CHAPTER 2

SEA LEVEL RISE CLIMATE SCIENCE AND SCENARIOS

In 2013, former San Francisco Mayor Ed Lee tasked a Sea Level Rise Technical Committee with reviewing the state-of-the-science and developing guidance for addressing SLR vulnerabilities. The committee produced a comprehensive summary of SLR science, as well as Guidance for Incorporating Sea Level Rise into Capital Planning in San Francisco (CPC Guidance), adopted in 2014 and revised in 2015.¹ The SLR capital planning checklist (a portion of the CPC Guidance) was updated in 2019 based on updated State science projections.

The CPC Guidance and the 2016 Sea Level Rise Action Plan relied on the best available science at the time – the National Research Council's (NRC's) 2012 Report, *Sea-Level Rise for the Coast of California, Oregon, and Washington: Past, Present and Future.*² The NRC report was also adopted as best available science by the State of California³ and the California

- 1 http://onesanfrancisco.org/sea-level-rise-guidance/
- 2 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.
- 3 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

Coastal Commission.⁴ However, the science related to understanding climate change and its projected trends and impacts is continually evolving. In response to updated national and regional reports,⁵⁶ ⁷ the State of California released updated Sea-Level Rise Guidance ⁸ (State Guidance) in 2018.

This chapter discusses historical changes in local sea levels, presents updated SLR projections consistent with the current science and State Guidance, and describes the 10 mapped SLR and storm surge scenarios used in this Assessment.

provided by the Ocean Protection Council's Science Advisory Team and the California Ocean Science Trust.

- 4 California Coastal Commission. 2015. Sea Level Rise Policy Guidance: Interpretive Guidelines for Addressing Sea Level Rise in Local Coastal Programs and Coastal Development Permits.
- 5 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.
- 6 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.
- 7 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.
- 8 http://www.opc.ca.gov/webmaster/ftp/pdf/agenda_items/20180314/ Item3_Exhibit-A_OPC_SLR_Guidance-rd3.pdf

2.1 HISTORICAL SEA LEVEL RISE

The Presidio Tide Gauge located near Crissy Field along the San Francisco shoreline is one of the country's major scientific landmarks – the oldest continually operating tide gauge in the Western Hemisphere. The tide gauge 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. Sea levels have risen eight inches between 1900 and 2000, as measured at the Presidio Tide Gauge, and SLR has accelerated in the most recent decades (see Figure 2.1). SLR is projected to rise at a more accelerated rate over the next century (i.e., SLR is not anticipated to be linear and the rate of rise will continue to increase). The modest historical rise in sea levels in the open Pacific Ocean and San Francisco Bay is already impacting San Francisco with periodic coastal flooding of low-lying shorelines and increased shoreline erosion. As sea levels rise further over the coming decades, the frequency and extent of coastal flooding will increase. Where shorelines are built on Bay fill, subsidence may further intensify flooding risks, and higher groundwater levels may increase liquefaction and seismic risks during earthquakes. 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.







2.2 SEA LEVEL RISE PROJECTIONS

Over the next few decades, climate and SLR projections have a relatively high degree of certainty. After mid-century, the changes are harder to forecast and depend on the amount of greenhouse gases (GHGs) emitted globally and on the sensitivity of Earth's climate to those emissions.⁹ In 2014, the Intergovernmental Panel on Climate Change (IPCC) adopted a set of four GHG concentration trajectories scenarios known as "Representative Concentration Pathways," or RCPs:

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

Current State Guidance relies primarily on RCP 8.5 and RCP 2.6. RCP 8.5 was selected because, thus far, worldwide GHG 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 GHG reduction efforts. To date, the City of San Francisco has selected RCP 4.5 instead of RCP 2.6 as a more realistic potential lower bound for SLR planning for two reasons. First, voluntary GHG emissions controls agreed to by all nations participating in the Paris Climate Agreement ("nationally determined contributions"), if successfully implemented, will result in warming by 2100 roughly equal to the RCP 4.5 scenario. And second, RCP 2.6 assumes significant actions at a global scale that are neither underway nor under San Francisco's control.

