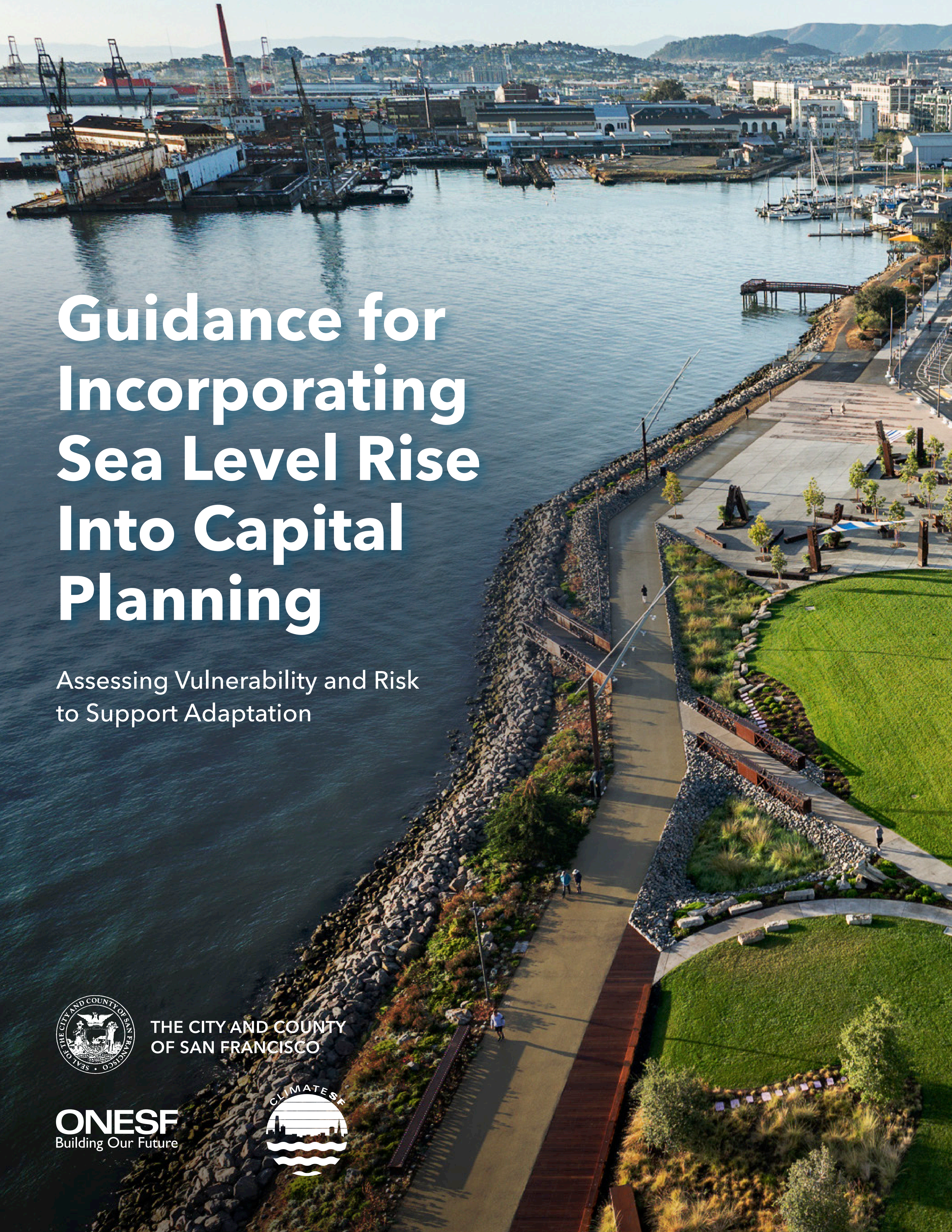

Guidance for Incorporating Sea Level Rise Into Capital Planning

Assessing Vulnerability and Risk to Support Adaptation

THE CITY AND COUNTY OF SAN FRANCISCO

ONESF
Building Our Future

CLIMATE SF

GUIDANCE FOR INCORPORATING SEA LEVEL RISE INTO CAPITAL PLANNING

ASSESSING VULNERABILITY AND RISK TO SUPPORT ADAPTATION

PREPARED BY THE CITY AND COUNTY OF SAN FRANCISCO

SEA LEVEL RISE COORDINATIONG COMMITTEE

FOR THE SAN FRANCISCO CAPITAL PLANNING COMMITTEE

Adopted on September 14, 2014

Revised on December 14, 2015

Updated on January 3, 2020

Updated on May 23, 2025

2025 Update by:
David Behar, SF Public Utilities Commission
Eric Vaughan, Office of Resilience and Capital Planning
Melissa Higbee, Office of Resilience and Capital Planning
Brad Benson, Port of San Francisco
Adam Varat, Port of San Francisco
Matthew Wickens, Port of San Francisco

Cover photo by Arianna Cunha

THIS PAGE LEFT INTENTIONALLY BLANK

GUIDANCE FOR INCORPORATING SEA LEVEL RISE INTO CAPITAL PLANNING

ASSESSING VULNERABILITY AND RISK TO SUPPORT ADAPTATION

TABLE OF CONTENTS

GUIDANCE FOR INCORPORATING SEA LEVEL RISE INTO CAPITAL PLANNING

ASSESSING VULNERABILITY AND RISK TO SUPPORT ADAPTATION

INTRODUCTION AND GOALS OF THIS GUIDANCE

In this section, you will find:

- A statement of project intent and goal
- The audience we are reaching with this guidance document
- How this report informs other city documents

Seas are rising globally due to climate change and will continue to rise at an accelerating rate for the remainder of the 21st century. As a consequence of rising sea levels, San Francisco will experience more frequent and severe coastal flooding than in the past. Areas that currently experience infrequent flooding will be inundated more often and more areas along our shorelines will be exposed to periodic flooding than in the past or today. Sea level rise, therefore, poses a pervasive and increasing threat along San Francisco's shorelines. As new infrastructure projects are planned along the shoreline, or existing assets are modified or improved, flooding due to rising sea levels – in combination with storm surge and wave run up – must be evaluated.

INTENT AND GOAL

This Guidance presents a framework for considering sea level rise within the capital planning process for the City and County of San Francisco (CCSF). The Guidance also outlines some key issues related to sea level rise adaptation planning; however, specific adaptation strategies and approaches are not provided. The range of available potential adaptation strategies is ever increasing and selecting the appropriate adaptation measures requires site and project specific information that will best emerge at a departmental level, informed by this Guidance, and coordinated through the CCSF capital planning processes. The goals of adaptation planning are to protect human life, health and property, do our best to ensure safety of development, maintain public access, and protect wetlands and other natural and cultural resources.

> *This document should be used by CCSF departments to guide the evaluation of projects considered for funding through the CCSF capital planning process. As with seismic and other natural hazards, an assessment of sea level rise vulnerabilities and a plan for addressing those vulnerabilities should be completed before a project is considered for funding. Consideration of sea level rise planning should begin at the initiation of every potential capital project.*

WHO IS THIS GUIDANCE FOR?

This Guidance provides direction from the Capital Planning Committee (CPC) to all departments on how to incorporate sea level rise into new construction, capital improvement, and maintenance projects. In addition to being useful to all departments, it can also be useful to the general public to see how the City is preparing for sea level rise in a coordinated and methodical way, updating with the latest data.

The Guidance identifies and describes four key steps for assessing and adapting to the effects of sea level rise in capital planning:

1. **Sea Level Rise Science Review:** What does the science tell us today?
2. **Vulnerability Assessment:** Which assets are vulnerable to sea level rise?
3. **Risk Assessment:** Of the vulnerable assets, which are at greatest risk to sea level rise?
4. **Adaptation Planning:** For those assets at risk, what can we do to increase their resilience to sea level rise?

This Guidance focuses primarily on the contribution of sea level rise to coastal flooding hazards. Some projects may require consideration of additional climate change impacts, such as changes in future precipitation events, to fully quantify climate change related vulnerability and risk.

Principles of Sea Level Rise Adaptation

- The **science** associated with sea level rise is continually being updated, revised, and strengthened
- The presence of redundancy in the system can increase its **adaptive capacity**
- City departments must develop and adopt a standard vulnerability assessment to aid **consistency** among CCSF departments

THE CAPITAL PLANNING COMMITTEE (CPC) AND PROCESS

The CPC makes recommendations to the Mayor and Board of Supervisors on all of the City's capital expenditures. The Committee is chaired by the City Administrator and includes all capital-intensive department heads as well as the President of the Board, the Planning Director, the Controller, and the Mayor's Budget Director.

Each year the CPC reviews and approves the City's Capital Budget and any issuances of long-term debt related to infrastructure projects. The CPC is also responsible for approving the City's 10-Year Capital Plan – a constrained long-term finance plan that prioritizes projects based on an approved set of funding principles. The Capital Plan provides a road map for ensuring the long-term safety, accessibility and modernization of San Francisco's public infrastructure and facilities. After the CPC approves the Capital Plan, it is sent to the Board of Supervisors and the Mayor for final adoption.

This Guidance provides CCSF departments with a step-by-step approach for considering sea level rise vulnerability, risk and adaptation planning within their department Capital Plans. The CPC, in turn, will use this Guidance to determine whether department Capital Plans have adequately addressed sea level rise vulnerabilities, risk and adaptation. If all departments follow this Guidance when developing their individual Capital Plans, the combined CCSF Capital Plan will increase the resilience of San Francisco's public infrastructure projects to adapt to anticipated sea level rise.

Some departments may want to address sea level rise on a larger sub-regional level rather than at a project level. For those instances where sea level rise has been addressed at a larger sub-regional level, any future individual projects within the sub-region shall satisfy the requirements by reference to the sub-regional project. In these cases, the Guidance (and subsequent updates) should still be used to prepare Capital Plans, albeit at a larger or sub-regional level, and applied as individual projects are implemented.

While primary responsibility for developing resilient Capital Plans resides within each department, the CPC and the City Administrator's Office (CAO) encourage and support collaborative planning across CCSF government. This Guidance facilitates the use of a common approach across all departments. The Guidance recommends using the same underlying science, tools (i.e., inundation maps), and methods, thereby increasing the potential for seamless collaboration and integration. This collaboration is most

The Port's seawall is one of the most important coastal structures along the city's waterfront. The seawall serves as a retaining wall for the adjoining land, which is comprised of significant quantities of fill material that extends hundreds of feet landward from the seawall. The seawall serves as the primary structural support for the Port's piers and wharves, as well a large network of structures and utilities belonging to the Port and other local agencies such as MUNI, SFPUC, and BART. The seawall's integrity and ability to provide structural support will decrease as sea levels rise. Coastal storm surge and wave hazards also pose a significant threat to the integrity of the seawall.

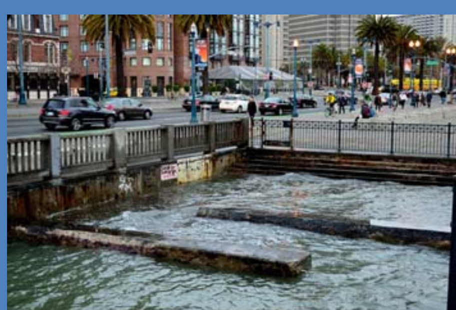

Photo credit: California King Tides Initiative

critical where infrastructure, and the adaptation plans needed to address the vulnerabilities of that infrastructure, cross departmental borders (see sidebars discussing Ocean Beach and the bayside seawall).

REVISITING AND UPDATING THIS GUIDANCE

The science related to understanding the impacts of climate change is continually evolving and advancing over time. Therefore, guidance documents like these must be revisited and updated at regular intervals. This version is an update of the Guidance for Incorporating Sea Level Rise into Capital Planning in San Francisco Revision Adopted January 3, 2020. In response to updated climate science information presented in national and regional reports[1,2] and the State of California released updated Sea-Level Rise Guidance[3] (State Guidance) in 2024. This revision provides a brief update on the latest science and describes the corresponding updates to the Sea Level Rise Checklist (see attachment) for a project by project approach. We also present the current sea level rise policy recommendations from the California Coastal Commission and the San Francisco Bay Conservation and Development Commission in this revision. See Appendix 2 for full Sea Level Rise Science and Checklist Update.

SEA LEVEL RISE AND COASTAL HAZARDS

San Francisco is susceptible to coastal flooding and wave hazards along three sides of the city, with the open Pacific Ocean to the west and San Francisco Bay to the north and east. Several areas along the shoreline are already experiencing periodic inundation and erosion, including: Ocean Beach on the Pacific Coast, which is subjected to significant coastal storms and waves; the Embarcadero, which

[1] Crimmins, A.R., et al. 2023. Fifth National Climate Assessment, U.S. Global Change Research Program, Washington D.C., USA. https://doi.org/10.7930/NCA5.2023.

[2] Sweet, W.V., et al. (2022). Global and Regional Sea Level Rise Scenarios for the United States: Updated Mean Projections and Extreme Water Level Probabilities Along U.S. Coastlines. NOAA Technical Report NOS 01. National Oceanic and Atmospheric Administration, National Ocean Service. https://sealevel.globalchange.gov/resources/2022-sea-level-rise-technical-report/

[3] California Sea Level Rise Guidance: 2024 Science and Policy Update. 2024. California Sea Level Rise Science Task Force, California Ocean Protection Council, California Ocean Science Trust.

is overtopped in several areas during the annual highest high tides, or King Tides; and San Francisco International Airport (SFO), which experiences wave overtopping of flood protection structures and inundation of low-lying areas. Projected sea level rise worsens these existing hazards by increasing the elevation and frequency of flooding, extending the coastal flood hazard zone further inland, and accelerating shoreline erosion. Areas of the shoreline that have been filled, such as the Embarcadero, Mission Bay, SFO, and Treasure Island, are especially at risk, as rising sea levels may influence groundwater levels, resulting in increased subsidence and liquefaction hazards.
The following coastal flood hazards may increase due to sea level rise:

- **Daily tidal inundation:** as sea level rises, the amount of land and infrastructure subjected to daily inundation by high tides will increase as a result of increased permanent future inundation of low-lying areas.
- **Annual high tide inundation (King Tides):** King Tides are abnormally high but predictable astronomical tides that occur approximately twice per year. King Tides are the highest tides that occur each year when the gravitational influence of the moon and the sun on the tides are aligned, rather than opposed, and when the earth is at a point in its rotation which is particularly close to either the moon or sun. When King Tides occur during winter storms, the effects are particularly pronounced and make these events more dramatic. King Tides result in temporary flooding, often involving low-lying roads, boardwalks, and waterfront promenades. The Embarcadero waterfront (Pier 14) and the Marina area in San Francisco experience flooding under current King Tide conditions.

***Urban flooding** that occurs inland when the storm sewer system exceeds its capacity is not specifically addressed by this Guidance. Sea level rise will exacerbate urban flooding, particularly when precipitation events coincide with high tides, therefore this Guidance document can be used to inform urban flooding assessments.*

- **Storm Surge:** When Pacific Ocean storms coincide with high tides, storm surge due to meteorological effects can elevate Pacific Ocean and San Francisco Bay water levels, resulting in temporary flooding. Such storm surge events occurred on January 27, 1983, December 3, 1983, February 6, 1998, January 8, 2005, December 31, 2006, and December 24, 2012. Extreme high tides can cause severe flooding of low-lying roads, boardwalks, promenades, and neighborhoods; exacerbate coastal and riverine flooding and cause upstream flooding; and interfere with stormwater outfalls. The Ocean Beach area is prone to inundation and erosion associated with extreme high tides and storm surge.
- **El Niño winter storms:** During El Niño[4], atmospheric and oceanographic conditions in the Pacific Ocean bring warm, higher waters to the Bay Area and may produce severe winter conditions that bring intense rainfall and storm conditions to the Bay Area. Tides are often elevated 0.5 to 1.1 feet above normal along the coast for months at a time, and additional storm surge and wave setup during storm events can elevate water levels even further. El Niño conditions prevailed in 1977-1978, 1982-1983, 1997-1998, 2009-2010, 2014-2016, and 2023-2024. Typical impacts include severe flooding of low-lying roads, boardwalks and waterfront promenades; storm drain backup; wave

[4] El Niño–Southern Oscillation (ENSO) is a natural oceanic-atmospheric cycle. El Niño conditions are defined by prolonged warming in the Pacific Ocean sea surface temperatures. Typically, this happens at irregular intervals of two to seven years, and can last anywhere from nine months to two years. [

damage to coastal structures and erosion of natural shorelines (see Ocean Beach sidebar which highlights the power of coastal erosion).

