Appendices

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Appendix A

Sea Level Rise Science and Projections for Future Change

DRIVERS OF SEA LEVEL RISE

The main mechanisms driving increases in *global* sea level are: 1) expansion of sea water as it gets warmer (thermal expansion) and, 2) increases in the amount of water in the ocean from melting of land-based glaciers and ice sheets as well as human-induced changes in water storage and groundwater pumping (Chao *et al.* 2008; Wada *et al.* 2010; Konikow 2011).[1] The reverse processes can cause global sea level to fall.

Sea level at the *regional and local levels* often differs from the average global sea level.[2] Regional variability in sea level results from large-scale tectonics and ocean and atmospheric circulation patterns. The primary factors influencing local sea level include tides, waves, atmospheric pressure, winds, vertical land motion and short duration changes from seismic events, storms, and tsunamis. Other determinants of local sea level include changes in the ocean floor (Smith and Sandwell 1997), confluence of fresh and saltwater, and proximity to major ice sheets (Clark *et al.* 1978; Perette *et al.* 2013).

Over the long-term, sea level trends in California have generally followed global trends (Cayan *et al.* 2009; Cayan *et al.* 2012). However, global projections do not account for California's regional water levels or land level changes. California's water levels are influenced by large-scale oceanographic phenomena such as the El Niño Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO), which can increase or decrease coastal water levels for extended periods of time. Figure A-1 shows how El Niño and La Niña events have corresponded to mean sea level in California in the past. California's land levels are also affected by plate tectonics and earthquakes. Changes to water as well as land levels are important factors in regionally down-scaled projections of future sea level. It follows that the sea level rise projections specific to California are more relevant to efforts in the coastal zone of California than projections of global mean sea level.

[1] Large movements of the tectonic plates have been a third major mechanism for changes in global sea level. The time periods for plate movements to significantly influence global sea level are beyond the time horizons used for even the most far-reaching land-use decisions. Plate dynamics will not be included in these discussions of changes to future sea level.

[2] For further discussion of regional sea level variations and regional sea level rise projections, see Yin *et al.* 2010, Slangen *et al.* 2012, and Levermann *et al.* 2013, as examples.

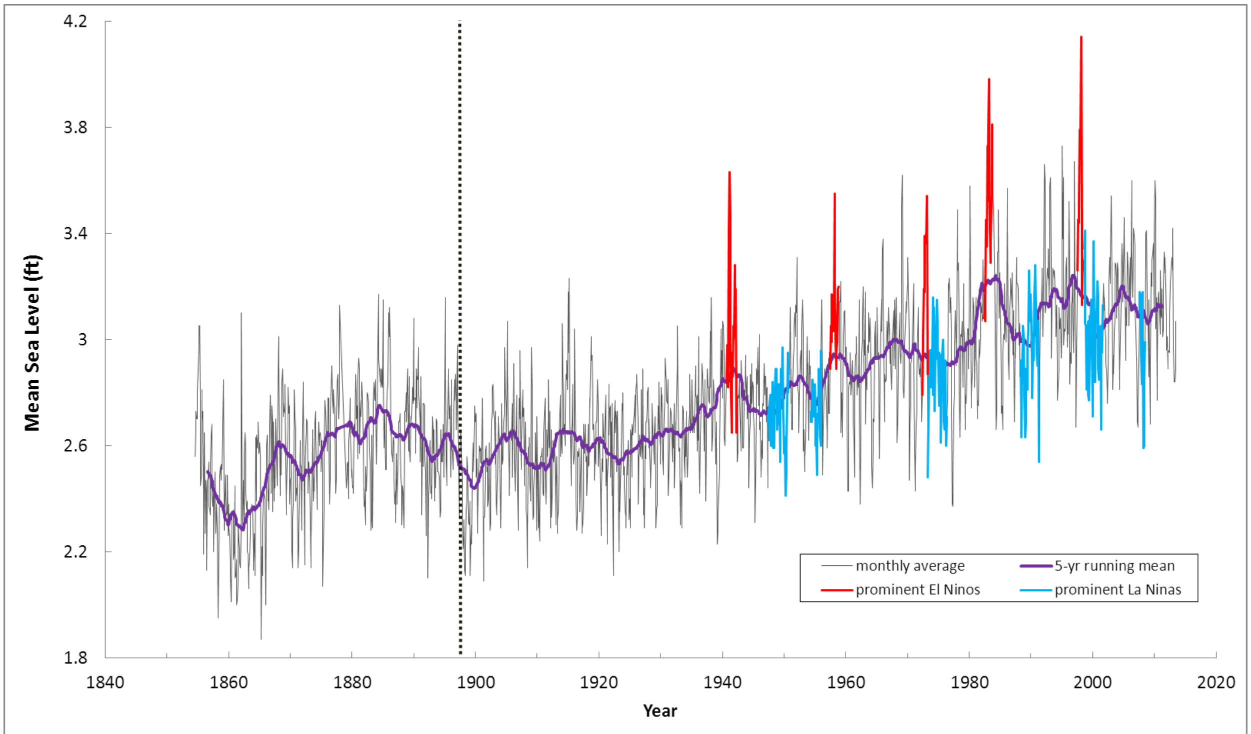

Figure A-1. Variations in monthly mean sea level at Fort Point, San Francisco, 1854 to 2013. Mean sea level heights (in ft) are relative to mean lower low water (MLLW). Purple line represents the 5-year running average. Note that the monthly mean sea level has varied greatly throughout the years and that several of the peaks occurred during strong El Niño events (red highlight). Periods of low sea level often occurred during strong La Niña events (blue highlight). The current "flat" sea level condition can also be seen in the 5-year running average. (*Sources: NOAA CO-OPS data, Station 9414290, http://tidesandcurrents.noaa.gov/ (sea level); NOAA Climate Prediction Center, http://www.elnino.noaa.gov/ (ENSO data)*)

APPROACHES FOR PROJECTING FUTURE GLOBAL SEA LEVEL RISE

This section provides an overview of some of the more well-known approaches that have been used to project sea level changes and their relevance to California. Appendix B will cover how these projections can be used to determine water conditions at the local scale.

There is no single, well-accepted technique for projecting future sea level rise. Understanding future sea level rise involves projecting future changes in glaciers, ice sheets, and ice caps, as well as future groundwater and reservoir storage. Two subjects in particular present challenges in sea level rise modeling. First, future changes to glaciers, ice sheets, and ice caps are not well understood and, due to the potential for non-linear responses from climate change, they present many difficulties for climate models (Overpeck 2006; Pfeffer *et al.* 2008; van den Broecke *et al.* 2011; Alley and Joughin 2012; Shepherd *et al.* 2012; Little *et al.* 2013). Second, the actual magnitudes of the two human-induced changes – pumping of groundwater and storage of water in reservoirs – are poorly quantified, but the effects of these activities are understood and can be modeled (Wada *et al.* 2010). Despite these challenges, sea level rise projections are needed for many coastal management efforts and scientists have employed a variety of techniques to model sea level rise, including:

1. Extrapolation of historical trends;
2. Modeling the physical conditions that cause changes in sea level;
3. Empirical or semi-empirical methods; and
4. Expert elicitations

There are strengths and weaknesses to each approach, and users of any sea level rise projections should recognize that there is no perfect approach for anticipating future conditions. This section provides users of the Guidance document with a general understanding of several of the most widely used sea level rise projection methodologies and their respective advantages and disadvantages. Figure A-2 provides a visual summary of several of the more commonly cited projections of future global and regional sea level rise.