The State Guidance also includes an extreme scenario (referred to as H++). This scenario represents a future with rapid Antarctic ice sheet mass loss, 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 2.2 presents the projected SLR curves for San Francisco for RCP 2.6, RCP 4.5, RCP 8.5, and H++. For the RCP curves, both the "Likely" value of SLR and the "1 in 200 Chance" SLR projections are presented.¹⁰ The RCP curves for all three emission scenarios are virtually identical through 2050; however, the curves diverge after 2050, with the highest projected SLR associated with 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 SLR is related to the rate of Antarctic ice sheet loss; therefore, this uncertainty is considered separately with the H++ scenario.

The CPC Guidance recommends the NRC 2012 SLR projections for the "Likely" and "Upper Range" scenarios for guiding design and adaptation decisions, respectively. The 2018 State Guidance recommends a different suite of SLR projections. Although the NRC 2012 and State Guidance projections compare reasonably well, the State Guidance recommends slightly different projections in the latter half of the century. For example, the recommended upper range number for long-range (2100) adaptation planning increases from 66 inches (NRC 2012) to between 71 and 83 inches (State Guidance). In addition, the recommended likely value of SLR at 2100 changes from 36 inches (NRC 2012) to 33 to 41 inches (State Guidance).

⁹ 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.

¹⁰ The "Likely" and "1 in 200 Chance" SLR projections are adopted from Kopp et al 2014. These probabilities are "Bayesian probabilities" that consider the likelihood of the SLR projection occurring given a defined set of global circulation model inputs for a specific GHG concentration trajectory. Therefore, each GHG concentration trajectory (e.g., RCP4.5 or RCP8.5) has its own distinct set of Bayesian probabilities. These probabilities are not the same as the more commonly used statistical analyses of historic events, such as the FEMA 1-percent annual chance flood event (a one in 100 Chance event). Although the terminology is similar, historical probabilities of past events are generally well defined based on historical observations, while probabilities and modeling, and different approaches may create different probabilities. As a result, their use as "predictions," or in a simple risk assessment context (Risk = Consequence X Likelihood), is typically discouraged.

Figure 2.2 Relative Sea Level Rise in San Francisco, California



Projected Sea Level Rise (in inches) for San Francisco

Table 2.1 San Francisco Sea Level Rise Projections (inches)

	NRC 2012		RCP 4.5 Ris	ing Seas 2017	RCP 8.5 Rising Seas 2017	
Year	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

2.3 SEA LEVEL RISE AND STORM SURGE SCENARIOS

This Assessment relies on a full range of SLR scenarios, from 12 to 108 inches, which provide compatibility with both the CPC Guidance and the State Guidance. This Assessment employs the "One Map, Many Futures" framework developed through the Adapting to Rising Tides (ART) program created by the San Francisco Bay Conservation and Development Commission (BCDC). The One Map, Many Futures approach defines 10 primary scenarios that represent a range of possible combinations of extreme tide levels and SLR.¹¹ Table 2.2 presents the 10 scenarios

11 For a complete discussion of the inundation scenarios and mapping, refer to Adapting to Rising Tides Bay Area Sea Level Rise Analyses and Mapping Project, Final Report, September 2017. Prepared by AECOM for the Bay Conservation and Development Commission, the Metropolitan Transportation Commission, and the Bay Area Tool Authority.

http://www.adaptingtorisingtides.org/project/ regional-sea-level-rise-mapping-and-shoreline-analysis/.

Table 2.2

Sea Level Rise Scenario (Inches above MHHW)

Mapping Scenario	Reference Water Level			
Scenario 1	MHHW + 12"			
Scenario 2	MHHW + 24"			
Scenario 3	MHHW + 36"			
Scenario 4	MHHW + 48"			
Scenario 5	MHHW + 52"			
Scenario 6	MHHW + 66"			
Scenario 7	MHHW + 77"			
Scenario 8	MHHW + 84"			
Scenario 9	MHHW + 96"			
Scenario 10	MHHW + 108"			