- **Ocean swell and wind-wave events (storm waves):** Pacific Ocean storms and strong thermal gradients can produce high winds that blow across the ocean and the Bay. When the wind blows over long reaches of open water, it generates large waves that impact the shoreline and cause damage. Typical impacts include wave damage along the shoreline, particularly to coastal structures such as levees, docks and piers, wharves, and revetments; backshore inundation due to wave overtopping of structures; and erosion of natural shorelines.
- **Urban flooding:** although urban flooding is primarily associated with rainfall runoff, higher tides due to sea level rise will reduce the capacity of existing storm sewer systems to discharge to the Bay via gravity. Typical impacts include flooding of low-lying areas during precipitation events that coincide with high tides or storm surge events.

Ocean Beach, on the open Pacific Coast of San Francisco, is subjected to extreme winter storm surge and wave conditions. The photo above was taken in December 2012. Extreme winter storms and wave conditions severely eroded portions of the beach, as shown in the photo below from January 2013. Periodic sand placement by the National Park Service and CCSF have been successfully managing and maintaining the beach. Adaptation options for maintaining the beach and protecting critical infrastructure are in development.

Physical damage from floods could include the following:

- **Inundation of facilities**, causing operational closures at critical transportation facilities such as SFO, the Port, BART, and various facilities operated by MTA.
- **Inundation and damage to various infrastructure** including buildings, roads, bridges, culverts, pump stations, support structures, parks, and open space.
- **Overland flooding** may block access to underground utilities, may damage electrical boxes and substations causing prolonged power outages, and may damage pump stations and other electrical equipment resulting in equipment failure.
- **Release of sewage and hazardous or toxic material** when wastewater treatment plants, storage tanks and other facilities are inundated and compromised.
- **Erosion of natural shorelines** and stream banks, disruption of wetlands and natural habitats, and undermining of the support foundations and structures of important facilities.

FOUR STEPS TO PREPARING FOR CLIMATE CHANGE

Many state and local governments are already preparing for the impacts of climate change through "adaptation," the practice of planning for anticipated climate change and developing strategies to address potential impacts. Planning efforts can no longer rely on historical ocean levels, or even the rates of sea level rise observed over the past century. Instead, they must incorporate the latest climate science to determine how to protect and modify existing assets and design new assets to be more resilient to rising seas. Adaptation planning requires the consideration of uncertainty and risk, because the science supporting sea level rise and climate change projections has many underlying uncertainties. As such, a robust adaptation plan requires that potential adaptation strategies be revisited as the science progresses and projections are updated.

While adaptation planning can take many forms, the process of assessing sea level rise vulnerability and risk follows some basic steps (see Figure 1):

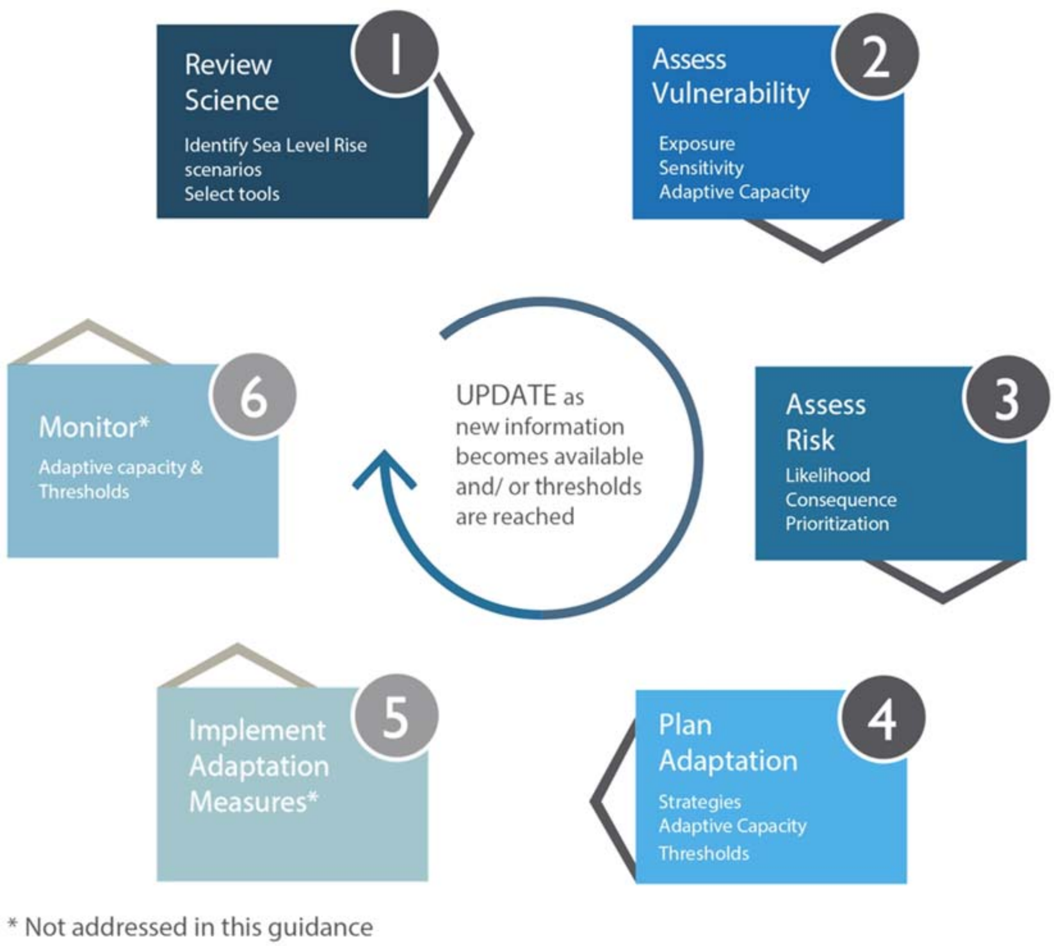

Figure 1. Sea Level Rise Vulnerability, Risk and Adaptation Planning Process

Step 1. Sea Level Rise Science Review

- Sea level rise estimates
- Storm surge, El Nino, and waves
- Sea level rise scenario selection
- Sea level rise inundation mapping

Step 2. Vulnerability Assessment

- Evaluate *exposure*: degree to which an asset is exposed (e.g., depth of flooding due to sea level rise, wave run up and/or storm surge)
- Assess *sensitivity*: degree to which an asset is affected (e.g., temporary flooding causes minimal impact, or results in complete loss of asset or an operational disruption)
- Determine *adaptive capacity*: ability of an asset to adjust to climate change, to moderate potential damages, to take advantage of opportunities, or cope with the consequences

Step 3. Risk Assessment

Evaluate *consequence* to help set priorities for adaptation planning (i.e., cost of reconstruction or repair, economic impact of disruption, length of disruption, irreversibility of impact)

Step 4. Adaptation Planning

Identify, prioritize, and incorporate means to reduce, mitigate or protect from unacceptable risks within project plans.

- Identify adaptation strategies and approaches to protect assets and increase adaptive capacity
- Prioritize strategies based on risk levels, sequence of expected impacts, and adaptive capacity:
- Timing of strategies: when do they need to be implemented

The following sections provide an overview of each of the steps outlined above.

1. SEA LEVEL RISE SCIENCE REVIEW

Adaptation to sea level rise begins with an understanding of the current state-of-the-science on sea level rise. [5]

HISTORIC SEA LEVEL RISE

Sea levels have risen eight inches over the past century, as measured at the Presidio Tide Gage located near Crissy Field along the San Francisco shoreline. Over the past century, the rate of sea level rise has averaged approximately 2.0 mm/year (~0.1 inches/year), as shown on Figure 2. However, the rate of sea level rise is not constant over time, and fluctuations associated with El Niño/La Niña cycles and the Pacific Decadal Oscillation can be observed within the tidal record. The rate of sea level rise is anticipated to increase at an accelerated rate over the coming century.

Understanding how fast sea levels may rise over the coming decades is critical to understanding how the City should respond and adapt, where the City needs to focus adaptation efforts, and how quickly the City needs to implement adaptation solutions.

***The Presidio Tide Gage** is one of the country's major scientific landmarks – the oldest continually operating tide gage in the Western Hemisphere. The tide gage has been collecting tidal observations since June 30, 1854 and has played a central role in understanding the impact of climate change on local and global sea levels.*

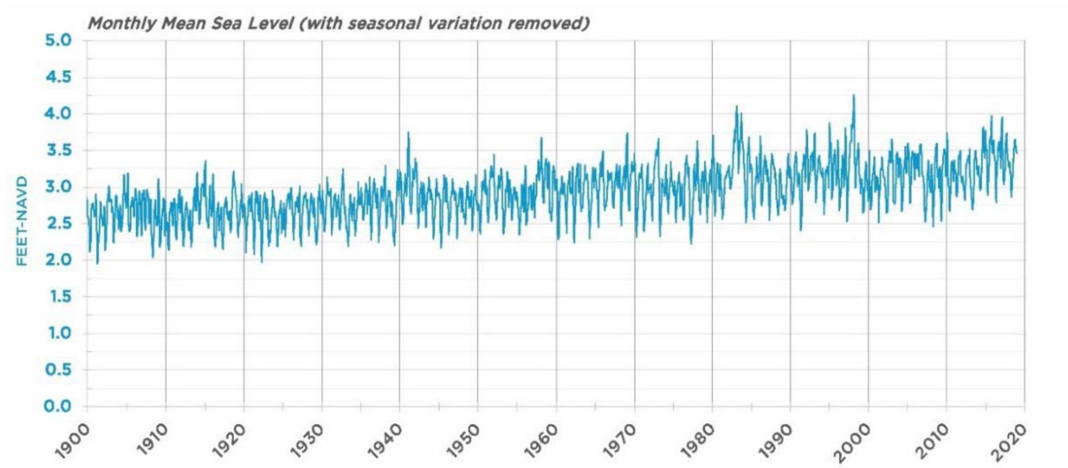

Figure 2. Historical Sea Level at the Presidio Tide Gage

[5] See Appendix 2 for a summary of current sea level rise science

SEA LEVEL RISE PROJECTIONS

The Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report, published in stages between 2021 and 2023, includes sets of future greenhouse gas scenarios based on future emissions, changes in population, and anticipated economic growth. The previous (fifth) assessment referred to these scenarios as "Representative Concentration Pathways," or RCPs. The Sixth Assessment refers to them as "Shared Socio-economic Pathways" or SSPs, which contain additional scenarios under each grouping:

IPCC Fifth Assessment	IPCC Sixth Assessment	Estimated Warming by 2100	Scenario Summary
RCP 8.5	SSP 5-8.5	4.4 °C	C02 emissions increase up to 400% from 2000 levels by 2100. Compared to 2000, these scenarios include no mitigation with high levels of fossil fuel development, population growth and economic growth.
RCP 7.0	SSP 3-7.0	3.6 °C	C02 emissions increase 75%-300% from 2000 levels by 2100. Compared to 2000, scenarios include limited to no mitigation with expanded fossil fuel development, modest population growth, and slow economic growth.
RCP 4.5	SSP 2-4.5	2.7 °C	C02 emissions reduce 46-67% from 2000 levels by 2100. Mitigation efforts include low-carbon technology and/or expanded renewable energy compared to those in use in 2000.
RCP 2.6	SSP 1-2.6	1.8 °C	C02 emissions rapidly decline and are net-negative by 2100. Mitigation efforts include increased renewable energy and adaptive capacity reflects effective governance institution, reduced inequality and international cooperation.
N/A	SSP 1-1.9	1.4 °C	

In the 2024 Guidance, the State of California adopted sea level rise scenarios presented in recent federal multi-agency reports. The current scenarios focus on a range of SSPs as shown in Figure 3. The scenarios show the projected rise in mean relative sea level over time and represent the best available scientific understanding as described both in the IPCC AR6 and in the summary of the science contained in the California guidance. Each scenario represents potential future sea level rise associated with a specific likelihood of occurrence within the range of possible outcomes associated with each SSP. For example, under the Intermediate-High scenario, there is a "<0.1%" chance of exceeding 4.9 ft of sea level rise with 3°C of warming by 2100.

It is important to note that these scenarios characterize probabilities using predictions from models and expert opinion, rather than statistical data, and therefore are imprecise probabilities. Very low probabilities at the extremes, in particular, such as "0.1% likely," are often criticized for providing a false sense of precision. Therefore, San Francisco should use these projections with caution, especially in the context of significant uncertainty about the future, in order to prevent overbuilding or maladaptation.

The city of San Francisco has selected SSP 5- 8.5 as the upper range and SSP 2-4.5 as the lower range for sea level rise planning. SSP 2-4.5 represents a more realistic potential lower range for sea level rise planning since emissions agreements and clean energy trends are tracking to this scenario and because achieving RCP 1-2.6 requires significant actions at a global scale that are not currently the subject of agreement.

Current State Guidance[3] recommends that the most precautionary approach to assessing sea level rise vulnerability is to use the Intermediate, Intermediate-High, and High scenarios based on an assessment of risk (as shown in Figure 3). As stated in the guidance, however, the High Scenario should be "used with caution." This scenario is predominantly based on "low confidence" science[1] and assumes a worst-case emissions scenario of SS5-8.5 and warming in 2100 of approximately five degrees Celsius. Current emissions reduction commitments and projected warming are significantly lower and more closely aligned with SSP2-4.5 and warming of approximately three degrees C by 2100[2]. The High Scenario is described in the State Guidance as having a likelihood of "effectively zero" and should therefore be considered highly precautionary as a worst-case scenario to keep in mind as the future unfolds, with careful monitoring of observations, global emissions, and new science essential before any adaptation investment using this scenario is planned. Currently, higher confidence science projects that a median date of occurrence for 2.0 meters of SLR in San Francisco under SSP5-8.5 is approximately the year 2240, while the median occurrence of 2.0 m in San Francisco under SSP2-4.5 is after the year 2300[3].

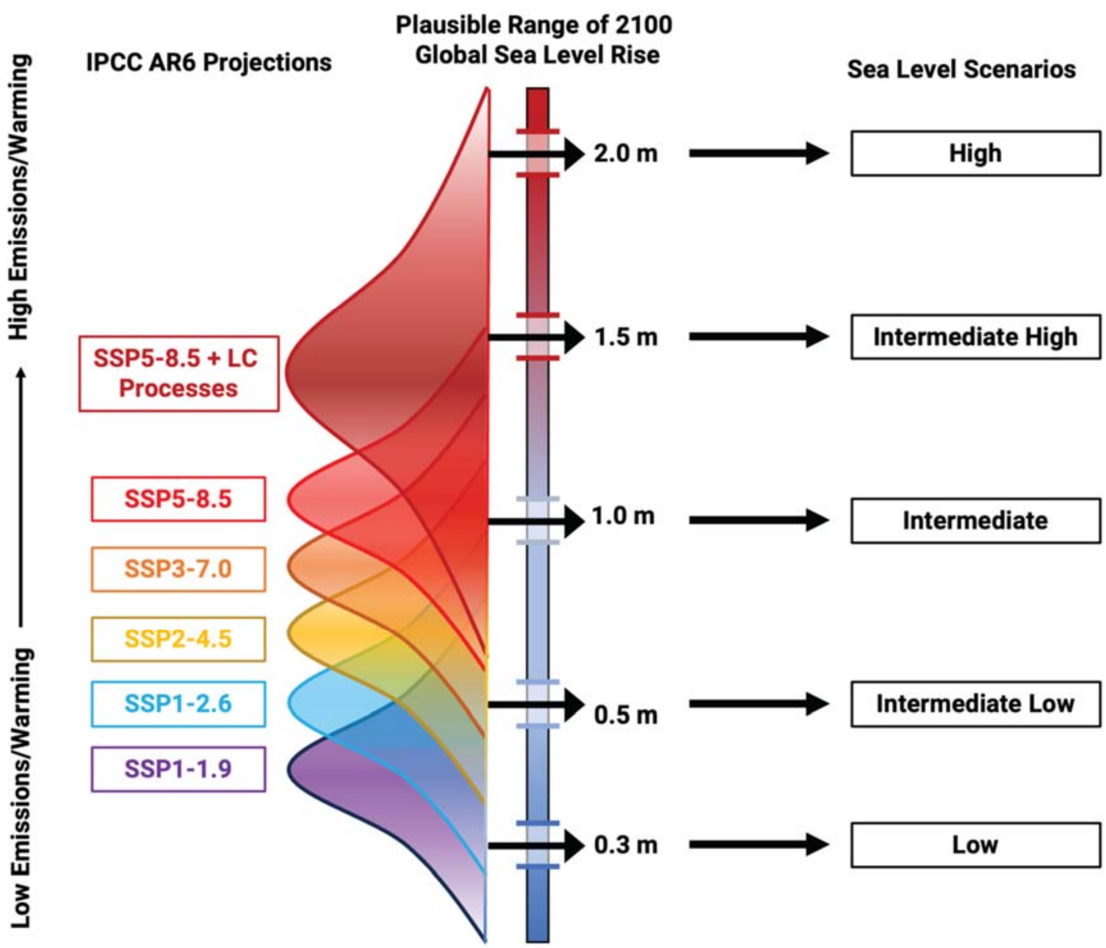

Figure 3. sea level scenarios (low to high) are based on SSPs, which inform a range of plausible future conditions

[1] AR6, chapter 9 and Sweet et al 2022

[2] Hausfather, Z. and G. Peters. Emissions – the 'business as usual' story is misleading. 2020. *Nature.;* Climate Action Tracker. "As the climate crisis worsens, the warming outlook stagnates." 2024. https://climateactiontracker.org/documents/1277/CAT_2024-11-14_GlobalUpdate_COP29.pdf; AR6.