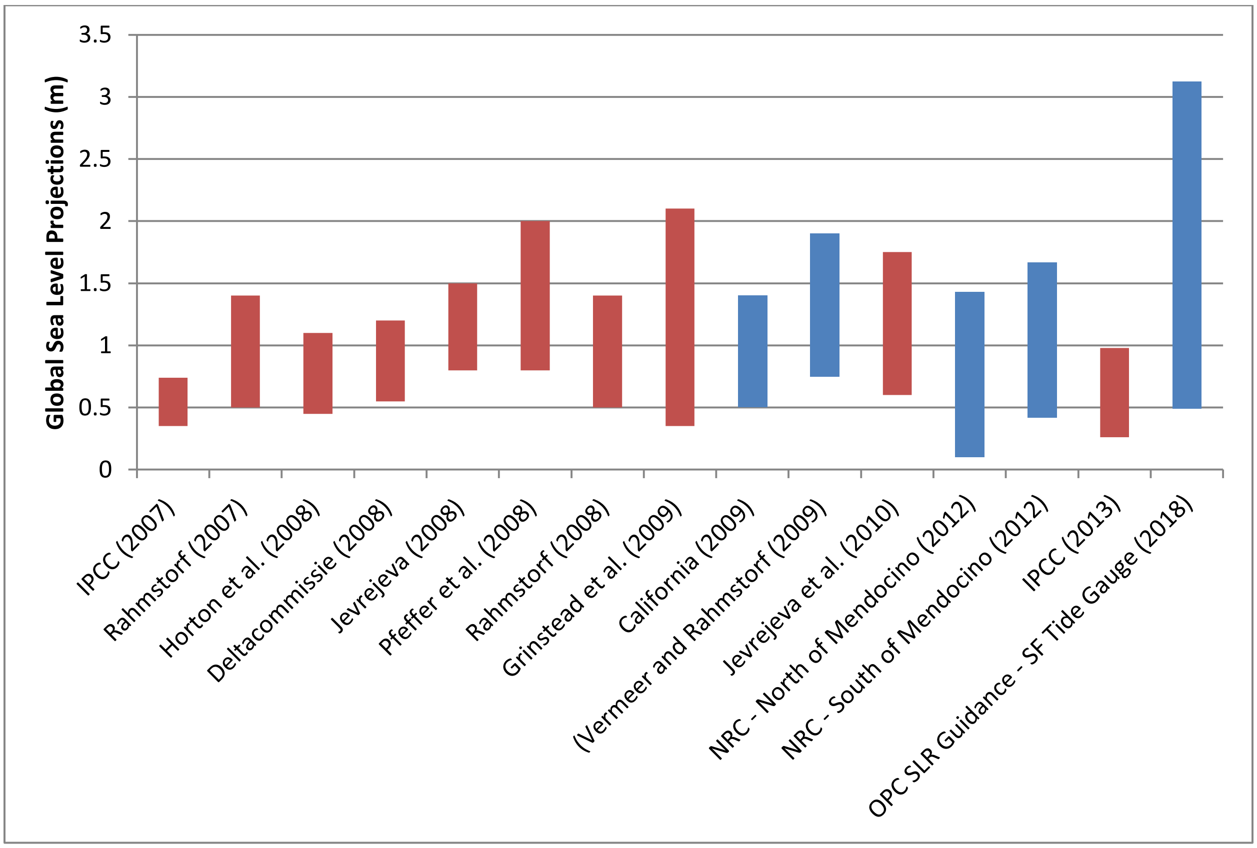

Figure A-2. Sea level rise projections for year 2100 from scientific literature. Graphic summary of the range of average sea level rise (SLR) projections by end of century (2090–2100) from the peer-reviewed literature as compared to the recent National Research Council report for California, Oregon and Washington. The light blue shaded boxes indicate projections for California. Ranges are based on the IPCC scenarios, with the low range represented by the B1 scenario (moderate growth and reliance in the future on technological innovation and low use of fossil fuels) and the high part of the range represented by the A1FI scenario (high growth and reliance in the future on fossil fuels). Details on the methods used and assumptions are provided in the original references.

Extrapolation of Historical Trends

Extrapolation of historical trends in sea level has been used for many years to project future changes in sea level. The approach assumes that there will be no abrupt changes in the processes that drive the long-term trend, and that the driving forces will not change. However, drivers of climate change and sea level rise, such as radiative forcing, are known to be changing, and this method is no longer considered appropriate or viable in climate science.

A recent modification to the historical trend method discussed above has been to estimate rates of sea level rise during the peak of the last interglacial (LIG) period (~125,000 years before present, when some drivers of sea level rise were similar to those today)[3] and use these as proxy records to project sea level rise rates to the 21st Century. For example, Katsman *et al.* (2011) and Vellinga *et al.* (2008) used the reconstructed LIG record of sea level change (from Rohling *et al.* 2008) to reconstruct sea level rise rates during rapid climate warming, and applied these rates to estimate sea level at years 2100 and 2200. Similarly, Kopp *et al.* (2009) used sea level rise rates inferred from the LIG to estimate a range of sea level rise for Year 2100 between 1-3 ft (0.3-1 m). Compared to traditional historical trend extrapolation, this modified approach has the advantage of including the dynamic responses of ice sheets and glaciers to past global climates that were significantly warmer than the present, but is limited by the large uncertainties associated with proxy reconstructions of past sea level.

Physical Models

Physical climate models use mathematical equations that integrate the basic laws of physics, thermodynamics, and fluid dynamics with chemical reactions to represent physical processes such as atmospheric circulation, transfers of heat (thermodynamics), development of precipitation patterns, ocean warming, and other aspects of climate. Some models represent only a few processes, such as the dynamics of ice sheets or cloud cover. Other models represent larger scale atmospheric or oceanic circulation, and some of the more complex General Climate Models (GCMs) include atmospheric and oceanic interactions.

Physical models of sea level changes account for the thermal expansion of the ocean and the transfer of water currently stored on land, particularly from glaciers and ice sheets (Church *et al.* 2011). Currently, coupled Atmosphere-Ocean General Circulation Models (AOGCMs) and ice sheet models are replacing energy-balance climate models as the primary techniques supporting sea level projections (IPCC 2013). Ocean density, circulation and sea level are dynamically connected in AOGCMs as critical components of the models include surface wind stress, heat transfer between air and sea, and freshwater fluxes. AOGCM climate simulations have recently been used as input for glacier models (Marzeion *et al.* 2012) which project land-water contributions to sea level.

The Intergovernmental Panel on Climate Change (IPCC) is one of the main sources of peer-reviewed, consensus-based modeling information on climate change. The IPCC does not undertake climate modeling, but uses the outputs from a group of climate models that project

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[3] During the last interglacial, global mean temperature was 1-2ºC warmer than the pre-industrial era (Levermann *et al.* 2013), while global mean sea level was likely 16.4-29.5 ft (5-9 m) above present mean sea level (Kopp *et al.* 2009; Dutton and Lambeck 2012; Levermann *et al.* 2013).

future temperature, precipitation patterns, and sea level rise, based on specific emission scenarios. Early in the 1990s, the IPCC developed basic model input conditions to ensure comparable outputs from the various models. The IPCC initially developed scenarios of future emissions, based on energy development, population and economic growth, and technological innovation. Four families of scenarios (A1, A2, B1, and B2) and subgroups (A1B, A1FI, A1T) were developed and used for climate and sea level rise projections for early IPCC reports (1990, 1995, 2001, 2007). IPCC used 4 new scenarios for the *5th Assessment Report* (AR5) in 2013, based on Representative Concentration Pathways (RCPs) that are different greenhouse gas concentration trajectories. These trajectories bear similarities to, but are not directly comparable to the earlier emission scenarios. Projections in IPCC AR5 (2013) differ from the earlier IPCC projections due to improvements in climate science, changes due to the new scenarios, and changes in the models to accommodate the new inputs, with improvements in climate science and model capabilities driving the bulk of the changes.

One finding of the earlier 2007 IPCC report called for improved modeling of ice dynamics. Focused research on ice dynamics to improve the ability of climate models to address the scale and dynamics of change to glaciers, ice sheets, and ice caps was subsequently undertaken (*e.g.*, Price *et al.* 2011; Shepherd *et al.* 2012; Winkelman *et al.* 2012; Bassis and Jacobs 2013; Little *et al.* 2013). Recent modeling results presented in the AR5 (IPCC 2013) reflect the scientific community's increased understanding in, as well as advances in modeling of the impacts of glacier melting and ocean thermal expansion on sea level change. AR5 scenarios reflect a greater range of global sea level rise (28-98 cm) based on improved modelling of land-ice contributions.