MHHW = Mean Higher High Water

" = inches

	Daily Tide	aily Tide Extreme Tide (Storm Surge)							
Cool ovel Disc	+SLR (in)	1-year	2-year	5-year	10-year	25-year	50-year	100-year	
Scenario	Water Level above MHHW (in)								
Existing Conditions	0	12	19	23	27	32	36	41	
MHHW + 6"	6	18	25	29	33	38	42	47	
MHHW + 12"	12	24	31	35	39	44	48	53	
MHHW + 18"	18	30	37	41	45	50	54	59	
MHHW + 24"	24	36	43	47	51	56	60	65	
MHHW + 30"	30	42	49	53	57	62	66	71	
MHHW + 36"	36	48	55	59	63	68	72	77	
MHHW + 42"	42	54	61	65	69	74	78	83	
MHHW + 48"	48	60	67	71	75	80	84	89	
MHHW + 52"	52	64	71	75	79	84	88	93	
MHHW + 54"	54	66	73	77	81	86	90	95	
MHHW + 60"	60	72	79	83	87	92	96	101	
MHHW + 66"	66	78	85	89	93	98	102	107	

Table 2.3 Sea Level Rise and Extreme Tide Matrix



Figure 2.3 Comparison of the SLR Vulnerability Zone and H++ with 100-year Storm Surge

H++ with 100 Year Storm Surge

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relative to SLR in inches above mean higher high water (MHHW). When expanded to consider extreme tides ranging from the 1-year to the 100-year recurrence frequency, these 10 scenarios can represent a matrix of over 50 possible combinations of SLR and extreme tides (see Table 2.3).

Table 2.3 presents the relationship between each scenario and different combinations of SLR and extreme tides. For example, Scenario 1 (MHHW + 12") can represent 12 inches of SLR (permanent inundation) or an annual extreme high tide with a 1-year recurrence interval (often correlated with a King Tide condition). Scenario 3 (MHHW + 36") could represent the area inundated with 36 inches of SLR (permanent inundation), or a temporary flood event today with a 50-year recurrence interval, or a range of SLR and extreme tide combinations in between the two bookends.

2.4 SEA LEVEL RISE VULNERABILITY ZONE VS. H++

In 2014, the City adopted a SLR Vulnerability Zone that represents an area that could be flooded by the end of the century by a 100-year coastal flood event coupled with 66 inches of SLR – a high-end scenario. Sixty-six inches of SLR represents the upper-bound SLR projection in NRC 2012. The SLR Vulnerability Zone was defined to identify potential public capital projects that must complete a Sea Level Rise Checklist as part of the submission to the Ten-Year Capital Plan. The CPC Guidance requires a completed checklist if a project falls within the SLR Vulnerability Zone.

Figure 2.3 presents a comparison of the area within the SLR Vulnerability Zone (108 inches) and the area that falls within H++ scenario coupled with a 100-year extreme tide (164 inches).¹²

The H++ scenarios include a high degree of uncertainty and were developed for the Bay shoreline due to the differences in the water level and wave dynamics in the Bay and the open Pacific Ocean. The extent of inundation is largely controlled by the changes in topography. That is, inundation is limited to the low-lying areas along the shoreline and does not directly flood the steep hills and upland areas.

For comparison purposes, the area inundated by the SLR Vulnerability Zone in Figure 2.3 is 3.9 square miles, H++ is 4.4 square miles (not shown on map), and the H++ plus 100-year extreme tide scenario is 5.5 square miles. At this time, the H++ scenarios are not used for planning or adaptation purposes; however, they help illustrate the uncertainties that remain with respect to the longer-term SLR projections.

2.5 DECISION MAKING WITH EVOLVING CLIMATE SCIENCE

Climate change science and SLR projections are continually evolving. This Assessment includes analysis of a wide range of possible scenarios between now and 2100, but it does not include the most extreme emerging science. Depending on future global climate mitigation efforts and the behavior of Antarctic ice sheets, the City may need to assess higher water levels in the future.

This assessment provides actionable information for near- and mid-term adaptation, but the work to increase the City's resilience to SLR is not complete. Adapting to SLR and other climate hazards and impacts will require ongoing monitoring of the science and local impacts, as well as applying lessons from the implementation of adaptation solutions within San Francisco and the larger San Francisco Bay Area region.

¹² It should be noted that the 100-year extreme tide (the Bay water level with a 1 percent annual chance of occurring in any even given year) would most likely change dramatically if the San Francisco Bay experiences 122 inches of SLR. However, in the absence of better information, the existing 100-year extreme tide was used for comparison purposes. The H++ plus 100-year extreme tide inundation boundary was provided by BCDC.

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Sunrise on Ferry Building in San Francisco Photo by Thomas Hawk (CC BY-NC 2.0)