[3] NASA Sea Level Rise Viewer. https://sealevel.nasa.gov/ipcc-ar6-sea-level-projection-tool?lat=37&lon=%20-123&data_layer=scenario

For most applications, the best starting point is basing adaptation planning on the Intermediate Scenario while closely evaluating risks at the high end associated with the Intermediate-High scenario. The revised SLR Checklist accordingly requires project managers to consider these two SLR scenarios, plus storm surge, for new capital projects in the SLR inundation zone. As discussed in the previous paragraphs, the High scenario should only be kept in mind as a 'worst case scenario' through careful monitoring of observations and the latest science before any additional adaptation investments are made in alignment with it.

Figure 4 illustrates the sea level rise scenarios recommended by State guidance over time as well as the extreme H++ scenario that was included in previous guidance but is no longer recommended. The curves follow a similar path through 2050 and increasingly diverge through 2100. The projections also become increasingly uncertain over time. As a result, very little difference in sea level rise rates across the SSPs is projected through 2050. Beyond 2050, greater uncertainty exists and the rate of sea level rise depends on which emissions pathway our future aligns with.

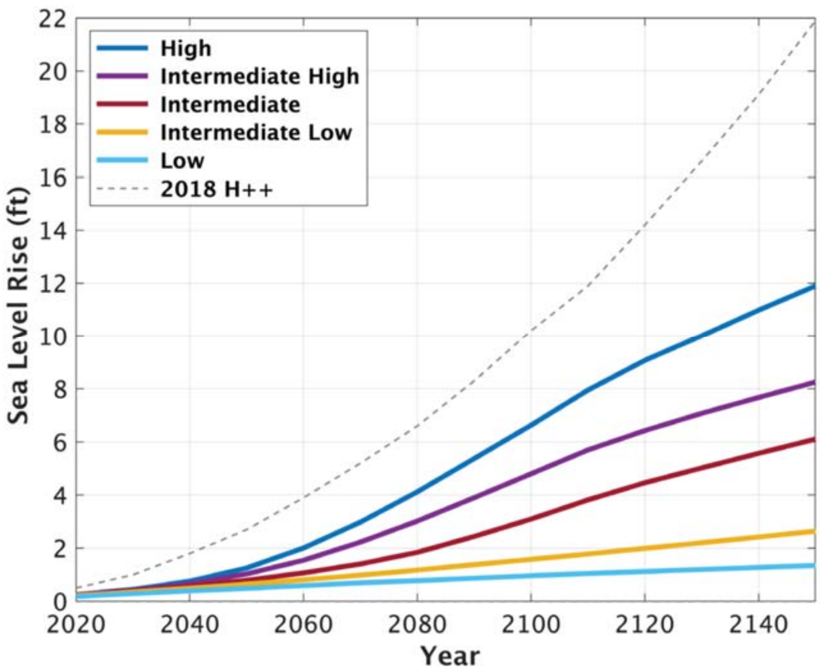

Figure 4. Relative Sea Level Rise through 2150 by Sea Level Rise Scenario

Year	Intermediate	Intermediate-High	High
2030	0.4	0.4	0.4
2050	0.8	1.0	1.2
2070	1.4	2.2	3.0
2100	3.1	4.9	6.6
2150	6.1	8.3	11.9

Table 1. Recommended Sea Level Rise Projections (in feet)

STORM SURGE AND WAVES

In addition to relative sea level rise, consideration must be given to El Niño events, storm surge, storm waves and wave run up along the San Francisco shorelines (see Figure 2). Planning within the coastal environment must consider the additive impact of large waves and extreme high tides on inundation and flooding. Table 3 provides an overview of factors in addition to sea level rise affecting existing water levels on the San Francisco open Pacific Coast and in San Francisco Bay. The Supplementary Document "Sea Level Rise Scenario Selection and Design Tide Calculations" provides an example approach for evaluating and comparing the factors affecting water levels along the San Francisco shoreline.

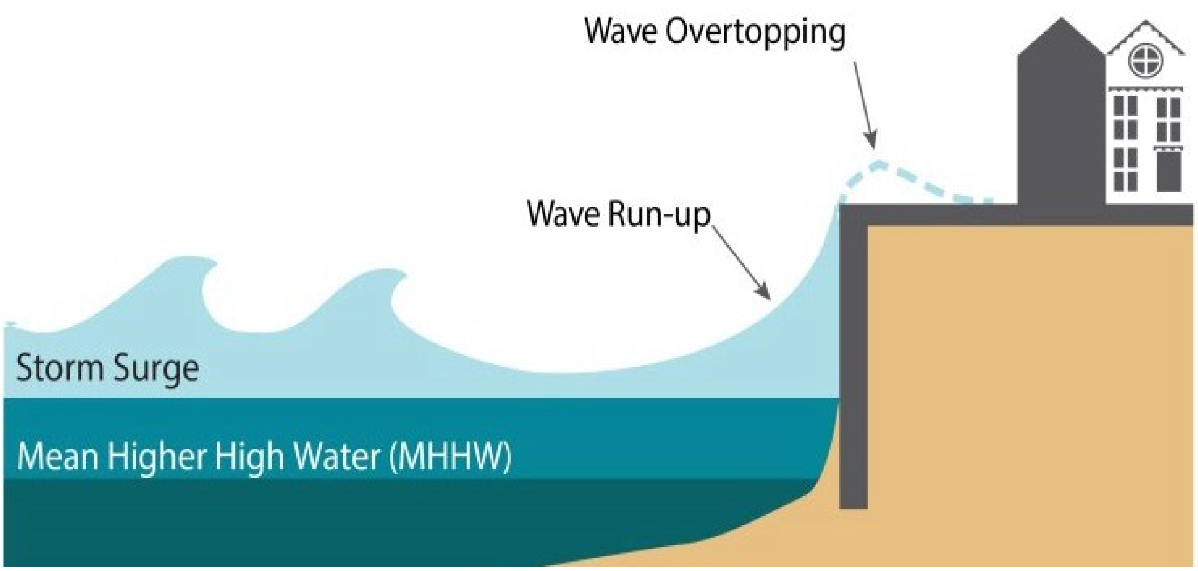

Figure 4. Storm Surge and Waves along the Shoreline

Factors Affecting Water Level	Typical Range CCSF Pacific Shoreline (a)	Typical Range CCSF Bay Shoreline (b)	Period of Influence	Frequency
Average Tides	5 to 8 ft	5 to 8 ft	Hours	Twice daily
Storm Surge	0.5 to 3 ft	0.5 to 3 ft	Days	Several times a year
Storm Waves	10 to 30 ft	1 to 4 ft	Hours	Several times a year
El Niño (within the ENSO cycle)	0.5 to 3 ft	0.5 to 3 ft	Months to Years	Every 2 to 7 years

Table 2: Factors that Influence Local Water Level Conditions in Addition to Sea Level Rise

Sources:

a) Typical ranges for tides, storm surge, and storm waves for the CCSF Pacific Coast: Baker, AECOM 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 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. Submitted to FEMA Region IX. October 2011.

GROUNDWATER RISE

Groundwater levels rise and fall over time due to various factors. Seasonal fluctuations in the groundwater table are largely based on rainfall patterns. The highest annual groundwater table occurs sometime after the rainy season depending on the size of the watershed and the permeability of the soil. Groundwater levels near the shoreline are also influenced by tidal fluctuations, including larger tidal events, such as King Tides or those following a major coastal storm. Groundwater pumping influences groundwater tables as well. Major pumping operations, such as those used to dewater underground tunnels or excavations can lower local groundwater levels while in operation.

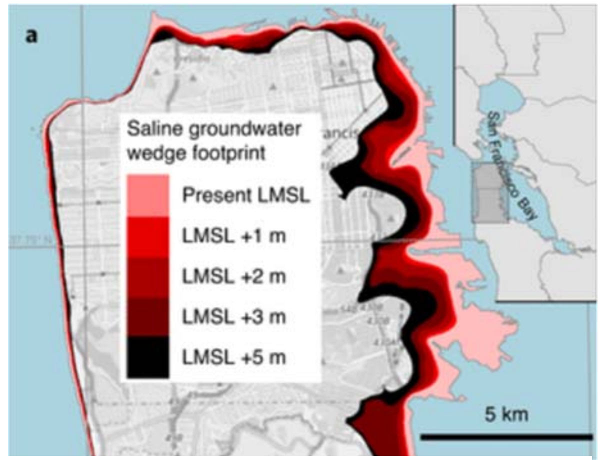

Figure 5, Saline groundwater wedge footprint under different sea level rise Projections[6]

Local groundwater conditions are expected to be influenced by sea level rise, particularly along the groundwater salt wedge. The groundwater salt wedge describes coastal areas where saline groundwater has infiltrated into the groundwater table, particularly in areas of reclaimed land.[6] While freshwater typically floats on top of denser saltwater, rising sea levels can reduce the buoyancy effect and result in saltwater intrusion further inland into existing aquifers. As shown in Figure 5, there is high potential for additional saltwater intrusion with sea level rise, particularly along the Bay shoreline.

A recent study conducted by the Pathways Climate Institute and the San Francisco Estuary Institute (SFEI) evaluated and mapped the potential influence of future sea level rise on groundwater levels.[7] Digital maps of existing groundwater conditions in San Francisco along with those associated with between 1 and 9 feet of sea level rise from the study are available.[7]

There are several potential impacts of groundwater rise to consider for projects that are influenced by underground conditions.[7] Underground infrastructure, such as tunnels, pipes, roadway subgrades and foundations are typically designed relative to the highest annual groundwater table, which fluctuates as stated above. In some instances, rising groundwater tables will begin to influence infrastructure currently above the groundwater table. Design cases include the evaluation of buoyancy forces pushing up, bearing capacity of the soils below, lateral earth pressure and hydrostatic loads around the infrastructure, as well as liquefaction potential of surrounding soils. Additionally, designs must also consider the potential for corrosion and inflow. Seasonal variations in the groundwater table can lead to changing load conditions throughout the course of the year.

When sea level rise elevates the groundwater table, design conditions may be exceeded, putting infrastructure at risk of damage. These changes should be anticipated during the design process and may result in increasing pump sizes, changing design details, or strengthening structural elements to mitigate risks associated with a changing groundwater table.

[6] May CL, et al. 2022. Shallow Groundwater Response to Sea-Level Rise: Alameda, Marin, San Francisco, and San Mateo Counties. Prepared by Pathways Climate Institute and San Francisco Estuary Institute. doi.org/10.13140/RG.2.2.16973.72164

[7] SFEI, Shallow Groundwater Response to Sea Level Risk. https://www.sfei.org/projects/shallow-groundwater-response-sea-level-rise

SEA LEVEL RISE SCENARIO SELECTION

During project planning, the selection of the appropriate sea level rise scenario, or scenarios, for the vulnerability and risk assessment of a particular asset or set of assets can be challenging. There are several factors that should influence scenario selection:

- **Functional Lifespan** – how long will the project be in use at this location (including regular repair and maintenance)?
- **Location** – is the project located in an inundation zone during its lifespan?
- **Underground Conditions** – Is the project expected to be influenced by potential changes in groundwater conditions.

Capital project planners should consider both the lifespan and the location of their project as they evaluate sea level rise vulnerabilities and risks and plan to accommodate or adapt to future sea level rise. During project planning, the selection of the planning horizon often influences the selection of appropriate sea level rise scenario(s). For example, if the planning horizon is 50 years, sea level rise scenarios for the year 2065 might be selected (i.e., 2015 + 50 years = 2065). However, climate change assessments are changing the way we think about planning horizons. Typically, engineers and planners select a planning horizon aligned with a project's "design life." The design life is the period of time during which the asset or facility is expected to perform within its specified parameters; in other words, the life expectancy of the asset or facility as constructed. However, most structures and facilities are in service at their given locations far beyond their design life as defined above. An asset might have a design life of 30 years but might in reality be in service for 50, 75, or 100 years or more with regular repair or maintenance. This timeframe, rather than design life, is needed for assessing vulnerability to sea level rise.

Most structures and facilities are in service at their given locations far beyond their engineered "design life". This "functional lifespan", not the engineered "design life", is what is needed when assessing vulnerability to sea level rise.

To distinguish between engineering design life and the true, reasonable life expectancy of the asset – and the timeframe for assessment -- this Guidance uses the term "functional lifespan" to refer to the period an asset will likely remain in place through multiple cycles of repair and rehabilitation. As a result, capital project planners should consider if one or more repair and rehabilitation cycles should be included when estimating the functional lifespan of a project. The supplemental document "Sea Level Rise Vulnerability Zone" should be used to assess if the asset or project is within a zone that could be inundated with 79 inches of sea level rise and a 100-year storm surge event. Any project within this zone is required to consider sea level rise vulnerabilities within the planning process and complete a "Sea Level Rise Checklist".

In most cases, it is appropriate to plan for the Intermediate or Intermediate-High scenarios while completing sensitivity testing and developing appropriate adaptation strategies that could be implemented in the future (e.g. for projects that have adaptive capacity – see Section 2.c. for a discussion of adaptive capacity). Alternately, capital project managers may choose to plan now for the High Scenario (e.g., 6.6 feet of sea level rise by 2100) – particularly for new assets with a long functional lifespan that must maintain their function as a critical service if inundated (e.g., emergency medical facility, transit center, fire station). This approach flexibly accommodates uncertainties in the science should the higher-end of the sea level rise projections become more likely. Although sea level rise estimates presented in Table 1 are presented relative to specific time horizons (e.g., 2030, 2050, and 2100), these estimates can be interpolated for alternate time horizons (e.g., 2080) if needed to consider different project planning horizons (See Appendix 3).

SEA LEVEL RISE INUNDATION MAPPING

Inundation maps are a valuable tool for evaluating potential exposure to future sea level rise and storm surge conditions and the most up-to-date maps should be referenced during project planning and design. The maps are typically used to evaluate when (under what amount of sea level rise and/or storm surge) and by how much (what depth of inundation) an asset will be exposed. A variety of inundation maps exist today for evaluating potential future sea level rise exposure. At the time of publication of this Guidance, the following inundation maps represent state-of-the-art products and should be used by CCSF departments in planning near the San Francisco Bay and Pacific Coast shorelines. These inundation maps were prepared by the San Francisco Public Utilities Commission (SFPUC) in conjunction with the Sewer System Improvement Program (SSIP) and provide the highest resolution, most comprehensive inundation mapping to date for the entire CCSF shoreline. (These maps, however, do not consider precipitation and runoff-driven flooding.)

For the Pacific Coast shoreline (i.e., Westside):

SFPUC Westside Inundation Maps: SFPUC produced sea level rise inundation maps for the open Pacific Coast shoreline (from the Golden Gate Bridge to the Westside CCSF/San Mateo County border). The inundation maps use a 1-meter horizontal grid resolution DEM[10] based on the 2010/2011 California Coastal Mapping Program (CCMP) LiDAR[11]. Along the open Pacific Coast, the importance and magnitude of coastal storm surge and wave hazards (see Table 3) requires an approach that captures these dynamic processes as they propagate landward. The Westside inundation maps leverage data from the Federal Emergency Management Administration (FEMA) California Coastal Mapping and Analysis Project. The leveraged data includes water level and storm surge data and coastal hazard analysis methods that consider shoreline types (i.e., sandy beaches, dunes, and bluffs), the presence of coastal structures, and erosion potential[12]. The inundation maps include a range of sea level rise estimates from 12 inches to 66 inches, and account for the dynamic overland water levels associated with sea level rise-driven changes to the 100-year coastal storm surge and wave hazards. These maps were published in June 2014 and are available through the SFPUC and the Sea Level Rise Committee.

[10] The horizontal grid resolution of a digital elevation model (DEM) defines the scale of the features which are resolved within the terrain. In order to resolve levees, berms, and other topographic features which are important for impacting floodwater conveyance, a 1-meter resolution DEM is recommended. Coarser grid resolutions (i.e., 2-meter, 5-meter) may not fully resolve these features, resulting in an over estimation of potential inundation extents.

[11] LiDAR (Light Detection and Ranging) is a remote sensing technology that measures distance by illuminating a target with a laser and analyzing the reflected light. LIDAR is commonly used to create high-resolution terrain models, topography data sets, and topographic maps.