Semi-Empirical Method

The semi-empirical method for projecting sea level rise is based on developing a relationship between sea level and some factor (a proxy) – often atmospheric temperature or radiative forcing – and using this relationship to project changes to sea level. An important aspect for the proxy is that there is fairly high confidence in models of its future changes; a key assumption that is made by this method is that the historical relationship between sea level and the proxy will continue into the future. One of the first projections of this kind was based on the historical relationship between global temperature changes and sea level changes (Rahmstorf 2007). This semi-empirical approach received widespread recognition for its inclusion of sea level rise projections. These projections looked at the temperature projections for two of the previous IPCC (2007) emission scenarios that span the likely future conditions within the report's framework – B1, an optimistic, low-greenhouse gas emission future, and A1FI, a more "business-as-usual" fossil fuel intensive future.[4] The Rahmstorf 2007 sea level rise projections were used in the California 2009 *Climate Change Scenarios Assessment* (Cayan 2009).

Since the initial semi-empirical projections for future sea level rise (Rahmstorf 2007), other researchers have published different projections based on the IPCC scenarios, using different

[4] When the IPCC began examining climate change, the available models used a broad range of inputs. In an attempt to evaluate the different model outputs based on the different model characteristics rather than the inputs, the IPCC developed a number of standard greenhouse gas emission scenarios. These scenarios are described in *Response Strategies Working Group III* (IPCC 1990). In general, the B1 scenario projects the lowest temperature and sea level increases and the A1FI projects the highest increases.

data sets or best-fit relationships.[5] Notably, Vermeer and Rahmstorf (2009) prepared a more detailed methodology that includes both short-term responses and longer-term responses between sea level rise and temperature. These 2009 projections of sea level rise were used in the *Interim Guidance on Sea Level Rise* (OPC 2010) and the California 2012 *Vulnerability and Assessment Report* (Cayan 2012).

There are also several new semi-empirical sea level rise projections based on scenarios other than those developed by the IPCC. For instance, Katsman *et al.* (2011) use a "hybrid" approach that is based on one of the newer radiative forcing scenarios and empirical relationships between temperature change and sea level. Future projections were then modified to include contributions from the melting of major ice sheets based on expert judgment[6]. This yields what they call "high end" SLR projections for Years 2100 and 2200 under several emissions scenarios.

Zecca and Chiari (2012) produced semi-empirical sea level rise projections based on their own scenarios of when fossil fuel resources would be economically exhausted. Though based on a different set of assumptions about human behavior/choices, in terms of global temperature and radiative forcing, the scenarios do not differ greatly from the IPCC scenarios. The results are identified as being "lower bound" sea level rise projections for high, medium, low fuel use scenarios, and "mitigation" (extreme and immediate action to replace fossil fuel use) scenarios. The report then provides projections for the 2000-2200 time period.

Expert Elicitation

Expert elicitation is one of the newer methods that have been used for projecting or narrowing ranges of future sea level rise. Using expert judgment has been an important aspect of scientific inquiry and the scientific method. The method of expert elicitation is a formalized use of experts in climate science and sea level change to help either narrow uncertainty for sea level projections, or to help with specifying extremes of a range. The elicitation method normally begins with experts refining model output information. One of the first attempts to use expert elicitation for sea level rise was a study by Titus and Narayanan (1996), when it was thought there was only 1% probability that sea level would exceed 3.3 ft (1 m) by Year 2100. In 2011, the Arctic Monitoring and Assessment Programme Report (AMAP 2011) surveyed the climate literature to construct a range of estimates of sea level rise by the year 2100, and then used a panel of experts to decide on a smaller, more plausible range. Not surprisingly, the projections supported by the AMAP experts fell right in the middle of the range shown in Figure A-2. Bamber and Aspinall (2013) used a statistical analysis of a large number of expert estimates to

[5] Semi-empirical projections of sea level rise using relationships between water level and radiative forcing such as those from Grinsted *et al.* (2009), Jevrejeva *et al.* (2010), Katsman *et al.* (2011), Meehl *et al.* (2012), Rahmstorf *et al.* (2012), Schaeffer *et al.* (2012), and Zecca and Chiari (2012) have shown general agreement with the projections by Vermeer and Rahmstorf (2009). The Grinsted *et al.* projections have a wider range than those of Vermeer and Rahmstorf, while the Jevrejeva *et al.* projections are slightly lower. All semi-empirical methods project that sea level in Year 2100 is likely to be much higher than linear projections of historical trends and the projections from the 2007 IPCC.

[6] Expert judgment has long been part of the scientific process. Expert elicitation, which is a formalized process for using expert judgment, has grown in importance and is discussed as a separate approach for projecting future sea level rise.

develop their projected range of future sea level, projecting sea level rise by 2100 ranging from 1–4.3 ft (0.33–1.32 m), under one of the intermediate AR5 scenarios (RCP 4.5).

Horton *et al.* (2014) surveyed experts in sea level science, based upon published papers, to develop a probabilistic assessment of long-term sea level rise (by the years 2100 and 2300), assuming two very different scenarios. Under one scenario, aggressive efforts would limit greenhouse gas concentrations that would cause global temperature to increase slightly until about 2050 when it would slowly drop (AR5's RCP 3 scenario). Under the other scenario, temperatures would continue to increase through to 2300 (AR5's RCP 8.5 scenario). Experts determined that it is likely that sea level rise could remain below 3.3 ft (1 m) for the low emission scenario (RCP 2.6), but that the likely range of future sea level rise for the high emission scenario (RCP 8.5) could be 6.6-9.8 ft (2-3 m).

Kopp *et al.* (2014) have combined detailed process modeling, community assessments and expert elicitation to assign probability distributions of local sea level rise through 2200 for identified communities around the world. Under the high concentration scenario, RCP 8.5, Kopp *et al*. estimate the "maximum physically possible rate of sea level rise" to be 8.2 ft (2.5 m) for the year 2100. This study also finds that sea level rise along the Pacific Coast of the US is close to the global average, and the likely range of sea level is 2-3.3 ft (0.6-1.0 m) by the year 2100 at San Francisco, under the high concentration scenario. In contrast, in areas of high subsidence such as Galveston, Texas, the likely range of sea level in by 2100 ranges from 3.3 to 5 ft (1.0-1.5 m). And, at many of the localities that were examined, including San Francisco, the current 1-in-10 year flooding event is likely to occur every other year by 2100 (five times more frequently) due to sea level rise; the frequency of the 1-in-100 year event is expected to double by the year 2100 with sea level rise.

Coastal communities cannot ignore sea level rise in long-term planning, permitting and project design. The four different approaches to projecting future sea level rise all have varying strengths and weaknesses. As noted earlier in this section, projections, like models, will not be completely accurate, but they are important tools for evaluation nonetheless[7]. The most commonly cited projections provide future sea level as a range, as a way to allow for many of the uncertainties that are part of future climate change. Often, projections of sea level rise rely upon multiple approaches. For example, the 2012 National Research Council (NRC) report was developed through expert judgment that combined information from both physical models and semi-empirical projections.

[7] George E.P. Box, mathematician and statistician is quoted as saying, "Essentially all models are wrong, but some are useful."

BEST AVAILABLE SCIENCE ON SEA LEVEL RISE

Global Projections of Sea Level Rise

The best available science on *global* sea level rise projections is currently the IPCC *Fifth Assessment Report: Climate Change 2013* (AR5) released in September 2013. The new report now projects a more rapid sea level rise than the *Fourth Assessment* (AR4) released in 2007. By Year 2100, the AR5 projects global sea level to be more than 50% higher (26-98 cm) than the old projections (18-59 cm) when comparing similar emission scenarios and time periods. The increase in AR5 sea level projections results from improved modelling of land-ice contributions. Substantial progress in the assessment of extreme weather and climate events has also been made since the AR4 as models now better reproduce phenomena like the El Niño-Southern Oscillation (ENSO; IPCC 2013).

