the previous adaptation chapter most of the bay shoreline adaptation concepts showed that it is hard to incorporate the piers into the shoreline protection measures. Only Bayward Development (Bay Shoreline Concept 4) can significantly protect the piers. In this scenario, the piers would reside behind a stormwater protection levee, and would, nevertheless, lose most if not all of their maritime functions. Three pier adaptation concepts are envisioned which are described on the following pages. Bay Concepts employing a levee or raised waterfront can incorporate the pier bulkhead buildings as historic resources. While the project area only has three piers touching the Mission Bay shoreline these adaptation concepts can be applied universally along the San Francisco waterfront and across the Bay Area where there are other fixed historic assets.



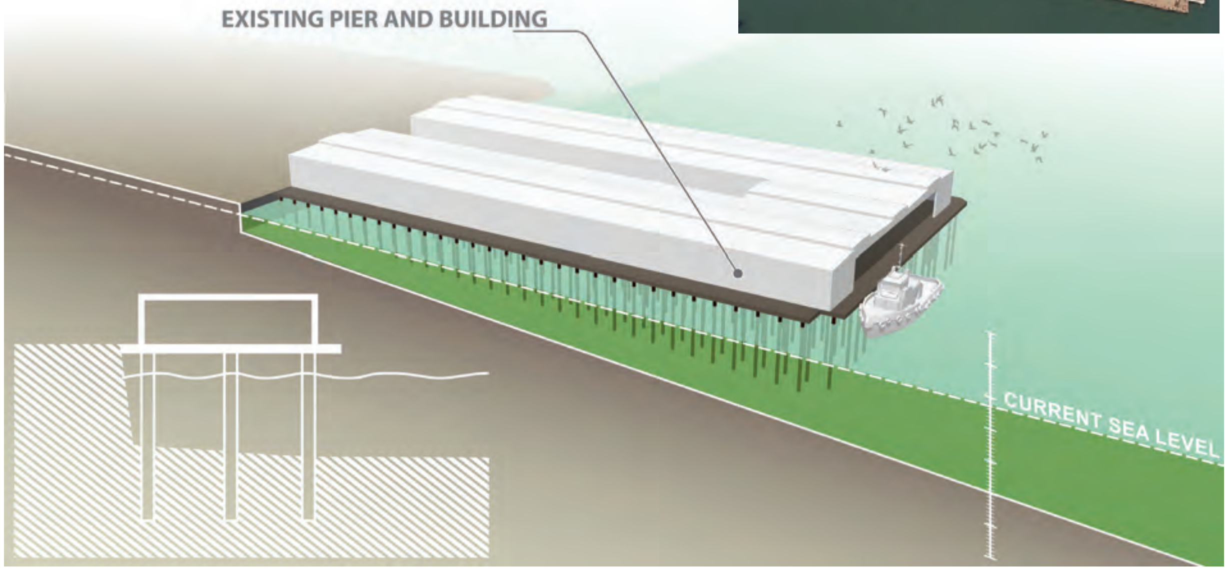


FIG 5–12: PIER EXISTING CONDITION ILLUSTRATION

PIER OPTION 1: RETROFIT FOR OCCASIONAL FLOODING

The identified vulnerabilities of the piers can be mitigated through retrofitting or so called 'flood proofing' to make them more resilient to occasional flooding. There are different ways to do this. For example: below-deck utility infrastructure is moved to be above-deck so that they are no longer exposed to wave action and high tides. The sheds on the pier could be flood proofed so that they can withstand some level of inundation. And last, the use of the pier by tenants could change so that (commercial) activities are mobile so that when high waters are expected these activities can temporarily move. By far the biggest challenge for this alternative will be to deal with uplift of the pier deck during high waters. Given that most of the piers are 70 to 90 years old the piles supporting them and the connection with the pier deck will be impacted by wave and tidal activity.