For the San Francisco Bay shoreline (i.e., Bayside):

- SFPUC Bayside Maps: SFPUC produced sea level rise inundation maps for the contiguous CCSF Bay shoreline (from the Golden Gate Bridge to the Bayside CCSF/San Mateo County border), including Treasure Island and SFO. The inundation maps use a 1-meter horizontal grid resolution DEM based on the same 2010/2011 CCMP LiDAR used for the Westside inundation mapping. The water level analysis leverages data from FEMA's California Coastal Mapping and Analysis Project. Inundation maps consider static sea level rise on top of mean higher high water (MHHW) in one-foot increments, as well as a range of storm surge and wave hazard events ranging from the 1-year to the 100-year storm surge event. These maps and the associated digital data were published in June 2014 with SFO maps and digital data were published in March 2015 and are available through the SFPUC and the Sea Level Rise Committee.

All inundation maps, including those produced by SFPUC for the SSIP, have caveats and uncertainties. Inundation maps, and the underlying associated analyses, are intended to be used as planning-level tools that illustrate the *potential* for flooding under future sea level rise and storm surge scenarios. Although this information is appropriate for conducting vulnerability and risk assessments, finer-grained information is needed for detailed engineering design and implementation – particularly for projects located near the shoreline. The maps depict *possible* future inundation that could occur if nothing is done to adapt or prepare for sea level rise over the next century. The SFPUC SSIP maps relied on a 1-meter (m) digital elevation model created from LiDAR data collected in 2010 and 2011. Although care was taken to capture all relevant topographic features and coastal structures that might impact coastal inundation, structures narrower than the 1-m horizontal map scale might not be fully represented. If development and earthwork has occurred along the shoreline after 2011 (i.e., if a project was completed that raised or modified ground elevations), these changes are not captured within the SFPUC inundation maps. In addition, the maps are based on model outputs and do not account for all of the complex and dynamic San Francisco Bay and Pacific Ocean coastal processes, or future conditions such as erosion, subsidence, future construction or shoreline protection upgrades, and other changes to the region that might occur in response to sea level rise.

GROUNDWATER RISE MAPPING

Maps that indicate changes in groundwater levels associated with sea level rise can be a valuable tool for evaluating potential exposure to changes in subsurface conditions when relevant to a project. They can be used to evaluate when (under what amount of sea level rise), by how much (what change in groundwater level), and additional corrosion an asset may be exposed. The Shallow Groundwater Response to Sea Level Risk Study[6], provides groundwater maps under different sea level rise scenarios[7]. These maps were prepared by the Pathways Climate Institute and SFEI in conjunction with stakeholders across the Bay Area, including San Francisco. As with the inundation maps, these maps have numerous assumptions and uncertainties. They should be used as planning-level tools that illustrate the potential for higher or more saline groundwater conditions, especially within the zone of the salt wedge. More detailed information is needed to inform engineering design and project implementation.

2. VULNERABILITY ASSESSMENT

The vulnerability assessment phase uses the results of the climate science review and sea level rise scenario selection, including inundation mapping, to help guide identification of the *exposure, sensitivity,* and *adaptive capacity* of an asset to understand that asset's vulnerability to sea level rise. By screening for vulnerability, we lay the groundwork for adaptation planning. Assets found to be vulnerable move on to the risk assessment and adaptation planning phases. The analysis for assets not evaluated as vulnerable is complete at this phase.

It is critical to develop and adopt a standard approach to performing a vulnerability assessment to aid in consistency across city departments.

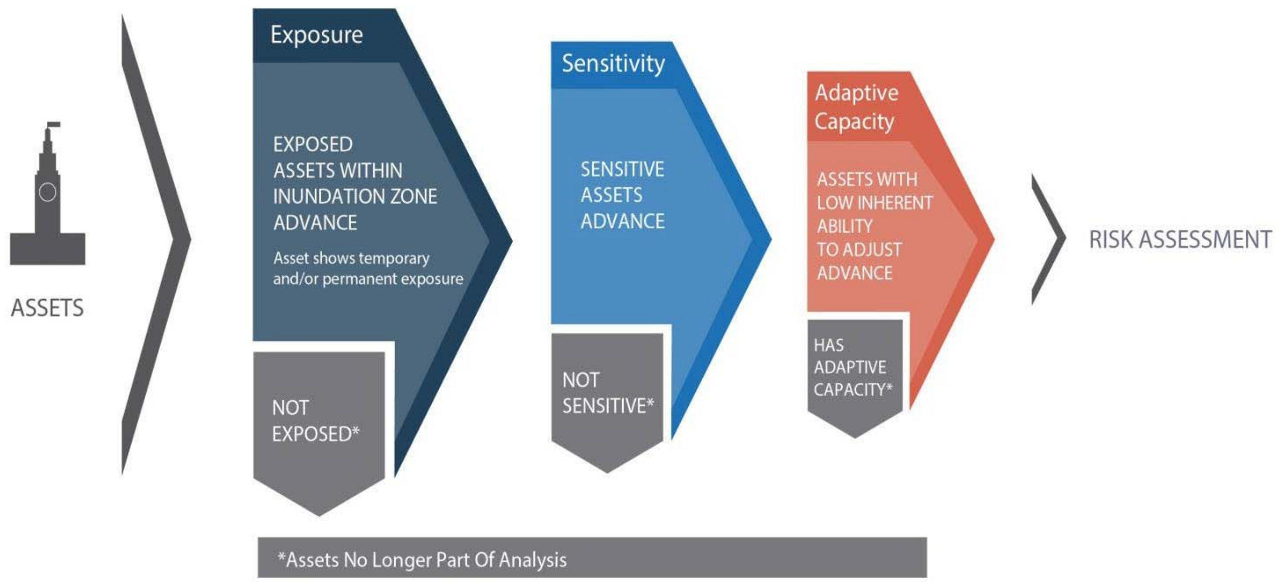

Figure 5. Vulnerability Assessment Process

Project Managers should evaluate the below prioritized factors for each capital plan asset or project:

PHASE 1. EXPOSURE The exposure of an asset is the degree to which an asset is susceptible to hazards (e.g., depth of flooding due to sea level rise, storm surge, wave run up, groundwater rise, etc.). Exposure is evaluated by type, magnitude, and duration of flooding using either inundation mapping at an appropriate scale and resolution, or by completing site-specific modeling and mapping of an accepted range of current and future sea level rise projections, storm surge conditions, wave hazards (including wave run-up if the asset is directly located along the shoreline), and groundwater rise. Measure exposure by overlaying the asset footprint with inundation mapping and extracting necessary information, such as depth of inundation, area inundated, and percent of area inundated. In addition, multiple scenarios for static sea level rise and/or storm surge and wave hazards can be used to help determine asset vulnerability under a variety of future conditions. If assets are not exposed, no further evaluation is needed. Projects that fall within an area of coastal inundation are considered to be exposed to groundwater rise.

[12] Federal Emergency Management Agency (FEMA) California Coastal Analysis and Mapping Project (CCAMP).

PHASE 2. SENSITIVITY If an asset is exposed, the analysis progresses to the next step of evaluating the sensitivity of the asset to sea level rise considerations. Sensitivity is the degree to which an asset is affected (i.e., temporary flooding causes minimal impact, or results in complete loss of asset or shut-down of operation). For example, on one hand, a roadway might be temporarily inundated under a storm surge scenario, but once the floodwaters recede, the roadway can resume useful service without the need for repair. Such a roadway would have a low sensitivity to periodic flooding; therefore, it might not need to be carried further in the process. Assets with low sensitivity might still benefit from adaptation measures, such as infrastructure improvements and/or operational adjustments; therefore, the inclusion or exclusion of exposed assets with low sensitivity should be considered on a case by case basis. On the other hand, an electrical substation might be completely taken out of service if it experiences even minor temporary inundation, requiring either major repairs or complete replacement. This asset would be considered highly sensitive to flood impacts and would be the subject of more complex analysis. Structural considerations should also be considered in a sensitivity analysis. For example, if there are underground elements to a project, potentially higher or more saline groundwater conditions may lead to future structural instability.

PHASE 3. ADAPTIVE CAPACITY If an asset is both exposed and sensitive, continue to the last evaluation--adaptive capacity. Adaptive capacity is defined as the asset's *inherent* ability to adjust to sea level rise impacts without the need for significant intervention or modification. An asset with adaptive capacity is less vulnerable to sea level rise impacts. For example, architects might design a boardwalk or building to be easily raised in the future, or engineers might design a floodwall to accommodate future increases in height without the need for significant modifications. Additionally, an underground structure may employ cathodic protection to accommodate future increased groundwater salinity. These assets have adaptive capacity. For new assets or assets with low adaptive capacity, enhancing or building in adaptive capacity will be an objective in Adaptation Planning, described below. Redundancy in the system can also increase its adaptive capacity. If one section of roadway, for example, floods, but another section provides at least a portion of the similar service, the system takes advantage of existing opportunities to minimize impacts and might score high for adaptive capacity.

Evaluating adaptive capacity is the most important step in assessing the nature of immediate or short-term adaptation planning. Adaptive capacity determines to a great degree what sea level rise scenario should be selected or adaptation to for a given capital project or suite of capital projects.

Evaluating adaptive capacity is the most important step in assessing the nature of immediate or short-term adaptation planning. As displayed in Table 1, for any given timeframe, sea levels could rise by relatively moderate amount, by an unlikely but possible, upper range amount, or by some amount in between. The adaptive capacity of the asset(s) determines to a great degree what sea level rise scenario should be selected for adaptation for a given capital project or suite of capital projects. If an asset location can adapt today for the most likely sea level rise level and can *relatively easily adapt again* in future decades for an upper range sea level rise condition, then you may plan for the most likely scenario today and incorporate adaptation strategies for future modification. This approach conserves scarce resources (e.g., funding). It is possible, for example, that if sea level rise proceeds at a moderate pace, the upper range figure for the year 2100 might not be reached until 2150 or beyond. Providing for future adaptation in this manner is consistent with “adaptive management” approaches long used in ecosystem science, wherein ecosystem management guidelines are developed based on what is known today, monitoring programs are put in place, and results of that monitoring are used to evaluate subsequent actions in a timely manner.

If an asset location is either impossible or relatively expensive to adapt – select adaptation measures for the upper range sea level rise projections for project planning and implementation today. In this instance, adapting now to long-term worse case scenarios represents an efficient use of resources, protecting valuable public assets against the full range of sea level rise possibilities without the need to re-adapt at great expense in the future.

Goal: At the end of this evaluation, each asset or project component has an exposure, sensitivity, and adaptive capacity rating. The ratings are useful in the risk assessment phase for assessing the consequence of the vulnerabilities, and ultimately, in setting priorities for adaptation planning. Table 4 presents a simple example of a vulnerability assessment matrix for one sea level rise scenario.

As part of the vulnerability assessment phase, the low, medium and high ratings must be defined using thresholds appropriate for the group of assets. No single, simple definition of low, medium and high exists that is applicable for all assets and projects: each department should be internally consistent in defining these ratings to produce supportable criteria for each step in the process. For example, exposure thresholds for low, medium, and high can be defined using inundated depth or inundation duration. This kind of subjective but consistent approach is also appropriate for subsequent phases of this guidance as each department prepares its capital plan.

The sample vulnerability matrix below was developed with the following definitions:

- No exposure or N/A = green = not vulnerable
- A score of 1 = yellow = limited exposure, minimal sensitivity, high adaptive capacity
- A score of 2 = orange = moderate exposure, some sensitivity, medium adaptive capacity
- A score of 3= red = significant exposure, high sensitivity, limited adaptive capacity

A low score (1) is associated with limited exposure, minimal sensitivity, and high adaptive capacity to sea level rise. A low score for all three characteristics would result in an asset with very low overall vulnerability. A high score (3) would represent an asset that is significantly exposed, highly sensitive, or with limited adaptive capacity to sea level rise. A high score for all three characteristics would result in a highly vulnerable asset. Thresholds for the ratings might vary based on different asset types and their tolerance for inundation.

Table 3: Example Vulnerability Matrix for One Sea Level Rise Scenario

Asset	Exposure to 2050 Sea Level Rise [a]		Sensitivity [b]			Adaptive Capacity [c] Total Score			
	Sea Level Rise	**Storm Surge**	**Sea Level Rise**	**Storm Surge**	**Ground-water Rise**	**Sea Level Rise**	**Storm Surge**	**Ground-water Rise**	
Asset #1	None	None	N/A	N/A	Low (1)	N/A	N/A	Low (1)	1
Asset #2	None	Low (1)	N/A	Low (1)	Low (1)	N/A	Low (1)	Low (1)	5
Asset #3	Low (1)	Low (1)	Low (1)	Med (2)	Med (2)	Med (2)	Med (2)	Med (2)	13
Asset #4	Med (2)	Med (2)	Med (2)	High (3)	High (3)	High (3)	Med (2)	High (3)	20
Asset #5	High (3)	High (3)	High (3)	Med (2)	Med (2)	High (3)	High (3)	High (3)	22

As stated above, assets not exposed to sea level rise or storm surge do not need to be considered further as they are not impacted by the sea level rise stressors. Assets that score low for sensitivity or high for adaptive capacity at the risk assessment phase might not need to be considered further as these assets are either not sensitive to the sea level rise impacts, or they have a high ability to adapt without the need for the identification, design, and implementation of new adaptation strategies (see example Asset #2). On the other hand, Assets #3 through #5 in Table 3 are exposed, sensitive to some degree, and have moderate to low adaptive capacity to sea level rise. Because they are at risk, these assets must be considered in the risk assessment phase, during which the consequence determination is made. In sum, the vulnerability assessment will produce a final list of assets, or project components, that warrant further evaluation in the risk assessment phase.

Note that an evaluation of multiple sea level rise and storm surge scenarios to accommodate different time scales or different assumptions about sea level rise might be needed to adequately assess overall vulnerability and to provide useful information to inform the consequence rankings and adaptation planning. The tables in this guidance, therefore, are provided as relatively simple examples of the kind of matrix that should be used by departments.

3. RISK ASSESSMENT

Risk is typically evaluated by comparing the probability that impacts would occur (or *likelihood*) to the *consequence* of these impacts. However, likelihood can be difficult to quantify when considering sea level rise related impacts, as most current scientific studies cannot calculate the probability of a sea level rise projection occurring in any given year or at any particular level. Therefore, when assessing the risk associated with sea level rise vulnerabilities identified through the vulnerability assessment, the most important component of classical risk assessment methods is the evaluation of consequence.

Calculating the consequence of failing to address sea level rise for a particular asset or project is useful in prioritizing assets for adaptation planning. Consequence considers the magnitude of the impact that would occur under the selected sea level rise and storm surge scenarios. Information about the asset, such as its age, condition, and materials are often informative when considering the consequences. The questions below can be useful in framing the consequence of sea level rise related impacts.

- **Damage**:
  - What is the level of damage to the asset?
  - Can the asset be repaired, or would the asset require complete replacement?

- **Disruption**:
  - Is there a disruption in service?
  - If yes, what is the length of that disruption, i.e., hours, days, weeks? Does the disruption threaten public health and safety?
- **Cost**:
  - What is the cost to repair or replace the asset?
  - What are the economic (or health and safety) costs associated with the service disruption?
  - Are there secondary impacts that need to be considered (i.e., costs to other sectors, such as the environment and public recreation)?

The best questions for framing consequence depend on the department and upon asset function or the type of service the asset provides (i.e., essential infrastructure, flood protection, health and safety, public access). The intent of the consequence determination is to develop a means to prioritize assets for adaptation plan development within each department, not CCSF-wide. Table 4 presents a simple example of a consequence matrix for one sea level rise scenario (same hypothetical assets as presented in Table 4); however, additional consequence factors might also be considered in practice, such as factors that consider economics, secondary impacts, or interdependencies. As noted in Table 4, Asset #1 was not considered vulnerable, so it was not evaluated in the risk assessment phase. For this selection of assets, Asset #4 is associated with the highest consequence rating; therefore, the development of an adaptation plan for Asset #4 might be a high priority. As part of the risk assessment phase, the low, medium, and high ratings must be defined using thresholds that are appropriate for the department and the group of assets.

To adequately assess consequences and to develop a prioritized list of short-term and long-term adaptation planning needs, decision-makers might need to evaluate multiple sea level rise and storm surge scenarios to accommodate different time scales or different assumptions about sea level rise.