National Projections of Sea Level Rise

The third National Climate Assessment (NCA) was released in May 2014 (Melillo *et al*.), and includes the current best-available science on climate change and sea level rise *at the national scale*.[8] The sea level rise projections in the NCA were informed by the 2012 NOAA report titled *Global Sea Level Rise Scenarios for the United States National Climate Assessment* (Parris *et al*.). This report provides a set of four scenarios of future global sea level rise, as well as a synthesis of the scientific literature on global sea level rise. The NOAA Climate Program Office produced the report in collaboration with twelve contributing authors.[9] The report includes the following description of the four scenarios of sea level rise by the year 2100:

- **Low scenario:** The lowest sea level change scenario (a rise of 8 in (20 cm)) is based on historical rates of observed sea level change.
- **Intermediate-low scenario:** The intermediate-low scenario (a rise of 1.6 ft (0.5 m) is based on projected ocean warming.
- **Intermediate- high scenario:** The intermediate-high scenario (a rise of 3.9 ft (1.2 m)) is based on projected ocean warming and recent ice sheet loss.
- **High scenario:** The highest sea level change scenario (a rise of 6.6 ft (2 m)) reflects ocean warming and the maximum plausible contribution of ice sheet loss and glacial melting.

The Parris *et al*. (2012) report recommends that the highest scenario be considered in situations where there is little tolerance for risk. It also provides steps for planners and local officials to modify these scenarios to account for local conditions. These steps are intended for areas where local sea level rise projections have not been developed. For California, the 2018 OPC SLR Guidance report (below) provides scenarios that have been refined for use at the local level, and the Coastal Commission recommends using the OPC projections rather than the global or national scenarios.

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[8] Note that the 4th National Climate Assessment is due to be released in late 2018. https://www.globalchange.gov/nca4

[9] Authors include NOAA, NASA, the US Geologic Survey, the Scripps Institution of Oceanography, the US Department of Defense, the US Army Corps of Engineers, Columbia University, the University of Maryland, the University of Florida, and the South Florida Water Management District.

California-Specific Projections of Sea Level Rise and Best Available Science

The State of California has long-supported the development of scientific information on climate change and sea level rise to help guide planning and decision-making. For example, the State helped support the development of the 2012 National Research Council (NRC) report, *Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future*, which provided an examination of global and regional sea level rise trends and projections of future sea level. This report was then incorporated into the Ocean Protection Council's 2013 *State Sea-Level Rise Guidance*, and was considered the best available science on sea level rise for California.

More recently, and in response to the release of new scientific studies related to sea level rise, Governor Brown directed the OPC to synthesize recent science on sea level rise and incorporate findings into updates to the State Guidance. In April 2017, a working group of OPC's Science Advisory team (comprised mainly of climate researchers at various academic institutions in California and throughout the country) released a report titled *Rising Seas in California: An Update on Sea-Level Rise Science*. The report highlighted seven key findings:

1. *Scientific understanding of sea level rise is advancing at a rapid pace*. Sea level rise projections have increased substantially over the last few years, particularly for late in the 21st century and under high emissions scenarios, due to our evolving understanding of the dynamics of ice sheet loss. However, there is still significant uncertainty regarding these processes.

2. *The direction of sea level change is clear*. Coastal California is already experiencing the impacts of rising sea levels, and impacts will increase in the future.

3. *The rate of ice loss from the Greenland and Antarctic ice sheets is increasing*. Ice sheet loss will soon overtake thermal expansion of seawater as the primary driver of rising sea levels. Due to a variety of ocean circulation dynamics, ice loss from Antarctica, and particularly West Antarctica, has an outsized impact on California compared to the rest of the world (Figure A-3). Continued research on this dynamic is critical for accurately projecting future sea level rise along our coast.

4. *New scientific evidence has highlighted the potential for extreme sea level rise*. Recent research (e.g., DeConto and Pollard, 2016; Sweet et al., 2017) has found that, if greenhouse gas emissions are not curtailed, glaciological processes could cross thresholds that lead to rapidly accelerating and effectively irreversible ice loss. The probability of this extreme scenario is currently unknown, but its consideration is important. Significant reductions in greenhouse gas emissions may reduce the likelihood of this extreme scenario, but does not completely eliminate the risk. Importantly, it is difficult to determine if the world is on the track for extreme and irreversible ice loss for some time because the processes that drive extreme ice loss in the later part of the century or beyond are different than those that are driving ice loss now.

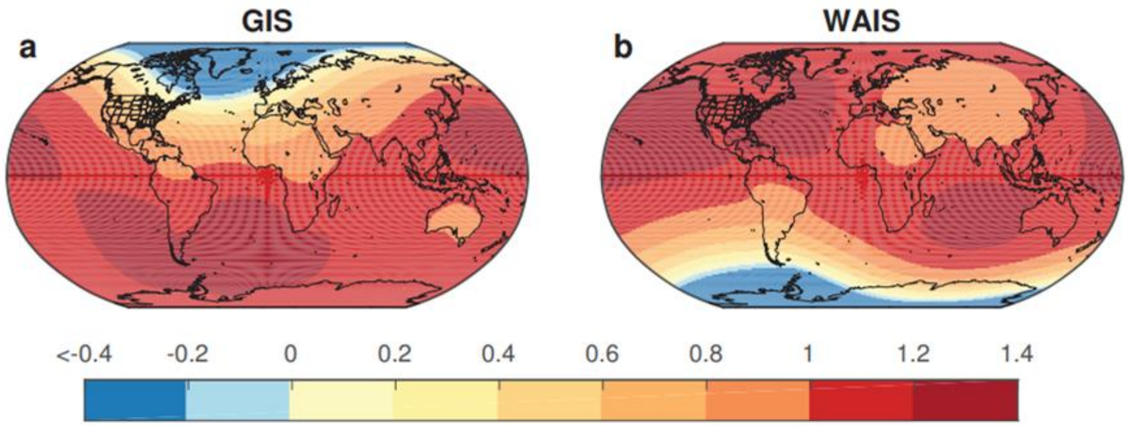

Figure A-3. Sea level 'fingerprints' resulting from the distribution of ice and water around the Earth and ensuing gravitational and rotational effects. The maps depict the relative response of sea-level to the loss of ice mass from (a) Greenland Ice Sheet (GIS) and (b) West Antarctic Ice Sheet (WAIS). The color bar represents the fractional departure of relative sea level rise from that expected given the ice contribution to global mean sea level. For example, when ice is lost from the Greenland Ice Sheet the relative effect on the US West Coast is 75% of the sea-level rise expected from the water volume added to the ocean. By comparison, when ice is lost from the West Antarctic Ice Sheet the US West Coast experiences 125% of sea-level rise from that expected from the water volume added (*from Griggs et al. 2017*).

5. *Probabilities of specific sea-level increases can inform decisions*. A probabilistic approach to sea level rise projections, combined with a clear articulation of the implications of uncertainty and the decision support needs of affected stakeholders, is the most appropriate approach for use in a policy setting.

   The OPC Scientific Working Group utilized a comprehensive probability approach based on Kopp et al. (2014) that estimates both a comprehensive probability distribution and the likelihood of extreme 'tail' outcomes. It is important to note that probabilistic projections do not provide probabilities of occurrence of sea level rise, but rather probabilities that the ensemble of climate models used to estimate contributions of sea level rise (from thermal expansion, ice sheet loss, oceanographic conditions etc.) will predict a certain amount of sea level rise.

   Note that the probabilistic projections do not consider the H++ extreme ice loss scenario. The extreme ice loss studies were not included in the inputs to the model ensemble, which means the probability distributions may be an underestimate.[10]

6. *Current greenhouse gas emissions policy decisions are shaping our coastal future*. Before 2050, differences in SLR projections under different emissions scenarios are minor. After 2050, SLR projections increasingly depend on the trajectory of greenhouse

[10] The 4th California Climate Assessment developed projections that present a broader range of SLR estimates than the Rising Seas science report and the 2018 OPC SLR Guidance. Both programs' projections are based on estimates of contributions to SLR from primary sources using different methods, including model projections and expert input. However, the 4th Assessment incorporates the findings from the recent studies regarding the potential for rapid loss of Antarctic ice sheets (which results in the H++ scenario of about 10ft. of SLR by 2100) into its probabilistic projections whereas the OPC reports do NOT include this possibility in the probabilistic projections, as explained above.

gas emissions. If greenhouse gas emissions are not curtailed worldwide, we will see significantly higher rates of sea level rise during the second half of the century.

7. *Waiting for scientific certainty is neither a safe nor prudent option*. Taking action today to assess vulnerabilities and identify and implement adaptation strategies will prevent much greater losses than will occur if action is not taken. Taking a precautionary approach that considers high and extreme scenarios is critical for safeguarding the people and resources of coastal California.

