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CLIMATE ASSOCIATES

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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[1] (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[2]. The NRC Report was also adopted as best available science by the State of California[3] and the California Coastal Commission[4]. 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[5,6,7], the State of California released updated Sea-Level Rise Guidance[8] (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.

[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 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

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.

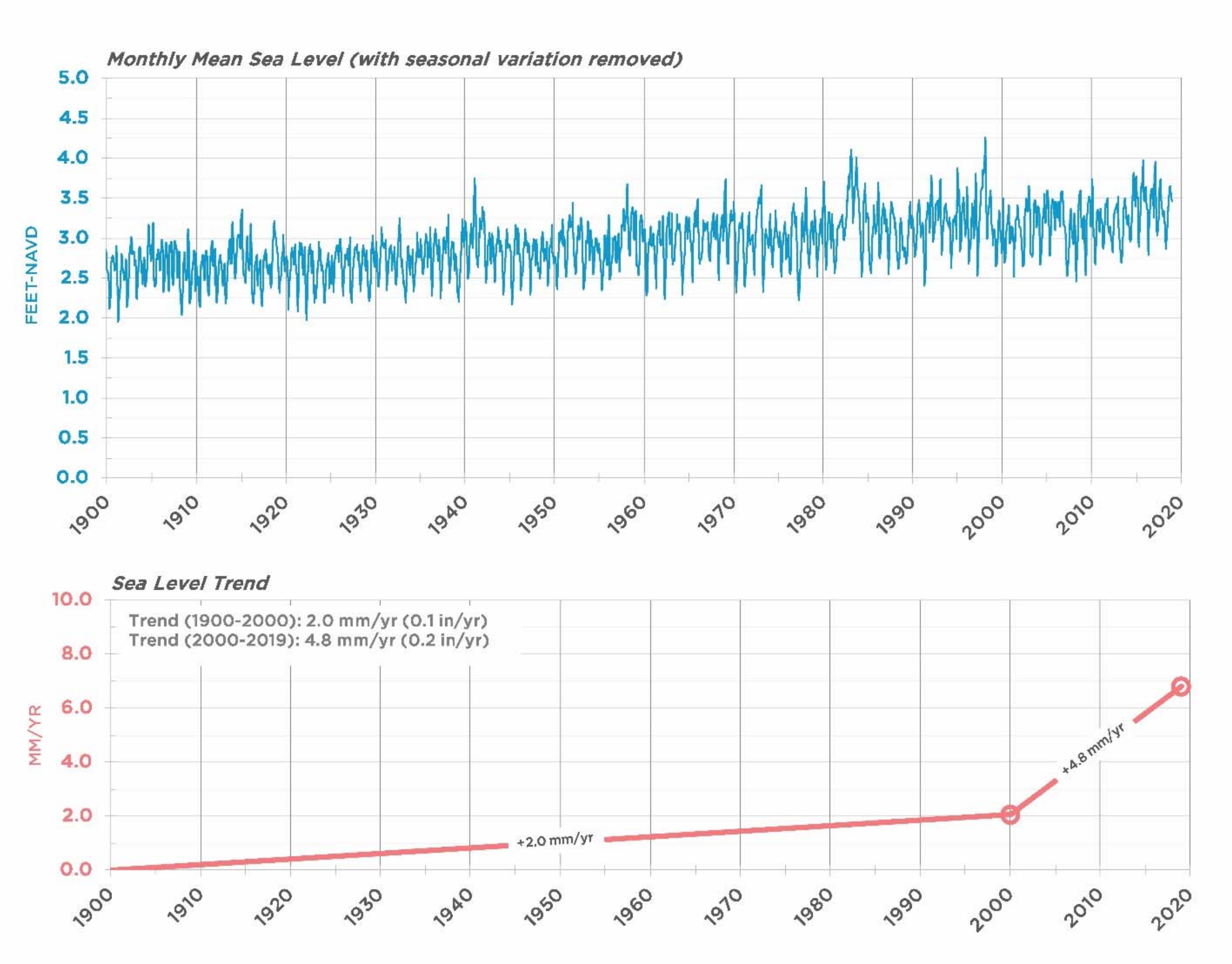

Figure 1. Sea Level Trends at the Presidio Tide Gage

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[9].