Table 4: Example Consequence Matrix for one Sea Level Rise Scenario

Asset	Damage			Cost (Repair/Replace)			Disruption			Total Score
	Sea Level Rise	**Storm Surge**	**GW rise**	**Sea Level Rise**	**Storm Surge**	**GW Rise**	**Sea Level Rise**	**Storm Surge**	**GW Rise**	
Asset #1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Asset #2	N/A	Low (1)	N/A	N/A	Med (2)	N/A	N/A	High (3)	N/A	6
Asset #3	Low (1)	Low (1)	Low (1)	Low (1)	Low (1)	Low (1)	Low (1)	Low (1)	Low (1)	9
Asset #4	Med (2)	High (3)	Med (2)	Med (2)	High (3)	Med (2)	Med (2)	High (3)	Med (2)	21
Asset #5	High (3)	High (3)	High (3)	High (3)	Med (2)	High (3)	Low (1)	Low (1)	High (3)	22

4. ADAPTATION PLAN DEVELOPMENT

During this phase, potential adaptation strategies are developed for assets or projects that are identified as vulnerable. The adaptation plan can focus on those assets or projects that also have a high consequence rating. Together, the vulnerability and consequence ratings can help a department develop a prioritized list of assets for adaptation strategy development and implementation. Given that the science of climate change is evolving and sea level rise projections have a wide range of values, projects should adopt a planning horizon based on project lifespan (see sea level rise scenario selection discussion) and include appropriate adaptation strategies to accommodate anticipated sea level rise.

In many instances, it is not feasible nor cost effective to design and build for long-term potential sea level rise scenarios of a highly uncertain nature, such as at the High scenario for the year 2100 (i.e., 6.6 feet of sea level rise). In this case, a project could be designed and constructed for a projected 1.0 feet of sea level rise by 2050, which is consistent with all the scenarios with design elements that enable adaptation to more severe sea level rise scenarios over time. An alternate approach would be to design using the Intermediate scenario (i.e., 3.1 feet of sea level rise by 2100) now while identifying the adaptive capacity of the asset to the High scenario for 2100 (i.e., 6.6 feet) in case future projections indicate that level becomes likely.

This approach seeks to create or enhance the adaptive capacity of the asset or asset location, thereby making that asset resilient. As defined in the Vulnerability Assessment phase description, adaptive capacity defines a project’s ability to adapt in a modular, or step-wise, fashion over time. The adaptation plan for the asset or project should include:

- sea level rise scenario appropriate for near-term project planning and implementation
- adaptation strategies that can be implemented over time if sea level rise exceeds or is anticipated to exceed the original estimate

The adaptation plan should clearly lay out the triggers or time horizons for implementing the identified strategies, and should include a means to monitor and respond to changes in the science or the condition of the asset. This approach can reduce the near term cost of project implementation, while providing for future flexibility and adaptation potential. In addition, the project's adaptation plan should consider the funding mechanism needed for implementing future adaptation strategies.

In evaluating the adaptive capacity of a project, these questions are often asked: does the project, project footprint, or adaptation feature(s) have the ability to be modified or changed to accommodate future higher sea level rise as new data and science emerges? In other words, can project resilience be secured for some logical period of time (e.g., through 2050) and *also* accommodate further adaptation measures based on new developments and science in subsequent years? What are those triggers or time horizons for implementation of adaptation measures (which make the project resilient now) and adaptive management approaches (which allow response to future trends with further measures)? Two examples of how adaptive capacity helps decision making are below:

If, due to site or project constraints, the adaptive capacity of a project is low (i.e. the ability to implement future adaptation strategies in response to new projections of additional sea level rise is low), the worst-case projections in initial adaptation plan development might be merited.

In 2008, the Treasure Island Community Development laid out an adaptation strategy on how to increase the resilience of a new development on Treasure Island to sea level rise and storm surge with a multi-facetted approach, including elevated development areas, wide set-backs and adaptive management strategies at the perimeter that allow for increasing the height of levees in the future.

Image credits: Moffat & Nichol Treasure Island Study 2008

If an existing flood protection feature was designed and constructed in such a way that its height or location can be easily adjusted or increased in the future to accommodate sea level rise or more severe storm surge events, the project would have some inherent adaptive capacity as its ability to accommodate future sea level rise is higher than a project that would require substantial reconstruction to increase its level of protection (see Treasure Island side bar as an example).

ACCOUNTABILITY

Adaptation plans should include clear accountability and trigger points for bringing adaptation strategies online. Departments should develop a well-defined process to meet milestones, consider the latest science, and complete vulnerability assessments as part of the capital planning process.

PERMITTING AND REGULATORY CONSIDERATIONS

Local General Plan and Planning Code and California's two coastal zone management agencies, the San Francisco Bay Conservation and Development Commission (BCDC) and the California Coastal Commission (CCC), regulate public and private development and infrastructure projects located in the City's bay and ocean shoreline areas. These agencies are required to ensure that projects and plans subject to their jurisdiction avoid or minimize hazards related to sea level rise. As such, CCSF departments should consider the applicable state regulations, policies and guidance concerning sea level rise and coordinate with the relevant department staff.

San Francisco Bay Conservation and Development Commission (BCDC)

The San Francisco Bay Conservation and Development Commission (BCDC) has permit jurisdiction over San Francisco Bay and the land lying between the Bay shoreline and a line drawn parallel to, and 100 feet from, the Bay shoreline known as the 100-foot shoreline band. BCDC defines the Bay shoreline along the mean high water elevation.

To accommodate evolving climate science, BCDC's 2011 Bay Plan adopted climate policies that were not prescriptive of specific future climate scenarios or sea level rise projections. Rather, the 2011 Bay Plan refers to the use of "best scientific data". Recently, BCDC has released a Regional Shoreline Adaptation Plan (RSAP, 2024) which contains standards for sea level rise planning under its jurisdiction. The RSAP include coastal flood hazards and sea level rise scenarios standards that are consistent with 2024 State Guidance.

For projects within BCDC's jurisdiction (i.e., generally within 100-feet of the shoreline), a risk assessment must consider the current 100-year base flood elevation[13] coupled with a best estimate of future sea level rise. At a minimum, projects must be "resilient" to midcentury sea level rise and include adaptation strategies that can be implemented over time to increase the project's resilience to end-of-century sea level rise. The guidance in this document is consistent with these minimum standards set forth in the RSAP.

California Coastal Commission (CCC)

All public and private projects in the City's coastal zone must be undertaken in accordance with an approved coastal development permit from either the City Planning Department or the California Coastal Commission (CCC).

The CCC adopted the 2018 State Guidance as best-available science in October 2018 (replacing NRC 2012) and made modifications to the CCC Sea Level Rise Policy Guidance in accordance with this change[14]. The CCC recommends consideration of RCP 8.5 (likely and 1-in-200 chance) and H++ sea level rise projections and does not recommend consideration of RCP 2.6 global greenhouse gas emissions are currently tracking with RCP 8.5. The summary below is related to the October 2018 updates to the CCC Sea Level Rise Policy Guidance. For projects within CCC jurisdiction, the full Guidance document should be reviewed for compliance.

[13] The 100-year base flood elevation is shown on FEMA Flood Insurance Rate Maps (FIRMs). The city of San Francisco currently has preliminary FIRMs, and final FIRMs are anticipated to be effective in 2020.

[14] https://documents.coastal.ca.gov/reports/2018/11/w7d/w7d-11-2018-exhibits.pdf

The CCC adopted the State Guidance's recommendation related to risk tolerance, with the following simplifications:

- **Low risk aversion scenario:** the upper value for the "likely range" (which has approximately a 17 percent chance of being exceeded); may be used for projects that would have limited consequences or a higher ability to adapt.
- **Medium-high risk aversion scenario:** the 1-in-200 chance (or 0.5 percent probability of exceedance); should be used for projects with greater consequences and/or a lower ability to adapt.
- **Extreme risk aversion (H++):** accounts for the extreme ice loss scenario (that does not have an associated probability at this time); should be used for projects with little to no adaptive capacity that would be irreversibly destroyed or significantly costly to repair, and/or would have considerable public health, public safety, or environmental impacts should that level of sea level rise occur.

The CCC recommends taking a long-term view when analyzing sea level rise impacts because land use decisions made today will affect what happens over the long term. The CCC recommends the use of RCP 8.5 (likely and 1-in-200 chance) and H++ sea level rise projections for project planning, design, and adaptation, as well as updates to Local Coastal Programs and other plans, including Long-Range Development Plans, Public Works Plans, Port Master Plans, and other similar planning processes undertaken by coastal communities.

The CCC recommends that all communities evaluate the impacts from the RCP 8.5 1-in-200 chance "medium-high risk aversion" scenario. Local governments should also include the H++ "extreme risk aversion" scenario to evaluate the vulnerability of planned or existing assets that have little to no adaptive capacity, that would be irreversibly destroyed or significantly costly to repair, and/or would have considerable public health, public safety, or environmental impacts should that level of sea level rise occur. Planners can also consider evaluating the lower projections (those with a higher probability) to gain an understanding on what is likely to be vulnerable regardless of modeling uncertainty and future greenhouse gas emissions.

Development within the coastal zone generally requires a Coastal Development Permit (CDP). The CCC recommends that projects requiring a CDP use the RCP 8.5 1-in-200 chance "medium-high risk aversion" scenario and the H++ "extreme risk aversion" scenario when evaluating sea level rise impacts, including the consideration of future inundation, flooding, wave hazards, coastal erosion, rising groundwater levels, and salt-water intrusion.

The CCC also recommends the use of adaptation pathways, which refers to an approach in which planners consider multiple possible futures and analyze the robustness and flexibility of various adaptation options across those multiple futures.

California Environmental Quality Act (CEQA)

Under the California Environmental Quality Act (CEQA), the CCSF is required to consider whether projects that the City undertakes or approves would expose people or structures to a significant risk of loss, injury or death due to flooding. In its role as the City's CEQA lead agency, the Planning Department interprets this requirement to include flooding due to sea level rise. Consistent with this Guidance, the Planning Department evaluates whether projects, both public and private, that are subject to CEQA would be vulnerable to flooding during the project's design life taking into consideration projected sea level rise. For purposes of this analysis, a project vulnerable to flooding during its design life under a 100-year flood condition in combination with projected sea level rise is considered to present a significant risk related to flooding. The Planning Department considers the best available source for sea level rise projections. As such, the methodologies and approach to evaluating risks related to sea level rise recommended in this Guidance are consistent with the City's existing practices under CEQA.

City & County of San Francisco General Plan

The guiding policy document for the City and County of San Francisco is the General Plan. This document, adopted by the Planning Commission and approved by the Board of Supervisors, serves as the embodiment of the community's vision for the future of San Francisco. The charter establishes that changes of use and public construction projects be consistent with this policy document. The General Plan guides decisions that both direct the allocation of public resources and that shape private development. For this reason, managers of capital projects should confirm that their proposed project is consistent with the General Plan early in the planning process. A part of the General Plan is also our Local Coastal Program (LCP). Within the General Plan, the Western Shoreline Plan, combined with the related sections of the San Francisco Zoning Code, and Zoning District Maps, together constitute the City's LCP. Meaning, projects in this area may require review by the City's Planning Commission, the Historic Preservation Commission, the Board of Supervisors, and the Coastal Commission.

Similarly, the Port Commission uses the Waterfront Land Use Plan to govern property under the Port Commission's jurisdiction. The Waterfront Land Use Plan (WLUP) was initially adopted by the Port Commission in 1997. It defines acceptable uses, policies and land use information applicable to all properties under the Commission's jurisdiction. Property under the jurisdiction of the Port may require review by the San Francisco Planning Commission and Board of Supervisors, BCDC, and the State Lands Commission to align the various land use plans and policies held by each entity.

EXAMPLE APPLICATIONS OF GUIDANCE IN CAPITAL PLANNING

The following example illustrates how a City department could consider the effects of sea level and groundwater rise in its capital planning process for several public assets in the same area – the construction of a new police station with subterranean parking garage, the rehabilitation of an existing vacant waterfront building into a visitor center, and the construction of a new shoreline park that raises the grade using lightweight fill. Based on a review of the readily-available inundation maps, these assets would be inundated permanently with 48 inches of sea level rise, and periodically inundated by the following flood scenarios:

- 6 inches of sea level rise plus a 100-year extreme high tide flood event
- 12 inches of sea level rise plus a 50-year extreme high tide flood event
- 24 inches of sea level rise plus a 5-year extreme high tide flood event
- 36 inches of sea level rise and a 1-year annual (King) tide event.

For each asset, the project manager would *select the most appropriate sea level rise scenario*, based on the asset's functional lifespan, location, and other factors, and also determine if using the *most likely* projections is adequate for current planning, or if the *upper end* ranges should be used for more conservative planning or for the development of potential adaptation strategies.

New Police Station

- ***Sea Level Rise Scenario Selection:*** The police station would not be located directly adjacent to the shoreline, but it is within the SLR Inundation Zone. The functional lifespan of the asset is 50 years, the consequence of the structure being flooded is extremely high as the police station is considered an essential asset during emergency situations, and adaptive capacity is limited. The project manager selects the *100-year flood* condition and uses the supplementary document "Sea Level Rise Scenario Selection and Calculating the Design Tide" to determine upper range sea level rise estimate for the year *2065 (34.6 inches as calculated using Appendix 3)* as the appropriate scenario for planning. Due to the location within the SLR Inundation Zone and presence of underground infrastructure, the facility is also exposed to potential groundwater rise.
- ***Vulnerability Assessment*:** Although the police station will not be permanently inundated with 24 inches of sea level rise, it would be inundated by the 100-year flood event for all sea level rise projections greater than 6 inches. The asset is given a *medium exposure* rating, and is considered *highly sensitive* due to its function as a critical infrastructure that must be operational during an extreme flood event.
- ***Risk Assessment*:** If the police station were inundated, it could be repaired at substantial cost. In addition, the disruption of its function during a flood event could lead to public safety impacts. The overall consequence, therefore, of siting the station in an area subject to this level of flooding is determined to be *high*. This project is a high priority for adaptation planning. Additionally, groundwater rise must also be considered in design of the project, such that basement walls, slabs and pumps are properly sized and protected from potential future corrosion.
- ***Adaptation Planning*:** The project manager evaluates raising grades, increasing pump and structural capacities, and flood proofing to increase the adaptive capacity of the police station; however, these improvements are insufficient as access roads surrounding the asset would also be compromised during an extreme flood event. It would be too costly to build in sufficient adaptive capacity to the police station and its surroundings. The project manager decides that the police station should be sited in an alternate location at a higher grade.

Rehabilitated Visitor Center

- ***Sea Level Rise Scenario Selection:*** The existing vacant structure is located directly adjacent to the shoreline where it could be exposed to storm surge and wave hazards. The functional lifespan of the rehabilitated structure is 25 years. The consequence of the structure being flooded is low as the structure is not a critical asset. The project manager selects the *2050* Intermediate *(1 foot) sea level rise estimate as* the appropriate scenario for planning. The project manager also selects the *5-year* and *100-year flood* events for the potential development of adaptation strategies (i.e. adaptive management).
- ***Vulnerability Assessment*:** The visitor center would have a *high exposure* rating based on its location, and a *medium sensitivity* rating since it could be temporarily closed after a flood event until it is repaired. It would have *low adaptive capacity* since the existing building was constructed without consideration of potential future flooding and may only partially recover from a flood event.
- ***Risk Assessment*:** Although damage from an extreme flood event could be moderate to high, the building could likely be repaired. Both the cost to repair the building and its potential disruption of service are considered acceptable. The temporary loss of the visitor center after a flood event would have minimal consequence to the public (no health or safety effects), resulting in an overall *low risk*.
- ***Adaptation Planning:*** The building is proposed to be retrofitted to meet flood resistant building standards, and shoreline improvements are planned that will make the overall site resilient to inundation by a 5-year flood event with 1 foot of sea level rise. The adaptation plan identifies adaptive capacity opportunities and potential shoreline improvements that can be constructed to make the site more resilient to a 5-year storm surge event by 2050. The adaptation plan also identifies short term closure strategies for more severe storm surge events.

New Shoreline Park

- ***Sea Level Rise Scenario Selection:*** A shoreline park site is located directly adjacent to the shoreline in a highly-exposed area. The shoreline improvements are intended to make the overall shoreline and inland developed areas more resilient to sea level rise through 2050 by raising the ground elevation using lightweight fill. The project manager selects the *2050 Intermediate* (1 foot) sea level rise projection for project planning. The project manager also selects the *10-year* and *100-year flood* events for planning purposes. The park will be planned to be resilient to *10-year flood inundation*, and to minimize adverse impacts associated with a *100-year flood event*.
- ***Vulnerability Assessment:*** Based on its location, the park has a *high exposure* rating. The park is given a *low sensitivity* rating since the existing area, and the future park, will accommodate inundation by a range of events. However, the use of lightweight fill introduces the potential for buoyancy at higher levels of sea level rise. The asset is not an existing asset; therefore adaptive capacity is only considered in terms of included design elements.
- ***Risk Assessment:*** The park is expected to require minimal repairs at relatively low cost after being inundated by an extreme event beyond the design event (10-year flood). The consequence to the public of not being able to access the park during repairs is also low. Therefore the overall risk rating is *low risk*.
- ***Adaptation Planning:*** The park will be constructed to accommodate flooding and provide protection to the adjacent areas. Flood resistant materials will be selected to minimize maintenance and repair requirements due to periodic flooding (e.g. benches are made of concrete and are securely anchored to the ground and the park is landscaped with salt tolerant species). The plan outlines shoreline strategies that could be implemented if a higher level of protection is needed to accommodate either higher sea level rates or flood scenarios. These strategies include measures to mitigate potential buoyancy effects through continued balance of surcharge and buoyant forces.