This scientific information was incorporated into OPC's *State Sea-Level Rise Guidance: 2018 Update*. The OPC Guidance includes projection tables for 12 tide gauges along the California coast for each decade from 2030 to 2150. OPC further recommends utilizing three different projection scenarios to guide planning, permitting, investment, and other decisions based on the type of project, its ability to cope with or adapt to sea level rise, and the consequences to the environment and the project associated with sea level rise. The projection table for the San Francisco tide gauge is provided below (Table A-1), and tables for other California tide gauges are presented in Appendix G. The 2018 OPC SLR Guidance (along with the foundational Rising Seas science report) is currently considered best available science on sea level rise for the State of California.

The Coastal Commission recommends that the low, medium-high, and extreme risk aversion scenarios from the OPC 2018 Sea-Level Rise Guidance be considered in all relevant local coastal planning and coastal development permitting decisions.

Table A-1. Sea Level Rise Projections for the San Francisco Tide Gauge[11] (OPC 2018)

Projected Sea Level Rise (in feet): *San Francisco*			
	Probabilistic Projections (in feet) (based on Kopp et al. 2014)		H++ Scenario (Sweet et al. 2017)
	Low Risk Aversion	**Medium-High Risk Aversion**	**Extreme Risk Aversion**
	Upper limit of "likely range" (~17% probability SLR exceeds...)	*1-in-200 chance (0.5% probability SLR exceeds...)*	*Single scenario (no associated probability)*
2030	0.5	0.8	1.0
2040	0.8	1.3	1.8
2050	1.1	1.9	2.7
2060	1.5	2.6	3.9
2070	1.9	3.5	5.2
2080	2.4	4.5	6.6
2090	2.9	5.6	8.3
2100	3.4	6.9	10.2
2110*	3.5	7.3	11.9
2120	4.1	8.6	14.2
2130	4.6	10.0	16.6
2140	5.2	11.4	19.1
2150	5.8	13.0	21.9

**Most of the available climate model experiments do not extend beyond 2100. The resulting reduction in model availability causes a small dip in projections between 2100 and 2110, as well as a shift in uncertainty estimates (see Kopp et al., 2014). Use of 2110 projections should be done with caution and acknowledgement of increased uncertainty around these projections.*

[11] Probabilistic projections for the height of sea level rise and the H++ scenario are presented. The H++ projection is a single scenario and does not have an associated likelihood of occurrence. Projections are with respect to a baseline year of 2000 (or more specifically, the average relative sea level over 1991-2009). Table is adapted from the 2018 OPC SLR Guidance to present only the three scenarios OPC recommends evaluating. Additionally, while the OPC tables include low emissions scenarios, only high emissions scenarios, which represent RCP 8.5, are included here because global greenhouse gas emissions are currently tracking along this trajectory. The Coastal Commission will continue to update best available science as necessary, including if emissions trajectories change.

REFERENCES: APPENDIX A

Alley RB, I Joughin. 2012. Modeling ice-sheet flow. *Science* 336(6081): 551-552. doi: 10.1126/science.1220530.

Arctic Monitoring and Assessment Programme (AMAP). 2011. *Snow, Water, Ice and Permafrost in the Arctic (SWIPA): Climate Change and the Cryosphere*. Arctic Monitoring and Assessment Programme, Oslo, Norway, 538 pp. http://www.amap.no/.

Bamber JL, WP Aspinall. 2013. An expert judgment assessment of future sea level rise from the ice sheets. *Nature Climate Change* 3: 424-427. doi:10.1038/nclimate1778.

Bassis JN, S Jacobs. 2013. Diverse calving patterns linked to glacier geometry. *Nature Geoscience* 6: 833-836. doi: 10.1038/ngeo1887.

Bedsworth, L, D Cayan, G Franco, L Fisher, S Ziaja. (CA Governor's Office of Planning and Research, Scripps Institution of Oceanography, CA Energy Commission, CA Public Utilities Commission). 2018. Statewide Summary Report. California's Fourth Climate Change Assessment. http://www.climateassessment.ca.gov/state/index.html

California Natural Resources Agency (CNRA). 2009. *California Climate Adaptation Strategy*. http://resources.ca.gov/docs/climate/Statewide_Adaptation_Strategy.pdf.

Cayan D, M Tyree, M Dettinger, H Hidalgo, T Das, E Maurer, P Bromirski, N Graham, R Flick. 2009. *Climate Change Scenarios and Sea Level Rise Estimates for the California 2009 Climate Change Scenarios Assessment*. California Climate Change Center, CEC-500-2009-014-F. http://www.energy.ca.gov/2009publications/CEC-500-2009-014/CEC-500-2009-014-F.PDF.

Cayan D, M Tyree, D Pierce, T Das. 2012. *Climate Change and Sea Level Rise Scenarios for California Vulnerability and Adaptation Assessment*. A White Paper from the California Energy Commission's California Climate Change Center, CEC-500-2012-008, http://www.energy.ca.gov/2012publications/CEC-500-2012-008/CEC-500-2012-008.pdf.

Chao BF, YH Wu, YS Li. 2008. Impact of artificial reservoir water impoundment on global sea level. *Science* 320(5873): 212. doi: 10.1126/science.1154580.

Church JA, NJ White, LF Konikow, CM Domingues, JG Cogley, E Rignot, JM Gregory, MR van der Broeke, AJ Monaghan, I Velicogna. 2011. Revisiting the Earth's sea-level and energy budgets from 1961 to 2008. *Geophysical Research Letters* 40(15): 4066. doi: 10.1029/2011GL048794.

Clark JA, WE Farrell, WR Peltier. 1978. Global changes in postglacial sea level: a numerical calculation. *Quaternary Research* 9(3): 265-287. doi:10.1016/0033-5894(78)90033-9.

DeConto RM, Pollard D. 2016. Contribution of Antarctica to past and future sea-level rise. Nature 531: 591-7

Deltacommissie. 2008. *Working together with water: A living land builds for its future*. Findings of the Deltacommissie 2008. http://www.deltacommissie.com/doc/deltareport_summary.pdf.

Dutton A, K Lambeck. 2012. Ice volume and sea level during the last interglacial. *Science* 337(6091): 216–219. doi: 10.1126/science.1205749.

Griggs, G, Árvai, J, Cayan, D, DeConto, R, Fox, J, Fricker, HA, Kopp, RE, Tebaldi, C, Whiteman, EA (California Ocean Protection Council Science Advisory Team Working Group). Rising Seas in California: An Update on Sea-Level Rise Science. California Ocean Science Trust, April 2017.

Grinsted A, J Moore, S Jevrejeva. 2009. Reconstructing sea level from paleo and projected temperatures 200 to 2100 AD. *Climate Dynamics* 34: 461- 472. doi:10.1007/s00382-008-0507-2.

Horton BP, S Rahmstorf, SE Engelhart, AC Kemp. 2014. Expert assessment of sea-level rise by AD 2100 and AD 2300. *Quaternary Science Review* 84: 1-6. doi: 10.1016/j.quascirev.2013.11.002.

Horton R, C Herweijer, C Rosenzweig, J Liu, V Gomitz, AC Ruane. 2008. Sea level rise projections for current generation CGCMs based on the semi-empirical method. *Geophysical Research Letters* 35: L02715. doi: 10.1029/2007GL032486.

Intergovernmental Panel on Climate Change (IPCC). 1990. *IPCC First Assessment Report (FAR). Climate Change: The IPCC Response Strategies.* Report prepared by Working Group III. 330 pp. http://www.ipcc.ch/publications_and_data/publications_ipcc_first_assessment_1990_wg3.shtml.

Intergovernmental Panel on Climate Change (IPCC). 1995. *IPCC Second Assessment Report (SAR). Climate Change 1995: The Science of Climate Change.* World Meteorological Organization (WMO) and United Nations Environment Programme (UNEP). 73pp. http://www.ipcc.ch/pdf/climate-changes-1995/ipcc-2nd-assessment/2nd-assessment-en.pdf.