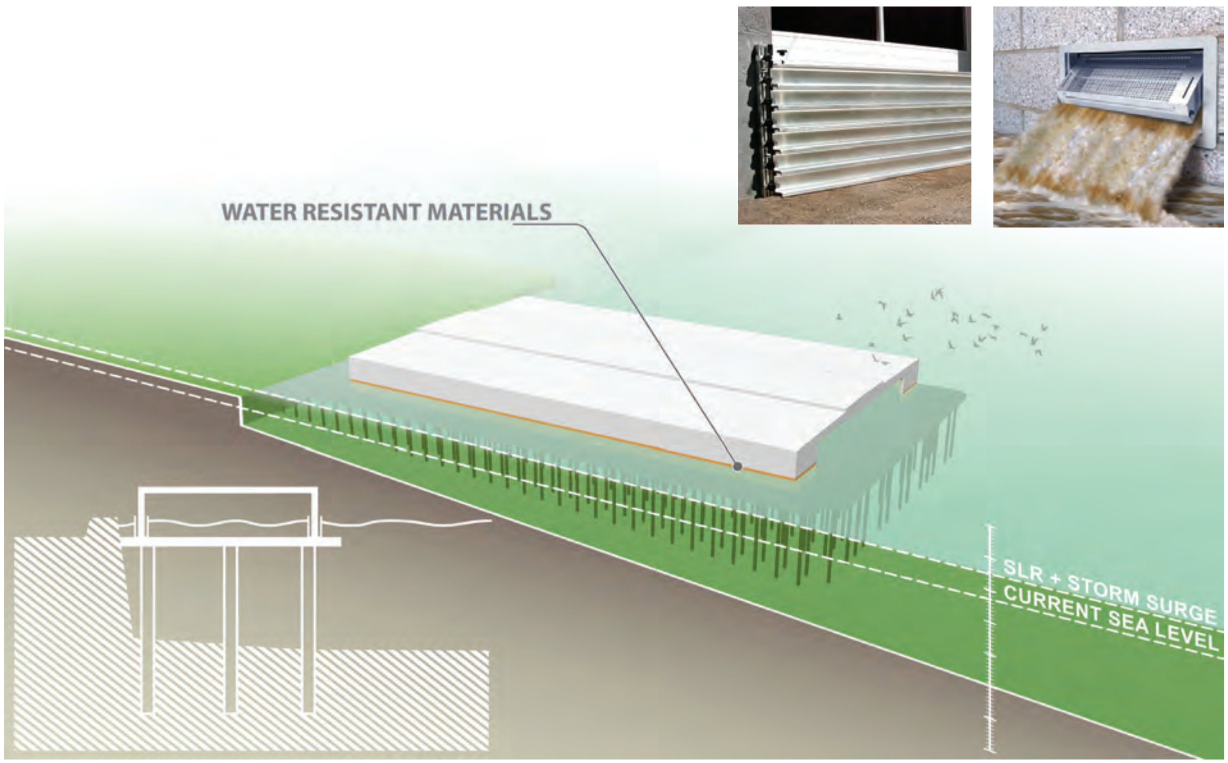


FIG 5–13: PIER OPTION 1- RETROFIT FOR OCCASIONAL FLOODING

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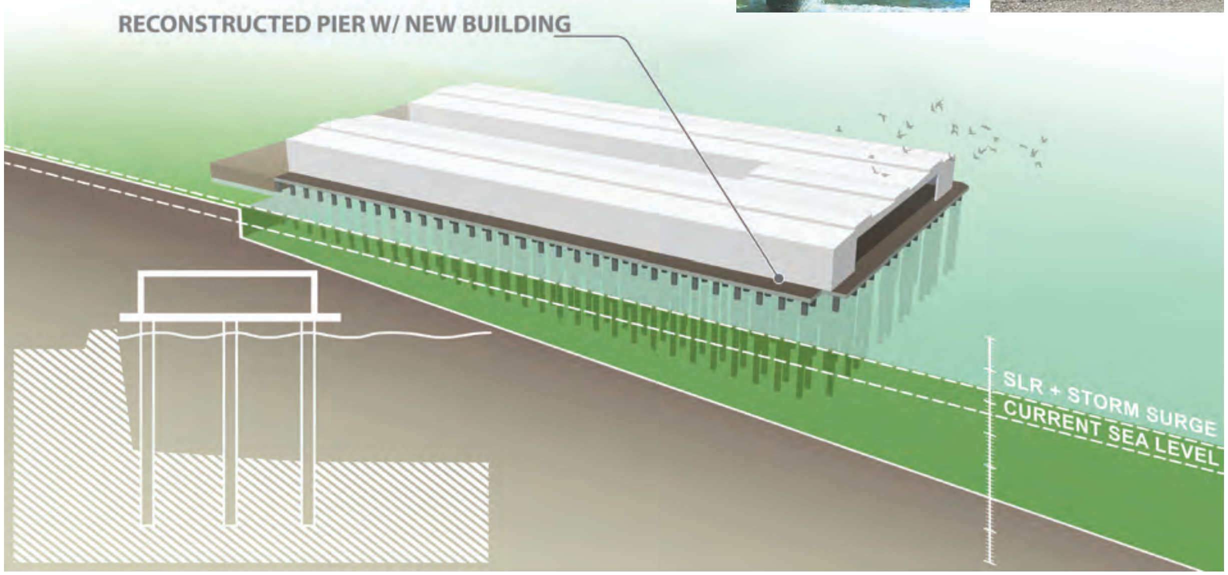
PIER OPTION 2: REBUILD

As is currently done with other some other piers in the city one alternative could be to raise and rebuild the piers. Although expensive, this alternative would mean that the commercial and maritime activities can be maintained and a cultural resource preserved. The piers can continue to serve as a revenue generator through long term leasing of the pier sheds. Examples of recent pier and sea wall rebuild projects outside of Mission Bay are the Pier 43 Bay Trail Link Project and the rebuild and raise of Brannan Street Wharf.

Total replacement of piers raises issues regarding status of historic and cultural assetts. This needs to be considered in any replacement program.

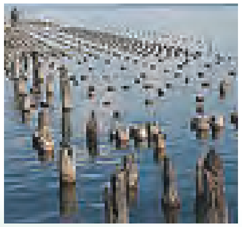


Note: This image depicts a conceptual idea and is not intended to be authoritative regarding proposed intensity of development or preferred mitigations regarding sea level rise. Further study and coordination between interested parties will be required to further refine these concepts toward a viable proposal.

FIG 5–14: PIER OPTION 2- REBUILD

PIER OPTION 3: MAINTAIN STATUS QUO

Maintain status quo means that piers will remain in use for as long a practically possible and safe. However as it is extremely costly to retrofit or rebuild piers, some might have to be given up, similar to how this has happened in the past. This would mean that revenues generated by the piers in question will go away and historic resources will be lost. This approach may be thought of as strategic retreat from the shoreline.