APPENDICES

APPENDIX 1 2014 AND 2019 SEA LEVEL RISE COMMITTEE MEMBERS

The following members comprised the City and County of San Francisco Sea Level Rise Coordinating Committee when the Guidance was developed and adopted in September 2014 and revised in December 2015:

Fuad Sweiss, City Engineer, Department of Public Works

David Behar (Chair), Climate Program Director, San Francisco Public Utilities Commission

Lauren Eisele, Senior Environmental Planner, Port of San Francisco

Frank Filice, Manager of Regulatory Affairs, San Francisco Department of Public Works

Chris Kern, Senior Environmental Planner, San Francisco Planning Department

Kris May, Climate Adaptation Practice Leader, AECOM

Craig Raphael, Transportation Planner, San Francisco Municipal Transportation Agency

Nohemy Revilla, Climate Change Liaison, San Francisco Public Utilities Commission

Anna Roche, Climate Change Adaptation Manager, San Francisco Public Utilities Commission

AnMarie Rodgers, Manager of Legislative Affairs, San Francisco Planning Department

Tania Sheyner, Environmental Planner, San Francisco Planning Department

Brian Strong, Director, San Francisco Capital Planning Program

Dilip Trivedi, Senior Coastal Engineer, Moffat and Nichol

Rosalyn Yu, Associate Engineer, San Francisco International Airport

The following members comprised the City and County of San Francisco Sea Level Rise Coordinating Committee when the Guidance was updated in January 2020:

Brian Strong, Director, Office of Resilience and Capital Planning

AnMarie Rogers, Director, Citywide Planning Division, San Francisco Planning Department

David Behar, Climate Program Director, San Francisco Public Utilities Commission

Boris Deunert, Manager of Regulatory Affairs, San Francisco Public Works

Timothy Doherty, Planning Manager, San Francisco Municipal Transportation Agency

Kris May, Principal, Silvestrum Climate Associates

Lindy Lowe, Resilience Program Director, Port of San Francisco

Alex Morrison, Resilience and Capital Planning Analyst, Office of Resilience and Capital Planning

Anna Roche, Project Manager, Climate Change, San Francisco Public Utilities Commission

Brian Stokle, Planner, San Francisco Parks and Recreation Department

Bimayendra Shrestha, PE, Engineer, San Francisco Public Works

APPENDIX 2 SUMMARY OF THE SCIENCE FOR THE 2019 REVISION

To:	Boris Deunert, Department of Public Works Anna Roche, Public Utilities Commission
From:	Kris May, PhD PE
Subject:	Sea Level Rise Science and Checklist Update
Date:	April 30, 2019

In 2013, former Mayor Ed Lee tasked a Sea Level Rise Technical Committee with reviewing the state-of-the-science and developing guidance for addressing sea level rise vulnerabilities. The committee produced a comprehensive summary of sea level rise science, as well as Guidance for Incorporating Sea Level Rise into Capital Planning in San Francisco, adopted in 2014 and revised and adopted in 2015[15] (CPC Guidance). The CPC Guidance relied on the best available science at the time – the National Research Council's (NRC) 2012 Report, Sea-Level Rise for the Coastal of California, Oregon, and Washington: Past, Present and Future[16]. The NRC Report was also adopted as best available science by the State of California[17] and the California Coastal Commission[18]. However, the science related to understanding climate change and its projected trends and impacts is continually evolving. In response to updated climate science information presented in national and regional reports[19,20,21], the State of California released updated Sea-Level Rise Guidance[22] (State Guidance) in 2018. This memorandum provides a brief update on the latest 2017 and 2018 sea level rise and describes the corresponding updates to the Sea Level Rise Checklist (see attachment). This memorandum also presents the current sea level rise policy recommendations from the California Coastal Commission and the San Francisco Bay Conservation and Development Commission.

---

15 http://onesanfrancisco.org/sea-level-rise-guidance/

16 National Research Council (2012). Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present and Future. Prepared by the Committee on Sea Level Rise in California, Oregon, and Washington, Board on Earth Sciences and Resources, Ocean Studies Board, and the Division on Earth and Life Studies.

17 California Ocean Science Trust (2013). State of California Sea-Level Rise Guidance Document. Developed by the Coastal and Ocean Working Group of the California Climate Action Team (CO-CAT), with science support provided by the Ocean Protection Council's Science Advisory Team and the California Ocean Science Trust.

18 California Coastal Commission (2015). Sea Level Rise Policy Guidance: Interpretive Guidelines for Addressing Sea Level Rise in Local Coastal Programs and Coastal Development Permits.

19 Sweet, W.V., R. Horton, R.E. Kopp, A.N. LeGrande, and A. Romanou, 2017: Sea level rise. In: Climate Science Special Report: Fourth National Climate Assessment, Volume I [Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 333-363, doi: 10.7930/J0VM49F2.

20 Sweet, W.V., R.E. Kopp, C.P. Weaver, J. Obeysekera, R.M. Horton, E.R. Thieler, C. Zervas. 2017. Global and Regional Sea Level Rise Scenarios for the United States. NOAA Technical Report NOS CO-OPS 083.

21 Griggs, G, J. Arvai, D. Cayan, R, DeConto, J. Fox, H.A. Fricker, R.E. Kopp, C. Tebaldi, E.A. Whiteman (California Ocean Protection Council Science Advisory Team Working Group). 2017. Rising Seas in California: An Update on Sea-Level Rise Science. California Ocean Science Trust.

22 http://www.opc.ca.gov/webmaster/ftp/pdf/agenda_items/20180314/Item3_Exhibit-A_OPC_SLR_Guidance-rd3.pdf

HISTORIC SEA LEVEL RISE

Sea levels have risen eight inches over the past century, as measured at the Presidio Tide Gage located near Crissy Field along the San Francisco shoreline. The Presidio Tide Gage is one of the country's major scientific landmarks – the oldest continually operating tide gage in the Western Hemisphere. The tide gage has been collecting tidal observations since June 30, 1854 and has played a central role in understanding the impact of climate change on local and global sea levels. Over the past century, the rate of sea level rise has averaged approximately 2.0 mm/year (~0.1 inches/year), as shown on Figure 1. Since the year 2000, the rate of sea level rise has doubled to roughly 4.8 mm/year (~0.2 inches/year). However, the rate of sea level rise is not constant over time, and fluctuations associated with El Niño/La Niña cycles and the Pacific Decadal Oscillation can be observed within the tidal record. The rate of sea level rise is anticipated to increase at an accelerated rate over the coming century. Understanding how fast sea levels may rise over the coming decades is critical to understanding how the City should respond and adapt, where the City needs to focus adaptation efforts, and how quickly the City needs to implement adaptation solutions.

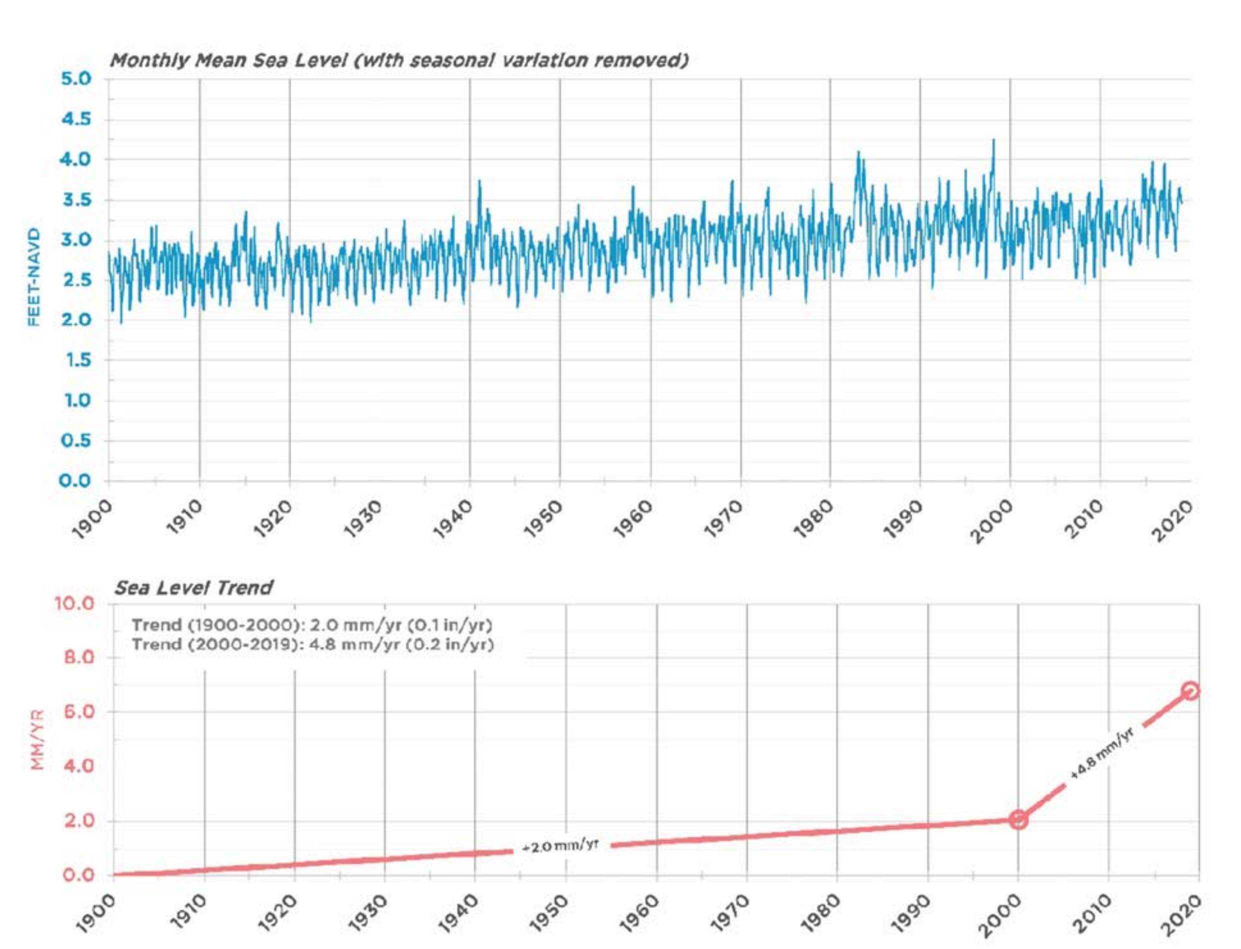

Figure 1. Sea Level Trends at the Presidio Tide Gage

SEA LEVEL RISE PROJECTIONS

In 2014, the Intergovernmental Panel on Climate Change (IPCC) adopted a set of four greenhouse gas concentration trajectories scenarios known as "Representative Concentration Pathways," or RCPs:

- RCP 8.5 assumes anthropogenic global greenhouse gas emissions continue to rise over the next century (i.e., there are no significant efforts to limit or reduce emissions)
- RCP 6.0 assumed anthropogenic global greenhouse gas emissions peak in 2080 and then decline
- RCP 4.5 assumes anthropogenic global greenhouse gas emissions peak in 2040 and then decline
- RCP 2.6 assumes stringent emissions reductions, with anthropogenic global emissions declining by about 70% between 2015 and 2050, to zero by 2080, and below zero thereafter (i.e., humans would absorb more greenhouse gasses from the atmosphere than they emit).

Over the next few decades, climate and sea level rise projections have a high degree of certainty. Very little difference in sea level rise rates across the RCPs is evident between the present and midcentury. After midcentury, greater uncertainty exists and the rate of sea level rise depends on the amount of greenhouse gases emitted globally and on the sensitivity of Earth's climate to those emissions[23].

Current State Guidance[4] recommends using the sea level rise projections associated with RCP 8.5 and RCP 2.6 for planning and design. RCP 8.5 was selected because thus far, worldwide greenhouse gas emissions have continued to follow this trajectory; and RCP 2.6 was selected because, although it will be challenging to achieve at the global scale, it aligns with California's ambitious greenhouse gas reduction efforts. The city of San Francisco has selected RCP 4.5 instead of RCP 2.6 as a more realistic potential lower bound for sea level rise planning since achieving RCP 2.6 requires significant actions at a global scale that are well outside of San Francisco's control.

The State Guidance also includes an extreme scenario (referred to as H++) that represents a future scenario with rapid loss of the West Antarctic ice sheet, under the premise that the physics governing ice sheet mass loss will change after mid-century due to overall warmer global temperatures. The H++ scenario is, at present, highly uncertain and is a topic of ongoing scientific research.

Figure 2 presents the projected sea level rise curves for San Francisco for RCP 2.6, RCP 4.5, RCP 8.5 and H++. For the RCP curves, both the "likely[24]" value of sea level rise and the "1-in-200 Chance[25]" sea level rise projections are presented (the values recommended in the State Guidance). The RCP curves for all three emission scenarios are virtually identical through 2050; however, the curves diverge after 2050, with the highest projected sea level rise associated with 1-in-200 Chance curve for RCP 8.5. It should be noted that the three RCP scenarios still show good general agreement through 2150. The largest uncertainty associated with future sea level rise is related to the rate of Antarctic ice sheet loss, and this is considered separately within the H++ scenario. Estimating the likelihood of the H+ scenario is not possible at this time; therefore, only one curve for H++ is shown on Figure 2.

---

[23] USGCRP, 2017**: Climate Science Special Report: Fourth National Climate Assessment, Volume I** [Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, 470 pp, doi:10.7930/J0J964J6.

[24] The likely value represents the upper end of the "likely range" that includes one standard deviation around the mean. The mean value was not selected by the state of California since the value of sea level rise is just as likely to fall above the mean as it is to fall below the mean. The upper end of the likely range represents a value where sea level rise is more-likely-than-not to fall at or below this value.

[25] A 1-in-200 chance value represents a value with a 0.5% probability of occurring within the suite of model projections associated with a specific RCP. The state of California selected this as a reasonable "upper bound" for sea level rise planning and design, particularly for projects that cannot be adapted over time.

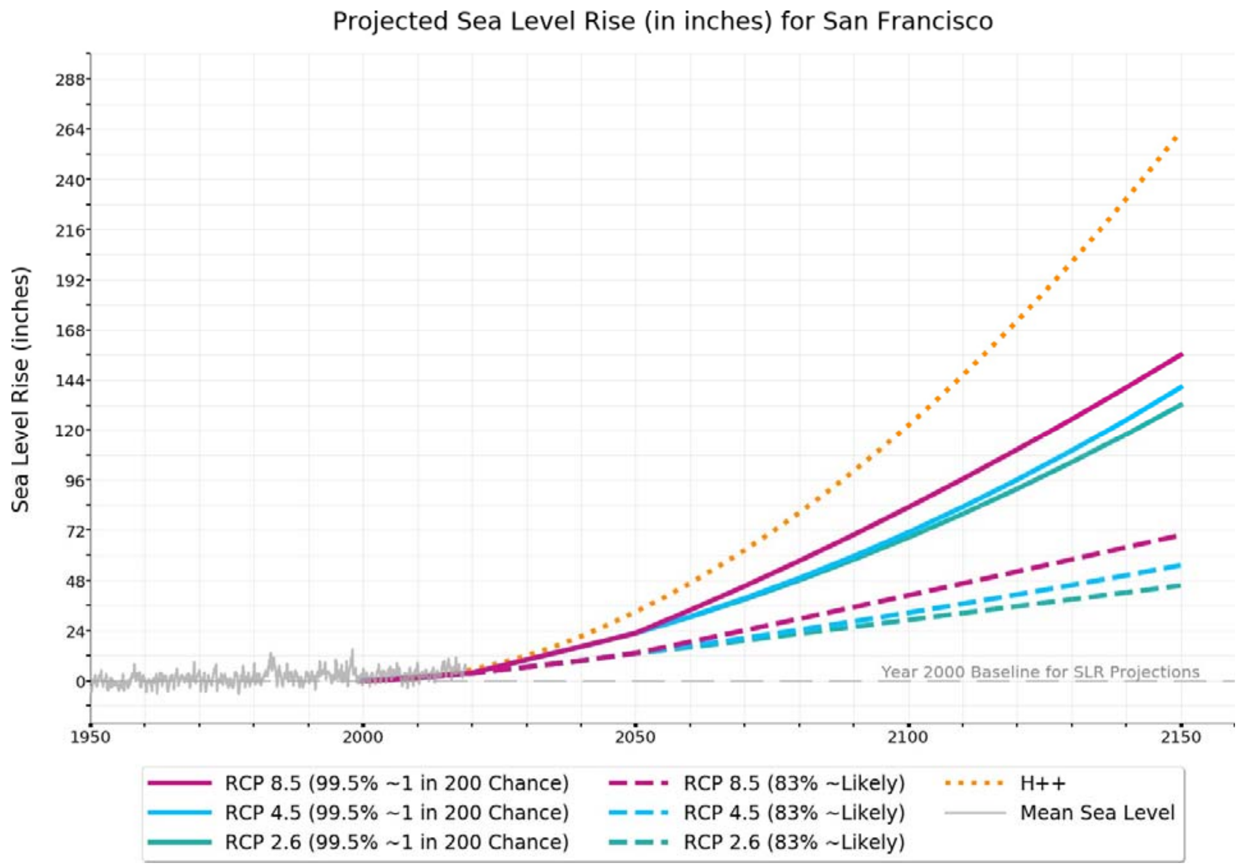

Figure 2. Relative Sea Level Rise in San Francisco, California

RECOMMENDED SEA LEVEL RISE PROJECTIONS

The 2015 CPC Guidance recommended the NRC 2012 sea level rise projections for the likely and upper range scenarios for guiding design and adaptation decisions, respectively (see Table 1). To accommodate the updated science, and the 2018 State Guidance, the Sea Level Rise Checklist has been updated to include the likely and 1-in-200 chance values for RCP 4.5 and RCP 8.5. For the likely values, NRC 2012 recommended using 36 inches at 2100. This compares well with the updated science, which ranges from 33 inches under RCP 4.5 to 41 inches under RCP 8.5. In the 2015 CPC Guidance, the likely value was recommended for most design decisions; therefore, little to no change it needed for compliance with the updated science. For the upper range values which are most often used for adaptation planning, NRC 2012 recommended using 66 inches of sea level rise by 2100. The 1-in-200 chance values for RCP 4.5 and RCP 8.5 both exceed this value, with 71 inches and 83 inches of sea level rise by 2100, respectively. Although this change is minor, it does represent an increase in the amount sea level rise recommended for use in adaptation planning.