Current State Guidance[8] 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[10]" value of sea level rise and the "1-in-200 Chance[11]" 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

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[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 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.

[11] 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.

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.

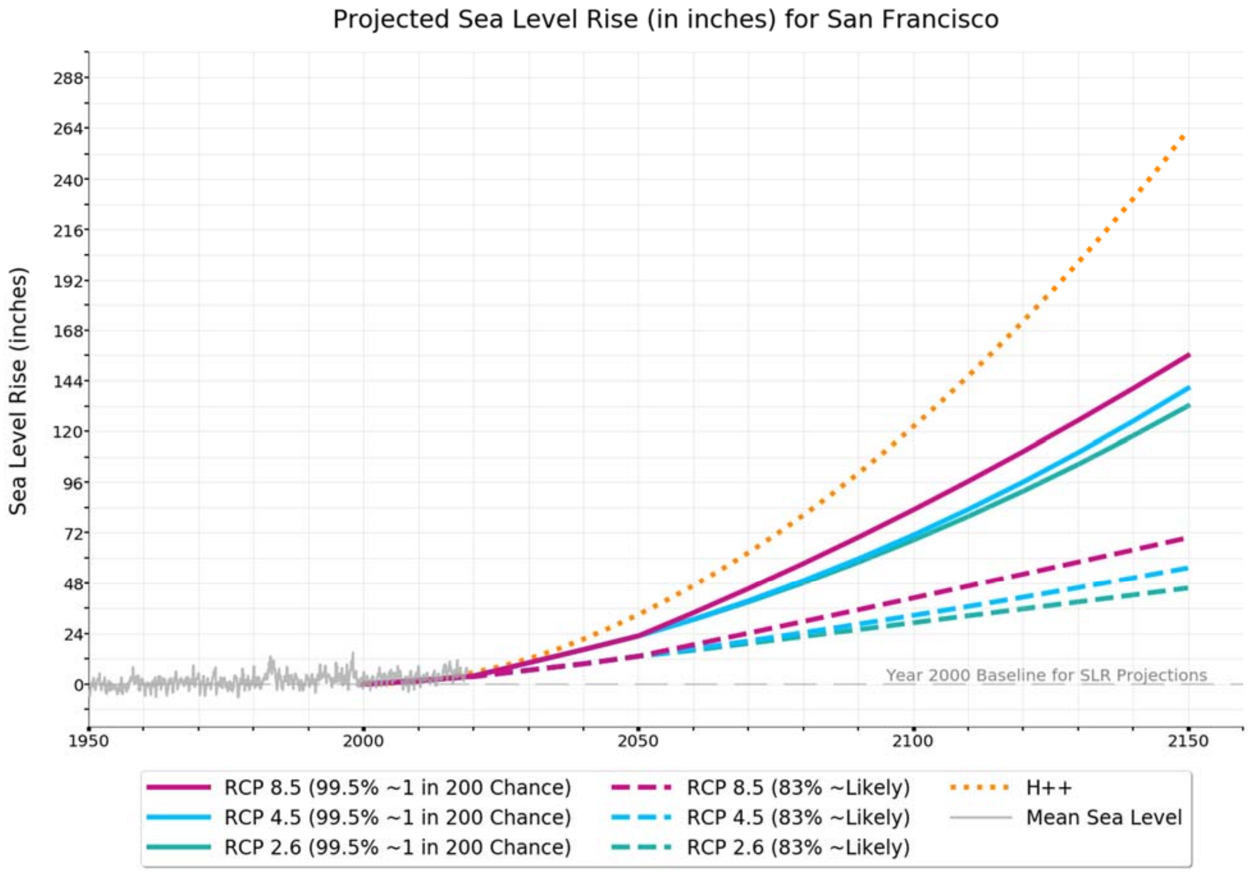

Figure 2. Relative Sea Level Rise in San Francisco, California

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

	NRC 2012		RCP 4.5 Rising 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

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[12]. 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 to the

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

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[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.

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.

[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.