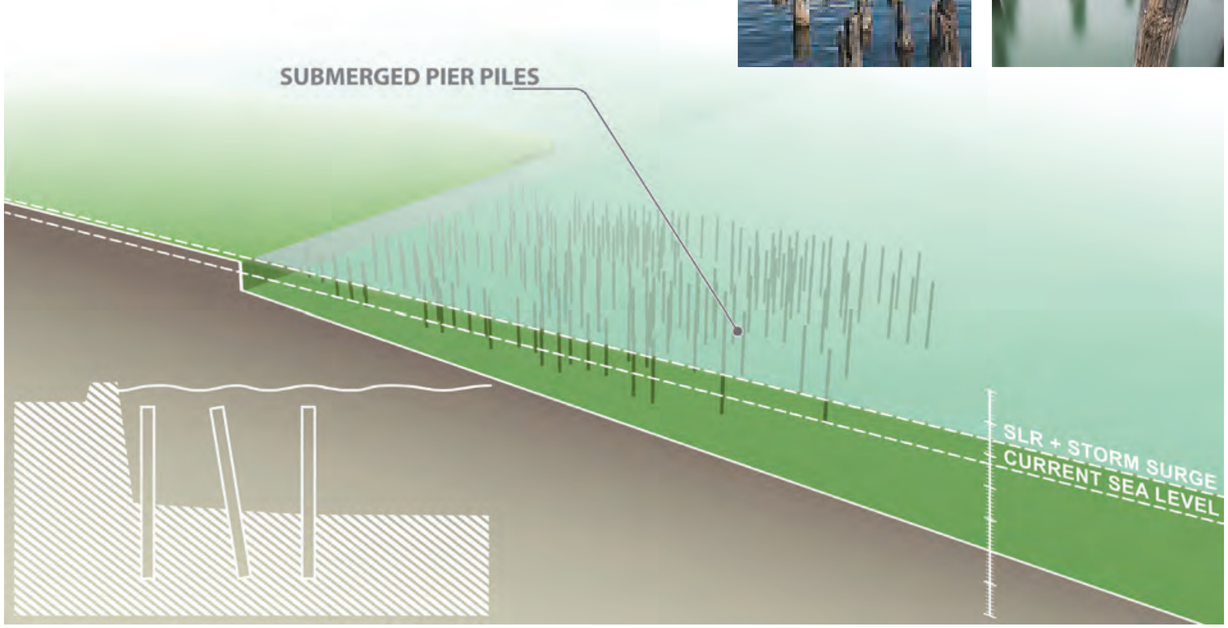


FIG 5–15: PIER OPTION 3- MAINTAIN STATUS QUO

Note: This image depicts a conceptual idea and is not intended to be authoritative regarding proposed intensity of development or preferred mitigations regarding sea level rise. Further study and coordination between interested parties will be required to further refine these concepts toward a viable proposal.

CHAPTER 6

IMPLEMENTATION, PLANNING + CONCLUSIONS

A Citywide Adaptation Plan would evaluate all risks, prioritize investments, while maintaining the city's competitive edge. Such a plan would encourage and integrate innovative, interdisciplinary design thinking and solutions for adaptation around Mission Creek and Mission Bay.

PLANNING AND IMPLEMENTATION

How do we get from now, to resilient? Adaptation will not happen overnight, and fortunately for San Francisco, neither will sea level rise. Though seas have not risen significantly to date, we know they will, and it will take some time to design, permit, fund, and construct the larger infrastructure needed to manage future high water.