Intergovernmental Panel on Climate Change (IPCC). 2001. *Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report (TAR) of the Intergovernmental Panel on Climate Change.* [JT Houghton, Y Ding, DJ Griggs, M Noguer, PJ van der Linden, X Dai, K Maskell, CA Johnson (eds.)], Cambridge University Press: Cambridge, UK, and New York, USA. 881pp. http://www.grida.no/publications/other/ipcc_tar/.

Intergovernmental Panel on Climate Change (IPCC). 2007. *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change.* [S Solomon, D Qin, M Manning, M Marquis, K Averyt, MMB Tignor, HL Miller, Jr., Z Chen (eds.)], Cambridge University Press: Cambridge, UK and New York, NY, USA. 91 pp. https://www.ipcc.ch/report/ar4/.

Intergovernmental Panel on Climate Change (IPCC). 2013. *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change.* [TF Stocker, D Qin, G Plattner, MMB Tignor, SK Allen, J Boschung, A Nauels, Y Xia, V Bex, PM Midgley (eds.)], Cambridge University Press: Cambridge, UK and New York, NY, USA. 1535pp. https://www.ipcc.ch/report/ar5/.

Jevrejeva S, JC Moore, A Grinsted. 2008. Relative importance of mass volume changes to global sea level rise. *Journal of Geophysical Research* 113: D08105. doi: 10.1029/2007JD009208.

Jevrejeva S, JC Moore, A Grinsted. 2010. How will sea level respond to changes in natural and anthropogenic forcings by 2100? *Geophysical Research Letters* 37: L07703. doi: 10.1029/2010GL042947.

Katsman CA, GJ van Oldenborgh. 2011. Tracing the upper ocean's "missing heat". *Geophysical Research Letters* 38(14), L14610. doi: 10.1029/2011GL048417.

Konikow LF. 2011. Contribution of global groundwater depletion since 1900. *Geophysical Research Letters* 38(14): L17401. doi:10.1029/2011GL048604.

Kopp RE, RM Horton, CM Little, JX Mitrovica, M Oppenheimer, DJ Rassussen, BH Strauss, C Tebaldi. 2014. Probabilistic 21st and 22nd century sea-level projections at a global network of tide-gauge sites. *Earth's Future* 2(8): 383-406. doi:10.1002/2014EF000239.

Kopp R, F Simons, J Mitrovica, A Maloof, M Oppenheimer. 2009. Probabilistic assessment of sea level during the last interglacial stage. *Nature* 462: 863-867. doi:10.1038/nature08686.

Levermann A, P Clark, B Marzeion, G Milne, D Pollard, V Radic, A Robinson. 2013. The multimillennial sea-level commitment of global warming. *Proceedings of the National Academy of Sciences* 110(34): 13745-13750. doi: 10.1073/pnas.1219414110.

Little CM, NM Urban, M Oppenheimer. 2013. Probabilistic framework for assessing the ice sheet contribution to sea level change. *Proceedings of the National Academy of Sciences* 110(9): 3264-3269. doi: 10.1073/pnas.1214457110.

Marzeion B, AH Jarosch, M Hofer. 2012. Past and future sea-level changes from the surface mass balance of glaciers. *The Cryosphere* 6: 1295-1322. doi:10.5194/tc-6-1295-2012.

Meehl GA, WM Washington, JM Arblaster, A Hu, H Teng, C Tebaldi, BN Sanderson, J Lamarque, A Conley, WG Strand, JB White III. 2012. Climate System Response to External Forcings and Climate Change Projections in CCSM4. *Journal of Climate* 25: 3661–3683. doi: 10.1175/JCLI-D-11-00240.1.

Melillo JM, TC Richmond, GW Yohe (eds). 2014. *Climate Change Impacts in the United States: The Third National Climate Assessment*. Report for the US Global Change Research Program, 841 pp. doi:10.7930/J0Z31WJ2.

National Research Council (NRC). 2012. *Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future*. Report by the Committee on Sea Level Rise in California, Oregon, and Washington. National Academies Press, Washington, DC. 250 pp. http://www.nap.edu/catalog/13389/sea-level-rise-for-the-coasts-of-california-oregon-and-washington.

Ocean Protection Council (OPC). 2010. *Interim Guidance: Coastal and Ocean Working Group of the California Climate Action Team (CO-CAT).* http://opc.ca.gov/webmaster/ftp/pdf/agenda_items/20110311/12.SLR_Resolution/SLR-Guidance-Document.pdf.

Ocean Protection Council (OPC). 2018. *State of California Sea-Level Rise Guidance: 2018 Update.* *http://www.opc.ca.gov/webmaster/ftp/pdf/agenda_items/20180314/Item3_Exhibit-A_OPC_SLR_Guidance-rd3.pdf*

Ocean Protection Council (OPC). 2013. *State of California Sea-Level Rise Guidance Document.*http://www.opc.ca.gov/webmaster/ftp/pdf/docs/2013_SLR_Guidance_Update_FINAL1.pdf.

Overpeck JT, BL Otto-Bliesner, GH Miller, DR Muhls, RB Alley, JT Kiehl. 2006. Paleoclimatic evidence for future ice-sheet instability and rapid sea-level rise. *Science* 311(5768): 1747-1750. doi: 10.1126/science.1115159.

Parris A, P Bromirski, V Burkett, D Cayan, M Culver, J Hall, R Horton, K Knuuti, R Moss, J Obeysekera, A Sallenger, J Weiss. 2012. *Global Sea Level Rise Scenarios for the US National Climate Assessment*. NOAA Tech Memo OAR CPO-1. 37 pp. http://scenarios.globalchange.gov/sites/default/files/NOAA_SLR_r3_0.pdf.

Perrette M, F Landerer, R Riva, K Frieler, M Meinshausen. 2013. A scaling approach to project regional sea level rise and its uncertainties. *Earth System Dynamics* 4(1): 11-29. doi:10.5194/esd-4-11-2013.

Pfeffer WT, JT Harper, S O'Neel. 2008. Kinematic constraints on glacier contributions to 21st century sea-level rise. *Science* 321(5894): 1340 -1343. doi:10.1126/science.1159099.

Price SF, AJ Payne, IM Howat, BE Smith. 2011. Committed sea-level rise for the next century from Greenland ice sheet dynamics during the past decade. *Proceedings of the National Academy of Sciences* 108(22): 8978-8983. doi:10.1073/pnas.1017313108.

Rahmstorf S. 2007. A semi-empirical approach to projecting future sea-level rise. *Science* 315(5810): 368-370. doi:10.1126/science.1135456.

Rahmstorf S, G Foster, A Cazenave. 2012. Comparing climate projections to observations up to 2011. *Environmental Research Letters* 7: 044035. doi:10.1088/1748-9326/7/4/044035.

Rohling E, K Grant, C Hemleben, M Siddall, B Hoogakker, M Bolshaw, M Kucera. 2008. High rates of sea-level rise during the last interglacial period. *Nature Geoscience* 1: 38-42. doi:10.1038/ngeo.2007.28.

Schaeffer M, W Hare, S Rahmstorf, M Vermeer. 2012. Long-term sea-level rise implied by 1.5˚C and 2˚C warming levels. *Nature Climate Change* 2: 867-870. doi:10.1038/nclimate1584.

Shepherd A, ER Ivins, A Geruo, VR Barletta, MJ Bentley, S Bettadpur, KH Briggs, DH Bromwich, R Forsberg, N Galin, M Horwath, S Jacobs, I Joughin, MA King, JTM Lenaerts, J Li, SRM Ligtenberg, A Luckman, SB Luthcke, M McMillan, R Meister, G Milne, J Mouginot, A

Muir, JP Nicolas, J Paden, AJ Payne, H Pritchard, E Rignot, H Rott, LS Sorensen, TA Scambos, B Scheuchl, EJO Schrama, B Smith, AV Sundal, JH van Angelen, WJ van de Berg, MR van den Broeke, DG Vaughan, I Velicogno, J Wahr, PL Whitehouse, DJ Wingham, D Yi, D Young, HJ Zwally. 2012. A reconciled estimate of ice-sheet mass balance. *Science* 338(6111): 1183-1189. doi: 10.1126/science.1228102.

Slangen ABA, CA Katsman, RSW van de Wal, LLA Vermeersen, REM Riva. 2012. Towards regional projections of twenty-first century sea-level change based on IPCC SRES scenarios. *Climate Dynamics* 38: 1191-1209. doi: 10.1007/s00382-011-1057-6.