Table 1. San Francisco Sea Level Rise Projections

Year	NRC 2012		RCP 4.5 Rising Seas 2017		RCP 8.5 Rising Seas 2017	
	Likely	Upper Range	Likely	1 in 200 Chance	Likely	1 in 200 Chance
2030	6	12	6	10	6	10
2050	11	24	13	23	13	23
2070	20	38	20	39	24	45
2100	36	66	33	71	41	83
2150	--	--	55	140	70	156

SEA LEVEL RISE CHECKLIST UPDATES

The Sea Level Rise Checklist has been updated to accommodate the updated sea level rise projections. On page 3 of the Checklist under Question 12, sea level rise projections for both RCP 4.5 and RCP 8.5 are calculated based on the remaining or potential future functional lifespan of the project (see Questions 3 and 4 of the Checklist).

Future Sea Level Rise Calculations

12. Calculate projected sea level rise at the end of the planning horizon year 2100 (from Question 4.)

(If your project is within 500 feet of the shoreline, or if it provides a critical service for the City, please select RCP 8.5 for all following calculations. If RCP 4.5 is selected, please provide justification for this selection below.)

☐ RCP 4.5
a) 33 in inches and 2.7 in feet -- likely value
b) 71 in inches and 5.9 in feet -- 1-in-200 chance value

☐ RCP 8.5
c) 41 in inches and 3.4 in feet -- likely value
d) 83 in inches and 6.9 in feet -- 1-in-200 chance value

For projects within 500 feet of the shoreline, or for projects that are providing a critical City service (e.g., fire station, water or wastewater pump station, power infrastructure, fixed public transportation infrastructure, etc.), RCP 8.5 should be selected for use in the remainder of the checklist. For inland projects, projects with a limited service life, or projects that can accommodate temporary flooding, RCP 4.5 can be selected. However, if RCP 4.5 is selected, justification for this selection should be provided within the Checklist.

Questions 13, 14, and 15 will auto-calculate the vulnerability of the project to permanent inundation (Question 13), temporary flooding associated with a 100-year extreme high tide (Question 14), and wave hazards associated with a 100-year total water level that includes wave runup along the shoreline (Question 15). It is recommended that the answers to these questions be evaluated under both RCP 4.5 and RCP 8.5 when completing the checklist.

STATE POLICY RECOMMENDATIONS

The following sections provide the sea level rise policies or recommendations provided by the State Guidance, the California Coastal Commission (CCC), and the San Francisco Bay Conservation and

Development Commission (BCDC). It should be noted that CCC and BCDC recommendations are for projects within their respective jurisdictions directly on the Westside (CCC) or Bayside (BCDC) shorelines.

STATE OF CALIFORNIA SEA LEVEL RISE GUIDANCE

The State Guidance recommends selecting the likely, 1-in-200 chance, or H++ scenario for use in planning and adaptation decisions based on the risk tolerance of a project. This approach is intended to ensure that consideration of sea level rise is precautionary enough to safeguard the people and resources of California, and that sufficient adaptation pathways and contingency plans are developed. The selection of the appropriate sea level rise projections is also intended to be flexible to allow for consideration of local priorities and trade-offs; therefore, the recommendations below are not necessarily prescriptive.

- **Projection for decisions with low risk aversion:** Use the upper value of the "likely range" for the appropriate timeframe. This recommendation is fairly risk tolerant, as it represents an approximately 17% chance of being overtopped, and as such, provides an appropriate projection for adaptive, lower consequence decisions (e.g. unpaved coastal trail) but will not adequately address high impact, low probability events. Additionally, it is important to note that the probabilistic projections may underestimate the likelihood of extreme sea-level rise, particularly under high-emissions scenarios.
- **Projection for decisions with medium to high risk aversion:** Use the 1-in-200 chance for the appropriate timeframe. The likelihood that sea level rise will meet or exceed this value is low, providing a precautionary projection that can be used for less adaptive, more vulnerable projects or populations that will experience medium to high consequences as a result of underestimating sea level rise (e.g. coastal housing development). Again, this value may underestimate the potential for extreme sea level rise.
- **Projection for decisions with extreme risk aversion:** Use the H++ scenario for the appropriate timeframe. For high consequence projects with a design life beyond 2050 that have little to no adaptive capacity, would be irreversibly destroyed or significantly costly to relocate/repair, or would have considerable public health, public safety, or environmental impacts should this level of sea-level rise occur, the H++ extreme scenario should be included in planning and adaptation strategies (e.g. coastal power plant). Although estimating the likelihood of the H++ scenario is not possible at this time (due to advancing science and the uncertainty of future emissions trajectory), the extreme sea level rise projection is physically plausible and will provide an understanding of the implications of a worst-case scenario.

CALIFORNIA COASTAL COMMISSION

The CCC adopted the 2018 State Guidance as best-available science in October 2018 (replacing NRC 2012) and made modifications to the CCC Sea Level Rise Policy Guidance in accordance with this change[26]. The CCC recommends consideration of RCP 8.5 (likely and 1-in-200 chance) and H++ sea level rise projections and does not recommend consideration of RCP 2.6 global greenhouse gas emissions are currently tracking with RCP 8.5. The CCC notes that they will continue to update best available science as necessary, including if global emissions trajectories change. The summary below is related

[26] https://documents.coastal.ca.gov/reports/2018/11/w7d/w7d-11-2018-exhibits.pdf

to the October 2018 updates to the CCC Sea Level Rise Policy Guidance. For projects within CCC jurisdiction, the full Guidance document should be reviewed for compliance.

The CCC has adopted the State Guidance's recommendation related to risk tolerance, with the following simplifications:

- **Low risk aversion scenario:** the upper value for the "likely range" (which has approximately a 17% chance of being exceeded); may be used for projects that would have limited consequences or a higher ability to adapt.
- **Medium-high risk aversion scenario:** the 1-in-200 chance (or 0.5% probability of exceedance); should be used for projects with greater consequences and/or a lower ability to adapt.
- **Extreme risk aversion (H++):** accounts for the extreme ice loss scenario (which does not have an associated probability at this time); should be used for projects with little to no adaptive capacity that would be irreversibly destroyed or significantly costly to repair, and/or would have considerable public health, public safety, or environmental impacts should that level of sea level rise occur.

The CCC recommends taking a long-term view when analyzing sea level rise impacts because land use decisions made today will affect what happens over the long term. The CCC recommends the use of RCP 8.5 (likely and 1-in-200 chance) and H++ sea level rise projections for project planning, design, and adaptation, as well as updates to Local Coastal Programs and other plans, including Long-Range Development Plans, Public Works Plans, Port Master Plans, and other similar planning processes undertaken by coastal communities.

The CCC recommends that all communities evaluate the impacts from the RCP 8.5 1-in-200 chance "medium-high risk aversion" scenario. Local governments should also include the H++ "extreme risk aversion" scenario to evaluate the vulnerability of planned or existing assets that have little to no adaptive capacity, that would be irreversibly destroyed or significantly costly to repair, and/or would have considerable public health, public safety, or environmental impacts should that level of sea level rise occur. Planners may also consider evaluating the lower projections (those with a higher probability) to gain an understanding on what is likely to be vulnerable regardless of modeling uncertainty and future greenhouse gas emissions.

Development within the coastal zone generally requires a Coastal Development Permit (CDP). The CCC recommends that projects requiring a CDP use the RCP 8.5 1-in-200 chance "medium-high risk aversion" scenario and the H++ "extreme risk aversion" scenario when evaluating sea level rise impacts, including the consideration of future inundation, flooding, wave hazards, coastal erosion, rising groundwater levels, and salt-water intrusion.

The CCC also recommends the use of Adaptation Pathways, which refers to an approach in which planners consider multiple possible futures and analyze the robustness and flexibility of various adaptation options across those multiple futures.

SAN FRANCISCO BAY CONSERVATION AND DEVELOPMENT COMMISSION

To accommodate evolving climate science, BCDC's 2011 Bay Plan adopted climate policies that were not prescriptive of specific future climate scenarios or sea level rise projections. Rather, the 2011 Bay Plan refers to the use of "best scientific data". BCDC has adopted the 2018 State Guidance as "best scientific data" on sea level rise and no updated to the 2011 Bay Plan are required to accommodate this change.

For projects within BCDC's jurisdiction (i.e., generally within 100-feet of the shoreline), a risk assessment must consider the current 100-year base flood elevation[27] coupled with a best estimate of future sea level rise. At a minimum, projects must be "resilient" to midcentury sea level rise and include adaptation strategies that can be implemented over time to increase the project's resilience to end-of-century sea level rise.

At present, BCDC has not restricted the use full suite of sea level rise scenarios recommended in the State Guidance. BCDC recommends evaluating the full range of possible futures, including a worst-case scenario, so that projects can fully evaluate future adaptation possibilities and constraints. BCDC has not yet finalized recommendations associated with the H++ scenario.

[27] The 100-year base flood elevation is shown on FEMA Flood Insurance Rate Maps (FIRMs). The city of San Francisco currently has preliminary FIRMs, and final FIRMs are anticipated to be effective in 2020.

APPENDIX 3 SCIENCE BASIS FOR 2015 REVISION

SCIENCE RESEARCH AND FINDINGS OF THE SEA LEVEL RISE COMMITTEE SUPPORTING RECOMMENDED SEA LEVEL RISE ESTIMATES FOR CAPITAL PLANNING

Prepared by David Behar
Chair, Sea Level Rise Committee
Climate Program Director, San Francisco Public Utilities Commission
September 15, 2014

There is significant uncertainty associated with climate change. This uncertainty relates not to the *fact* of climate change, of which there is virtually no doubt within scientific circles, but to the *nature* and *scope* of climate change's secondary effects such as sea level rise (SLR). New projections are emerging regularly, models are getting more complex, and observations are accumulating. In such a dynamic environment, decision-makers are regularly cautioned by climate scientists and science translation professionals to never rely upon a single source of information, be it a single climate model or a single expert, and to carefully consider uncertainties in the science when planning adaptation. At the same time, we know seas are rising and will continue to rise at an accelerated rate, threatening valuable infrastructure and public safety. We don't have the luxury to wait for perfect information to arrive before assessing and, where advisable, adapting to the effects of sea level rise.

The Sea Level Rise Committee (Committee) of the City and County of San Francisco (CCSF) surveyed three of the most highly respected science bodies and their recent reports in developing this Guidance.

Intergovernmental Panel on Climate Change (IPCC) The most highly respected international climate science body is the Nobel Prize-winning IPCC. The IPCC's 5th Assessment Report (Working Group I) was released in September, 2013 and included a comprehensive chapter on global sea level rise.

> *Climate Change 2013: The Physical Science Basis. Working Group 1 Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Summary for Policymakers. 2013. Intergovernmental Panel on Climate Change.*

National Research Council (NRC) The NRC is the principal operating agency of the National Academy of Sciences and National Academy of Engineering. In 2008, Governor Schwarzenegger in Executive Order S-13-08 asked the NRC to assess sea level rise in California to assist state agencies planning adaptation. Subsequently, the states of Washington and Oregon, as well as U.S. Army Corps of Engineers, National Oceanic and Atmospheric Administration, and U.S. Geological Survey joined California in sponsoring this study, which was released in 2012.

> *Sea Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future. National Research Council, 2012*

National Climate Assessment (NCA) The NCA is a massive national study mandated by Congress as a state-of-the-art assessment of the nation's vulnerability to climate change. At the time of the Committee's deliberations, the final 2014 NCA was not out, but an article commissioned by the NCA on SLR had been released.

> Parris, A., et al. *Global Sea Level Rise Scenarios for the United States National Climate Assessment*, December 6, 2012, produced for NOAA, USGS, SERDP and USACE.

In addition to the above reports, the Committee reviewed two important state agency documents providing guidance to government agencies seeking, like CCSF, to incorporate sea level rise projections into planning. These guidance documents were:

> *State of California Sea-Level Rise Guidance Document. Developed by the Coastal and Ocean Working Group of the California Climate Action Team (CO-CAT), with science support provided by the Ocean Protection Council's Science Advisory Team and the California Ocean Science Trust. March 2013 Update.*
>
> *California Coastal Commission Draft Sea-Level Rise Policy Guidance. California Coastal Commission, Public Review Draft. October 14, 2013.*

Finally, the Committee also used a peer-reviewed survey of 90 international sea level rise experts to discern consensus estimates of SLR through the end of the century:

> *Benjamin P. Horton, Ramstorf, S, Engelhart, S, and Kemp, A. Expert assessment of sea-level rise by AD 2100 and AD 2300, Quarternary Science Reviews 84 (2014) 1-6.* [28]

While a case could have been made that any of these sources individually represented "best available science" and could have been used alone to set policy, the Committee believed the strongest basis for planning would exist if a scientific consensus could be extracted from these sources. At first glance, however, the leading science reports appeared to provide a dizzying array of projections that held little hope of consensus. The range of sea level rise projections for the year 2100 provided by the scientific bodies cited above are shown in Figure 1.

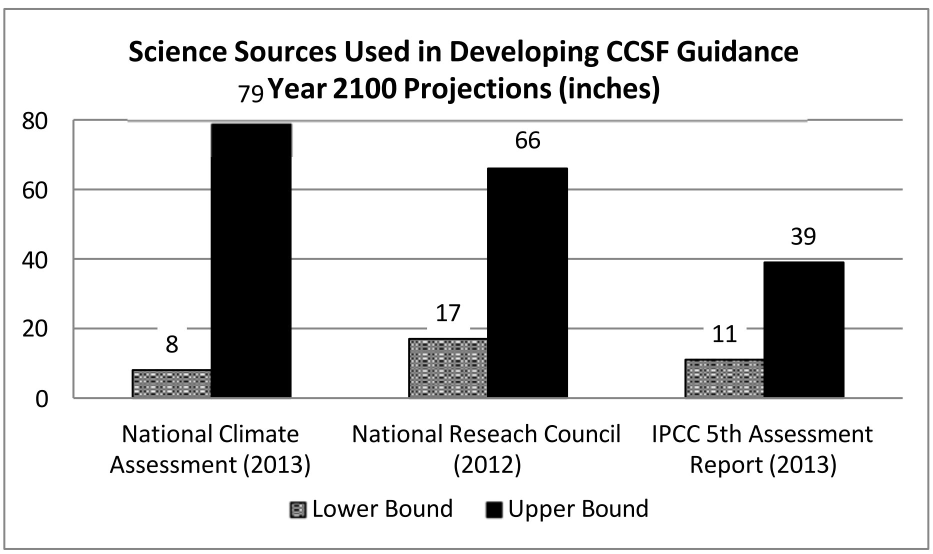

Figure 1: Science sources used by the SLR Committee in developing Guidance. These are the "ranges," or low and high bounded estimates, provided by each source.