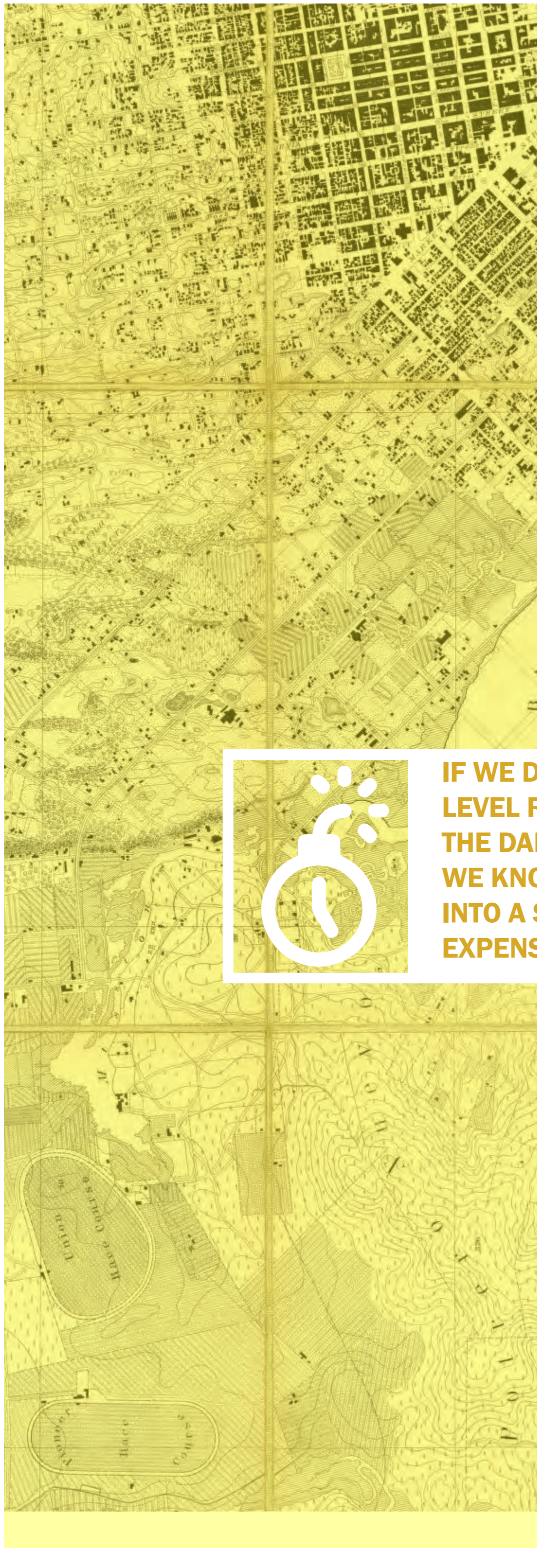
Going forward, local leaders can build upon what has been started here in the Mission Bay district and along Mission Creek. After identifying goals and objectives that move the region toward the future it wants, identifying the steps necessary to get us there will be critical. For example, what kind of funding will be required to construct, operate, and maintain new infrastructure or flood proof existing urban cores? What regulatory or permitting processes enable or inhibit implementing that vision? What kind of governance will be required to ensure long term success in adaptation and reducing flood risk? Are we using a systems approach and considering redundancy in the adaptation strategy? Is there more than one line of defense to ensure safety for most critical assets, populations, and functions?

Much of California and San Francisco, by 2100, will be quite different from what is here today. The City has already changed rapidly over the last few decades; the 1970s' San Francisco, for example, likely could not have envisioned Silicon Valley as it is today. Even more recently, a 1990s San Francisco may not have envisioned the lively Market Street and SOMA district that has developed in the last several years. These proposed strategies for the shoreline have a precedent deep in San Francisco's history. The city's sea wall, though mostly hidden from view, was envisioned in the late 1800s and has served to protect San Francisco's bustling waterfront for decades. Similarly, while creating new land may seem new to most of us, much of Mission Bay and San Francisco are in fact, built on reclaimed land from the last century. Though society has moved away from many of these policies, most notably bay fill, even regulatory agencies like BCDC that were created to stop bay fill are reexamining this issue in light of sea level rise.

Since the Save the Bay movement of the 1960s, the region has diligently worked to protect Bay waters from needless fill and development. We face a future with a growing Bay, which, if left unchecked, will inundate neighborhoods and critical habitat. We must reconsider our hard-line stance against fill and evaluate its strategic use to shore up ecosystem habitat, and to retain vibrant waterfront neighborhoods, without sealing them off from the water by seawalls or levees.

Adaptation will happen in phases, where near term solutions will be implemented to manage flood risk now, and the long term goals and objectives, will help drive measures for the future. Those ideas that may not be well accepted today by all stakeholders will have time to settle in the minds of San Franciscans and marinate--and their acceptance may grow along with the city's understanding and motivation to take action on sea level rise. Beginning the adaptation process now enables multiple disciplines and stakeholders to come to the table and agree upon a common vision for today and beyond 2100; it enables designers and planners to integrate adaptation into the City's urban fabric rather than adding it on after. Lastly, and very importantly, beginning adaptation now enables the development of creative partnerships and financing mechanisms to provide the revenue stream necessary to implement adaptation.