Smith WH, DT Sandwell. 1997. Global sea floor topography from satellite altimetry and ship depth soundings. *Science* 277(5334): 1956-1962. doi: 10.1126/science.277.5334.1956.

Sweet, W.V., R.E. Kopp, C.P. Weaver, J. Obeysekera, R.M. Horton, E.R. Thieler and CZ. Global and Regional Sea Level Rise Scenarios for the United States. 2017.

Titus JG, V Narayanan. 1996. The risk of sea level rise. *Climatic Change* 33(2):151-212. doi: 10.1007/BF00140246.

Van den Broeke MR, J Bamber, J Lenaerts, E Rignot, 2011. Ice sheets and sea level: thinking outside the box. *Surveys in Geophysics 32*(4-5): 495-505. doi: 10.1007/s10712-011-9137-z.

Vellinga P, C Katsman, A Sterl, J Beersma, W Hazeleger, J Church, R Kopp, D Kroon, M Oppenheimer, H Plag, S Rahmstorf, J Lowe, J Ridley, H von Storch, D Vaughan, R van de Wal, R Weisse, J Kwadijk, R Lammersen, N Marinova. 2009. *Exploring high-end climate change scenarios for flood protection of the Netherlands. International Scientific Assessment*, Prepared for the Delta Committee. Scientific Report WR-2009-05. KNMI, Alterra, The Netherlands. 150pp. http://edepot.wur.nl/191831.

Vermeer M, S Rahmstorf. 2009. Global sea level linked to global temperature. *Proceedings of the National Academy of Science* 108: 21527-21532. doi:10.1073/pnas.0907765106.

Wada Y, LPH van Beek, CM van Kempen, JWTM Reckman, S Vasak, MFP Bierkens. 2010. Global depletion of groundwater resources. *Geophysical Research Letters* 37: L20402. doi:10.1029/2010GL044571.

Winkelman S, J Mueller, E Jue. 2012. *Climate Adaptation & Transportation: Identifying Information and Assistance Needs*. Summary of an Expert Workshop held November 2011, Center for Clean Air Policy & Environmental and Energy Study Institute. http://ccap.org/assets/Climate-Adaptation-and-Transportation_CCAP-EESI-May-2012.pdf.

Yin J, SM Griffies, RJ Stouffer. 2010. Spatial variability of sea-level rise in the twenty-first century projections. *Journal of Climate* 23(17): 4585-4607. doi: 10.1175/2010JCLI3533.1.

Zecca A, L Chiari. 2012. Lower bounds to future sea-level rise. *Global and Planetary Change* 98-99: 1-5. doi:10.1016/j.gloplacha.2012.08.002.

Appendix B

Developing Local Hazard Conditions Based on Regional or Local Sea Level Rise Using Best Available Science

This Appendix provides technical information regarding how to determine local hazard conditions for sea level rise planning efforts. This process is described more broadly as Steps 1-3 in Chapters 5 and 6 in this document, and includes determining a range of sea level rise projections and analyzing the physical effects and possible resource impacts of sea level rise hazards.

Water level varies locally, so this analysis must be performed on a regional or site specific basis, and applicants and planners should prioritize obtaining data or conducting research at the correct geographical scale. The 2018 OPC Sea-Level Rise Guidance is considered the best available science on California's regional sea level rise, and the Commission recommends using it when sea level rise projections are needed. Equivalent resources may be used by local governments and applicants provided that the resource is peer-reviewed, widely accepted within the scientific community, and locally relevant.[97]

Much of the research by the Intergovernmental Panel on Climate Change (IPCC) and others has focused on global and regional changes to mean sea level. However, the coast is formed and changed by local water and land conditions. Local tidal range influences where beaches, wetlands and estuaries will establish; waves and currents are major drivers of shoreline change; and storms and storm waves are often the major factors causing damage to coastal development. It is local conditions that influence beach accretion and erosion, storm damage, bluff retreat, and wetland function.

Local water levels along the coast are affected by local land uplift or subsidence, tides, waves, storm waves, atmospheric forcing, surge, basin-wide oscillations, and tsunamis. Some of these factors, such as tides and waves, are ever-present and result in ever-changing shifts in the local water level. Other drivers, such as storms, tsunamis, or co-seismic uplift or subsidence, are episodic but can have important influences on water level when they occur. The following section discusses these factors in the context of sea level rise and how to incorporate them into planning and project analysis.

In most situations, high water will be the main project or planning concern. For wetlands, the intertidal zone between low and high tides will be of concern, while in some special situations, such as for intake structures, low water might be the main concern. In situations where low water is the concern, current low water is likely to be the low water planning condition and there may be no need to factor future sea level rise into those project or planning situations. In most other situations, hazards analyses will need to account for sea level rise. The following box identifies some of the key situations in which it may be important for coastal managers and applicants to consider sea level rise during project review.

[97] This appendix is written in such a way that it complements the materials from the 2012 NRC Report and the 2018 OPC SLR Guidance, which is currently considered the best available science on sea level rise in California. As new reports are issued in the future, Commission staff will assess whether they should be considered the best available science and update the approaches or terminology in this Appendix accordingly.

General situations needing sea level rise analysis include when the project or planning site is:

- Currently in or adjacent to an identified floodplain
- Currently or has been exposed to flooding or erosion from waves or tides
- Currently in a location protected from flooding by constructed dikes, levees, bulkheads, or other flood-control or protective structures
- On or close to a beach, estuary, lagoon, or wetland
- On a coastal bluff with historic evidence of erosion
- Reliant upon shallow wells for water supply

For situations where future sea level conditions will be important for the analyses of hazards or resource impacts, the following sections are provided as guidance for determining local hazards. Figure B-1 shows the general progression for going from global sea level projections to the possible consequences or impacts that can result from local water levels.

The following information provides guidance on using temporally- and regionally-appropriate sea level rise projections to determine future tidal elevations and inundation, future still water, future shoreline change and erosion, potential flooding, wave impacts and wave runup, and flooding from extreme events[98].

Most of these analyses must occur sequentially. Sea level rise is used to determine changes in tidal conditions, and tidal conditions are combined with future surge, El Niño Southern Oscillation (ENSO) events, and Pacific Decadal Oscillations (PDOs) to estimate local still water. Changes in the frequencies of still water levels will in turn affect erosion rates, and the amount of erosion will affect future wave impacts, runup and flooding.

To be consistent with other sections, these different efforts are presented as Steps, with a discussion of how to accomplish each and the expected outcome. Depending upon the planning or project concerns and required analysis, it may not be necessary to proceed step-by-step and readers should use their judgment as to which items are relevant to their concerns. For example, if the concern is about runup on a non-erosive slope due to an increase in the still water level of 5.5 ft (1.7 m), the guidance on wave runup analysis may be all that is necessary.

[98] Importantly, the 2018 OPC SLR Guidance includes projections tables for 12 tide gauges throughout California, and for every 10 years from 2030 to 2150. As such, adjusting the projections to account for more localized conditions or specific years is likely unnecessary. This is a change from the 2012 NRC report, which included projections for north and south of Cape Mendocino and for only three time periods. Thus, sections within this Appendix that pertained to developing temporally- and spatially-adjusted projections (including mathematic interpolation methods) have largely been removed in the 2018 update.

Step 1 – Develop temporally- and spatially-appropriate sea level rise projections
Step 2 – Determine tidal range and future inundation
Step 3 – Determine still water level changes from surge, El Niño events and PDOs
Step 4 – Estimate beach, bluff, and dune change from erosion
Step 5 – Determine wave, storm wave, wave runup, and flooding conditions
Step 6 – Examine potential flooding from extreme events

A Note on Hydrodynamic Models versus "Bathtub Fill" Models

It is important to be aware of the differences between a so-called "bathtub fill" model and hydrodynamic models, and the related pros and cons of each for analysis of sea level rise impacts. In general, "bathtub fill" refers to those models that analyze flooding or inundation based solely on elevation. In other words, if sea level is projected to rise 3 ft (1 m), thereby increasing flooding/inundation from a current elevation of +10 ft (3 m) to +13 ft (4 m), these models will, in general, flood everything below the +13 ft (4m) elevation. The modeling does not take into consideration whether the new flood areas are connected to the ocean, nor does it consider how the changes to the water level will change wave propagation or overtopping of flood barriers. This is a significant oversimplification of the processes involved in flooding, but it provides value in allowing individuals to gain a broad view of the general areas that could be impacted by sea level rise without requiring a great deal of technical information.