In particular, the upper estimates for SLR in 2100 in each report are strikingly different, particularly for the IPCC, whose upper bound of 39 inches is markedly different than the figures for NCA and NRC.

[28] This Summary of the Science does not review the findings related to either the NCA paper or the Horton, et al journal article. The information presented in each was found by the Committee to agree sufficiently with the conclusions outlined in this Summary to support the Committee's recommendations.

The IPCC made the following statement explaining why it rejected estimating global SLR higher than 39 inches in 2100:

> The basis for higher projections of global mean sea level rise in the 21st century has been considered and it has been concluded that there is currently insufficient evidence to evaluate the probability of specific levels above the assessed *likely* range. Many semi-empirical model projections of global mean sea level rise are higher than process-based model projections (up to about twice as large), but there is no consensus in the scientific community about their reliability and there is thus *low confidence* in their projections (emphasis in original). [29]

This reflects the approach of the IPCC, a demanding scientific consensus-building process with over 800 authors from over 100 countries requiring strong agreement before making official statements. In this instance, a consensus did not exist that significant land ice melt in Antarctica and Greenland beyond what is currently projected is likely to occur. Substantial Antarctic and Greenland melt leads to the highest SLR estimates for 2100 in the literature.

The NRC report was found by the Committee to be different from IPCC in a number of ways. First, its origins in California Executive Order S-13-08 gave it special credence in Sacramento, and ostensibly particular usefulness for local and regional planners. Second, with a relatively small committee of thirteen scientists, it could venture into worst case scenarios, including for land ice melt – and did. And third, the report provided projections of *relative* sea level rise, as well as global SLR, by incorporating estimates of local thermal expansion of seawater, wind driven components, land ice melt local effects, and vertical land motion to differentiate relative SLR for different coastal regions across the west coast of the United States.[30]

Reflecting its origins in the Schwarzenegger Administration, the NRC report was adopted as “best available science” by the State of California when it came out and provided the basis of state guidance cited above from CO-CAT/OPC/OST and from the Coastal Commission. Both entities cited the ranges for each of three time periods cited in the report, as shown in Figure 2.

---

[29] IPCC, Summary for Policymakers, p. 24.

[30] The chief differentiator among relative sea level rise projections along the west coast derives from vertical land motion estimates, which show uplift (reducing relative sea level rise) of lands north of Cape Mendocino and subsidence (increasing relative sea level rise) of lands south of Cape Mendocino. For San Francisco, then, the upper bound SLR figure of 66 inches in NRC reflects approximately 55 inches in estimated *global* SLR plus an additional 11 inches in *subsidence* by the year 2100. Inquiries by the SLR Committee of NRC report authors revealed that the vertical land motion estimates contained in the report are relatively coarse for these regions. Alternative figures that more accurately reflect VLM for San Francisco’s shorelines, however, were unavailable at the time this Guidance was developed. Monitoring progress in more accurately representing VLM for our shorelines should be a focus when revisiting this Guidance.

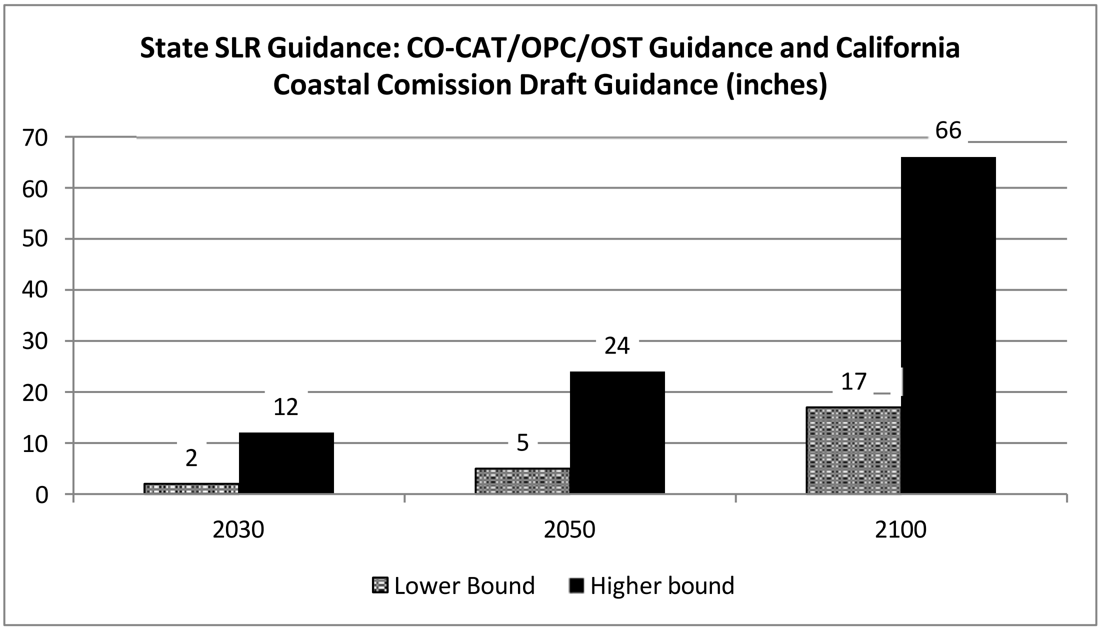

Figure 2: Ranges of SLR cited by two State of California sea level rise guidance documents as of 2013. These represent low and high end ranges for the three time periods covered in the NRC report.

While use of these sole-sourced figures has the advantage of eliminating confusion between competing sources, the Committee didn't feel qualified to differentiate between sources so readily. More important, it found such broad ranges problematic in an adaptation context. Clearly, very different adaptation prescriptions are called for in the instance of, for example, planning for the year 2050, where NRC and the state guidance document articulate possibilities from five inches of SLR to twenty-four inches of SLR. When spending public dollars on potentially expensive adaptation solutions, these ranges do not provide "actionable" information.

In the course of its work, however, the Committee discovered an important element of the NRC report not reflected in state Guidance. The NRC report in fact describes not just upper and lower bounds of SLR, but in addition "projections" of SLR of an intermediate nature. Where the ranges were intended to present best and worst case scenarios, the "projections" were developed to show more plausible, likely scenarios based on what we know today. Though presented in numerous places in the NRC report, [31] the narrative did not clearly and articulately explain the differences and use value of each estimate. This failure on the part of the NRC may help explain the omission of the "projections" from state guidance documents. This kind of confusion is actually common in the interface between science and society and illustrates a widely documented challenge faced by a climate change adaptation community seeking to translate highly technical science products into language understandable to decision makers.

The differences between the ranges and projections are substantial. For 2100, for example, the projection figure is 36 inches; for 2050 it is 11 inches. For each projection figure, the report adds one standard deviation (1 σ) to bound uncertainty; in the case of 2100, those figures are 36 inches +/- 10 inches. Figure 3 shows both the ranges and projections with standard deviations from the NRC report.

[31] Including Table 5.2 (p. 89); Figure 5.5 (p. 93); Table 5.3 (p. 96); Figure 5.10 (p. 103); Figure S.1 (p. 5), which is repeated as Figure 5.9 (p. 102); and the narrative beginning on page 92.

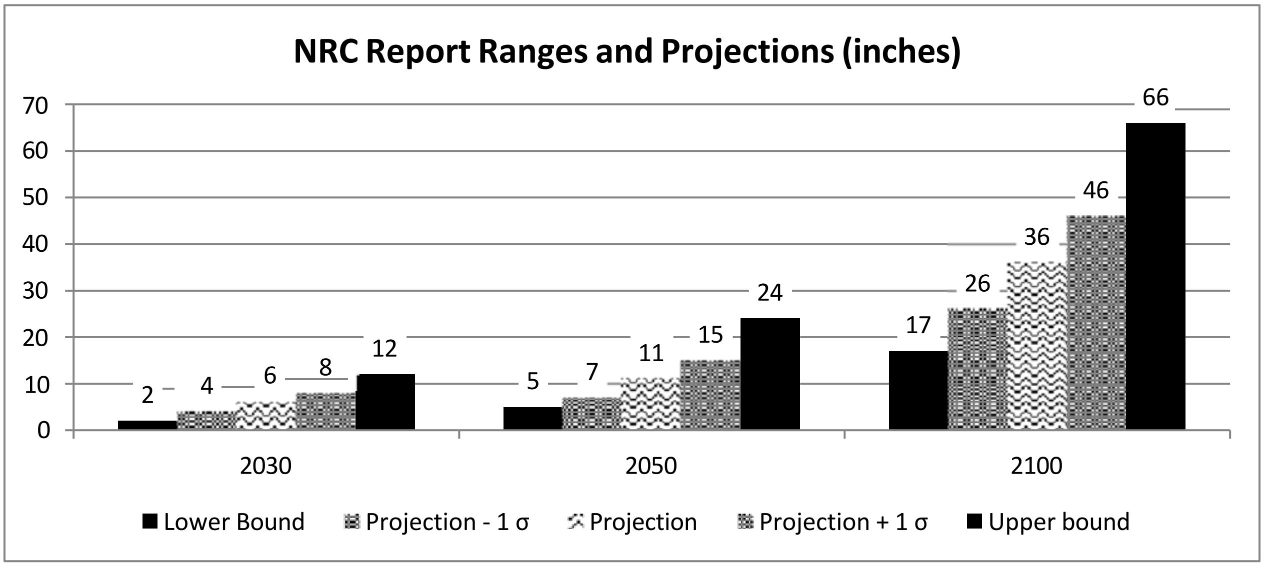

Figure 3: Projections and Ranges for sea level rise in NRC Report. The projections include both the mean of models used ("projection") and +/- one standard deviation (projection - 1 σ, projection + 1 σ).

Overall, the mid-level "projection" figures represent the *most likely* SLR effects expected, while the "ranges" are considered by scientists to be *possible, but unlikely.*[32] In this understanding, and contrary to initial impressions, the NRC figures actually mirror the IPCC 5th Assessment Report figures – NRC's projection of 36 inches and IPCC's high end estimate of 39 inches are extremely close and both represent consensus estimates of likely sea level rise for 2100. At the same time, state guidance documents presented the upper and lower bounds in that report to bracket the adaptation challenge but omitted the likely figures from NRC, which the CCSF Sea Level Rise Committee believes are very useful[33]. A summary of all these sources – and estimates for SLR recommended by the Committee for use in planning by the City and County of San Francisco, is shown in Figure 4.

[32] We are using these terms as understood in plain English to articulate the meaning behind the science for a lay audience, rather than in a formalized definition of terms such as "likely" as IPCC and other climate science entities sometimes define them. Support for these characterizations can be found in: Pfeffer, W.T., et al. *Kinematic Constraints on Glacier Contributions to 21st-Century Sea-Level Rise,* Science, Vol 321 (2008); and *Climate Change 2013: The Physical Science Basis. Working Group 1 Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, *Summary for Policymakers.* 2013. p. 23-24. Intergovernmental Panel on Climate Change. Also: Personal communication, Tad Pfeffer (NRC Report co-author).

[33] The Ocean Science Trust, in response to comments from the SFPUC, recommended in September 2014 that the Ocean Protection Council make reference in some fashion to the projection figures in their Guidance or supplemental materials. This action is pending.

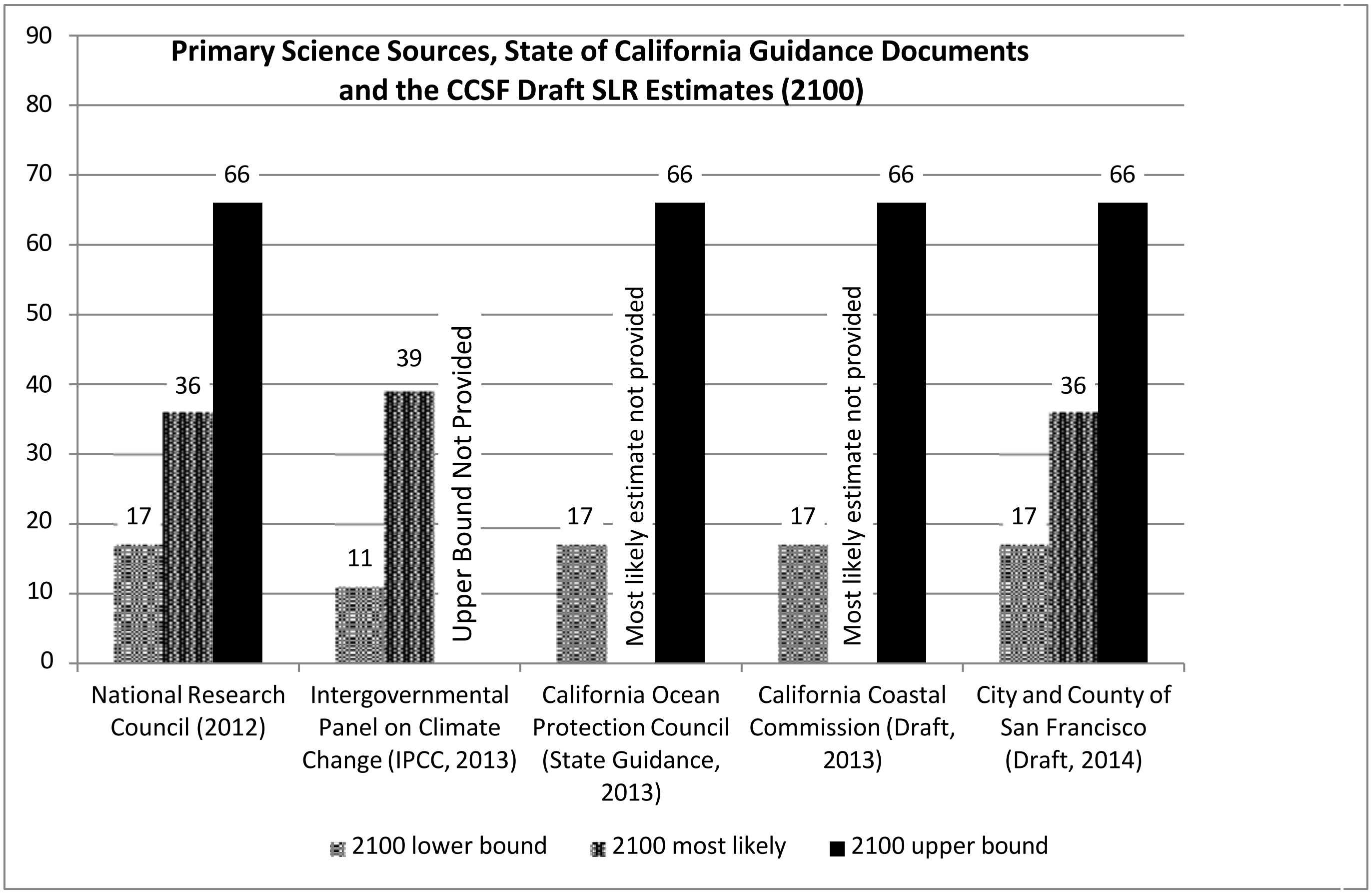

Figure 4: SLR estimates for two key science and two key state guidance documents, with lower, most likely, and upper estimates – and omitted estimates where applicable, characterized based on SLR Committee research and findings. The selected estimates in the CCSF SLR Guidance are included and are identical to those presented in the NRC report.

With this understanding, the Committee found that the NRC report does indeed represent "best available science" on sea level rise at this time, that the sea level rise estimates presented in that report should be used in full in adaptation planning for the City and County of San Francisco, and that this science is consistent with that presented by the IPCC in the 5th Assessment Report and other sources reviewed by the Committee.

If departments want to make sea level rise calculations for years other than 2030, 2050, and 2100, a simple interpolation "best fit" equation may be used. Different equations are required for the projections and the upper end of range estimates in the NRC Report and this Guidance because each estimate of accelerated increase in sea levels has its own curve.

The following equations produce SLR estimates *in centimeters* for the upper end of range and most likely projection for years other than 2030, 2050, and 2100:

1. Upper End of Range (cm) Unlikely but possible = $0.00925t^2 + 0.73959t$

2. Projection – Most Likely (cm) = $0.00678t^2 + 0.23960t$

Where "t" is the number of years after 2000

For example, if an asset has an expected life of 60 years and you wanted to know the upper range of sea level rise between 2000 (the baseline year for all estimates in this Guidance) and 2060, you would use Equation (1), with t = 60.

Upper Range (cm)	$= 0.00925 \times (60)^2 + (0.73959 \times 60)$
	= 33.30 + 44.37
	= 77.67 cm, SLR in 2060, Upper Range
Convert to inches	= 77.67 / 2.54 cm/inch
	= 30.6 inches, Upper Range for sea level rise in 2060