When it comes to managing hazards and adapting to risks, California is ahead of the curve. Our history in dealing with and preparing for earthquakes is seen as an example for other states to adopt around the country. San Francisco has an opportunity (and precedent) to be a leader in sea level rise adaptation as well.



KNOWING HOW TO ADVANCE THE CAUSE

Sea level rise adaptation is not going to be easy given the wide range of local interests, increasingly limited financial resources, and a national paradigm rooted in reacting to disasters rather than preventing them. However, reducing risk to life and property, and preserving one of San Francisco's finest assets (its waterfront) is an easy decision. Though cities tend to delay action because they doubt the return on their investment in flood management, studies show that one dollar of investment in mitigation now avoids four dollars of disaster recovery later. Deciding early therefore, enables both choice in how to invest and reduced costs. Investments not only pay off because of damages avoided, but also because of reduced flood insurance rates, and because people will know San Francisco is safe and resilient, which attracts investment and improves property values.

IF WE DO NOT PLAN TO ADAPT TO SEA LEVEL RISE, WE ARE FORCED TO ACCEPT THE DAMAGES AND DISRUPTION THAT WE KNOW ARE IMMINENT, AND BACK INTO A SOLUTION THAT IS LIKELY MORE EXPENSIVE, AND NOT PREFERRED.

Adaptation will require utilizing the full range of available tools and the best available science, from heavy gray or "green" infrastructure with multi-purpose levees that reduce the frequency of floods, to regulatory, policy, or insurance-based measures that enhance adaptability of individual assets and reduce the consequences of floods. Adaptation can provide other opportunities for improving our City and generating a higher return on investment. Providing the public more access to the waterfront, encouraging unique private-public partnerships, and new financial or regulatory options are only a few of the opportunities available to us. Decisions will need to be informed by a clear understanding of the risks and trade-offs amongst alternatives.

Adapting to Sea Level Rise in Mission Bay is but a cross section of what is happening piecemeal across the Bay Area. The design process of adaptation planning itself will require engaging many stakeholders to develop buy-in and minimize resistance toward progress. It requires leadership, but provides an opportunity to bring together diverse interests and stakeholders around a common challenge, develop a common vision, and come up with solutions that work for most of us. In the Netherlands, this century-old practice is called "Poldering" and of all places in the United States to embrace and implement this model, San Francisco is at the forefront. Delaying or avoiding adaptation means accepting the damage and disruption that we know are imminent - we would back into a solution that is likely more expensive, and less preferable.

Building resilience in San Francisco is not just about the flood hazard or about the direct economic damages; it is about maintaining San Francisco's competitive edge as a global financial center, and preserving one of the world's finest places to live. Though the Bay Area has a challenge ahead with rising sea levels and the uncertainty associated with climate change, it is a region with both a vision and experience in hazard adaptation. What will distinguish it from other global cities threatened by natural hazards is whether San Francisco Bay and its leaders can get out ahead of the disaster by reducing flood risk now and planning for the future.

NEXT STEPS

In order to maintain the enthusiasm around this project, it is recommended that work begin towards a Citywide Adaptation Plan, consistent with the recently published San Francisco Sea Level Rise Adaptation Plan. This plan would encompass the entire bay shoreline, but also develop near-term adaptation plans for high-risk shoreline assets and geographic areas. Such a plan should encourage and integrate innovative, interdisciplinary design thinking and solutions for adaptation.

A Citywide Adaptation Plan for San Francisco would involve conducting a detailed risk assessment that evaluate the potential damages to the city, assess tolerable risk levels to establish goals for an appropriate level of flood protection, investigate the feasibility of different adaptation measures (projects), prioritize investments based on necessity, risk reduction and stakeholder preferences, include a plan for financing and lays out a roadmap for how to address key regulatory challenges. Despite those challenges, the choice is clear, Bay Area citizens and leaders cannot afford not to take action.

KEY MESSAGES OF THIS REPORT

L1 **VIABLE OPTIONS**

There are many different ways that Mission Creek and Mission Bay can be protected from future sea level rise.

L2 **MULTIPLE BENEFITS**

Well-designed adaptation can not only protect our city, but can also enhance public enjoyment of our waterfront.

L3 **ANTICIPATION**

Planning and adaptation now will be much less expensive than incurring damages in the future.

L4 **GOING FORWARD**

The alternatives presented suggest a variety of public realm preferences and implementation methods that will require further evaluation.

APPENDIX I

DEVELOPMENT OF THE POST-SETTLEMENT DIGITAL ELEVATION MODELS AND SEA LEVEL RISE MAPS

The maps in this report represent state of the art of sea level rise mapping, and provide the highest resolution and most comprehensive inundation mapping to date for the shoreline of the City and County of San Francisco. These adaptation concepts can and should be updated to reflect more accurate maps that will surely come in the future.

SEA LEVEL RISE MAPS - DEVELOPMENT OF THE POST-SETTLEMENT DEM

Inundation maps of the Mission Creek area have recently been prepared by the San Francisco Public Utilities Commission (SFPUC) in conjunction with the Sewer System Improvement Program (SSIP 2014). These maps represent state of the art of sea level rise mapping in the city and provide the highest resolution and most comprehensive inundation mapping to date for the City and County of San Francisco shoreline (with the exception of the SFO airport).

The maps utilize a 1-meter horizontal grid resolution digital elevation model (DEM) based on the 2010/2011 California Costal Mapping Program LiDAR, surface water elevations (SWELs) are based on data from FEMA's San Francisco Bay Area Coastal Study (FEMA 2013), which is based on a 31-year simulation of hydrodynamics and storm surge. In addition to static sea level rise levels, the inundation maps also consider high tide events (mean higher high water, MHHW) and a range of storm events, from 1-year to 100-year events. In this study, SWELs were taken for the 100-year event at MHHW with sea level rise in the year 2050 and 2100, resulting in water level increases of +52 inches and +77 inches, respectively.

While SWELs could be taken from prior studies, recent development in the Mission Creek area has rendered the existing DEM obsolete locally due to street level grade improvements. Furthermore, the existing DEM does not include the piers at Mission Creek, specifically Piers 48, 50, and 54. As such, an assessment of inundation in the area required the DEM to be updated with development drawings and pier elevations and the flooded depths to be recalculated based on these new elevations.

However, since this study looks at future sea level rise, future grade levels were used to account for 50 year settlement in Mission Bay post-development. This was performed using ArcGIS via the following steps:

1. Points marked in the Mission Bay Grading Plan (Catellus Development Corporation 2000) were digitized, along with the annotated existing elevations, initial as-built elevations, and expected settled elevations (50 years after construction).
2. The difference between the settled elevations and the LiDAR DEM was computed for each point.
3. The points were converted into a triangular irregular network (TIN) using ArcGIS. A TIN allows interpolation of values over an area. In this case the TIN was used to interpolate differences between settled elevations and the LiDAR DEM at the same resolution as the LiDAR DEM across Mission Creek.
4. The difference layer was added to the LiDAR DEM to generate an updated DEM with graded/settled ground elevations.
5. Pier outlines were drawn via satellite imagery and elevations were imposed based on (URS/AGS Joint Venture 2011) to create an updated DEM with both graded/settled ground elevations and pier elevations.
6. Inundation depths were calculated by finding the difference between the two SWEL cases and the updated DEM, then cropping any areas higher than the SWEL.

Regions lower than the SWEL but not hydraulically connected to a flood source (e.g. Mission Creek) were cropped from the inundation maps.