Conversely, hydrodynamic modeling takes into account the details of local development patterns and the characteristics of waves and storms, and can therefore provide a much better understanding of local sea level rise impacts than is possible from "bathtub fill" models. In particular, hydrodynamic models take into account factors that alter flooding and inundation patterns and impacts. Such factors may include the extent and orientation of development – for example, roadways and linear features that tend to channelize water flows, and buildings or flood barriers that can block and divert flows – as well as the conditions that contribute to flooding and inundation, such as wave conditions, flow velocities, the extent of overtopping, and so on. Although the initial development of the modeling grid that is used to depict the community development patterns can be quite time-consuming to create and the model output will change with differing grid designs (Schubert and Sanders 2012), once the grid is developed, hydrodynamic modeling can be used to better characterize areas of flooding and to distinguish areas of concentrated flooding from those areas that may experience small amounts of flooding only during peak conditions (Gallien *et al.* 2011, 2012).

Significantly, many of the analyses described in this Appendix are the kinds of analyses that go beyond "bathtub fill" modeling to include the hydrodynamic factors that help to specify the more location-specific impacts for which planners should prepare.

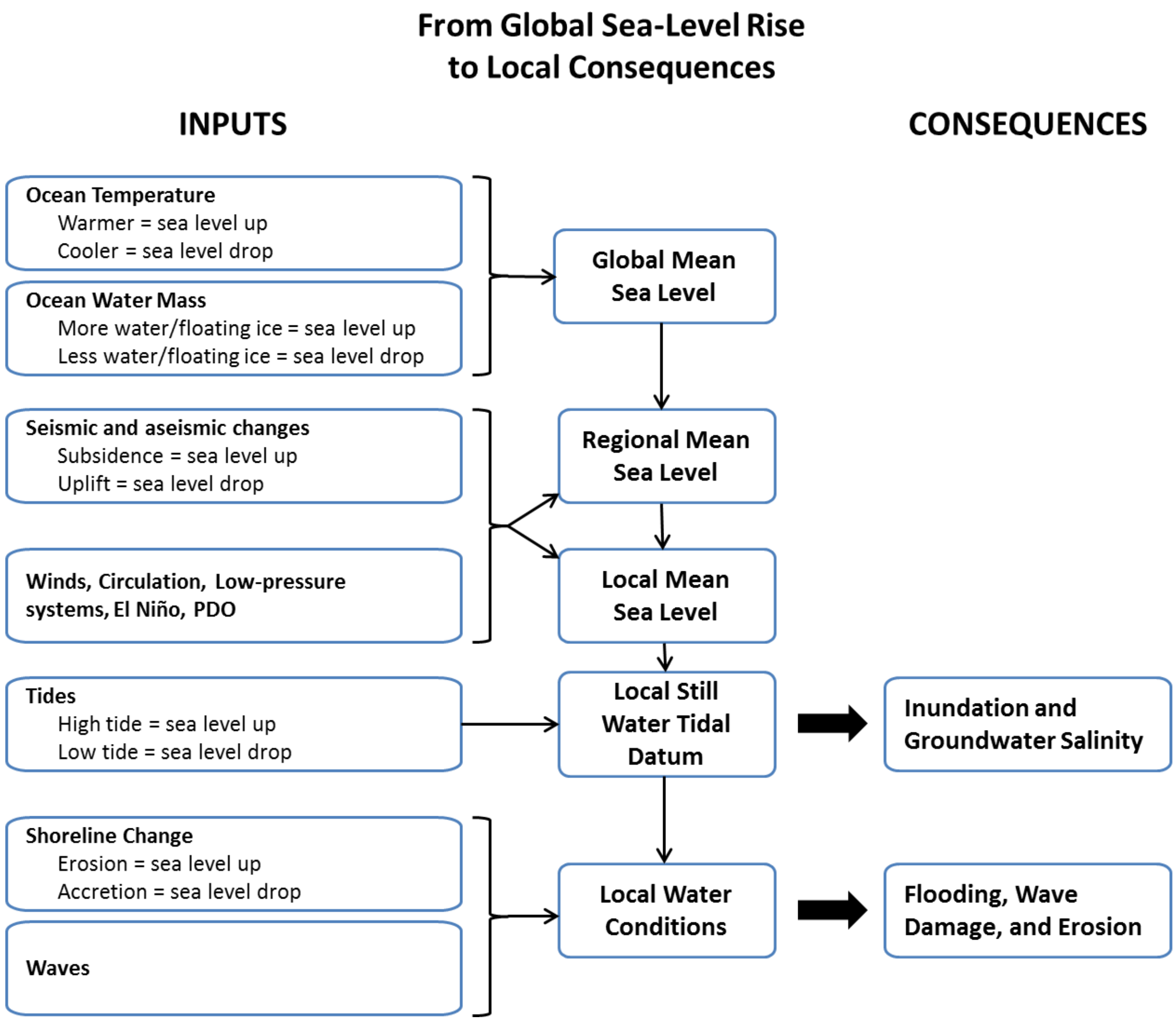

Figure B-1. General process for translating global sea level rise to local consequences

Step 1 – Develop temporally- and spatially-appropriate sea level rise projections

a. Identify the nearest tide gauge

The 2018 OPC Sea-Level Rise Guidance contains projection tables for 12 tide gauges along the California coast in order to account for localized trends in relative sea level rise, related mainly to different rates of vertical land motion. The 12 tide gauges are mapped in Appendix 2 of the OPC Guidance (and copied in Appendix G here). OPC directs users to identify the nearest tide gauge to the project or planning site and to use the associated projection table in planning and permitting. In some cases it may be appropriate to interpolate between two tide gauges (if the project site is equidistant between tide gauges) or to use more locally-specific scientific data, if available. In many cases, though, the differences among projections (either between two tide gauges or from more localized data) are likely to be small, and therefore may be insignificant compared to overall uncertainty in modeling and/or future greenhouse gas emissions scenarios.

b. Determine appropriate planning horizon or expected project life and identify relevant sea level rise projections

The first step in a sea level rise analysis is to determine the appropriate planning horizon based on the expected life of the project. The longer the life of a project or planning horizon, the greater the amount of sea level rise the project or planning area will experience.

Local governments should select their planning horizons to evaluate a broad range of planning concerns. Planning horizons could address the 20-year time period that is typical for *General Plan* updates as well as the long-range planning that is necessary for infrastructure and new development. The 20-year planning horizon may help identify areas within the coastal zone that are now or will soon be vulnerable to sea level rise related hazards as an aid for focusing adaptation planning on the areas of greatest need. Local Coastal Program (LCP) planning will likely use multiple planning horizons and undertake hazards analyses for multiple time periods, multiple sea level rise projections, or both.

At the project level, the LCP may provide insight into the time period that should be considered for the expected project life. At present, LCPs typically provide only a single standard (if any) for the expected life of a structure or development, such as 50, 75, or 100 years. Future LCPs and LCP Amendments (LCPAs) may find it useful to provide greater guidance on expected project life, with differentiations among major development or use classifications. For example, a general range may be chosen based on the type of development such that temporary structures, ancillary development, amenity structures, or moveable or expendable construction should identify a relatively short expected life of 25 years or less. Residential or commercial structures, which will be around longer, should choose a time frame of 75 to 100 years to consider. A longer time frame of 100 years or more should be considered for critical infrastructure like bridges or industrial facilities or for resource protection or enhancement projects that are typically meant to last in perpetuity.

For projects with long lead times, the analysis of impacts from sea level rise should use the projections for the time period when the development will be in use, rather than the current period because the trajectory of future sea level rise is not expected to be linear. For example, a project built today will experience less sea level rise over a 50-year lifetime (about 1.9 feet under the “medium-high risk aversion” scenario at the San Francisco tide gauge) than the same project if it were built in the year 2050 (about 5 feet under the “medium-high risk aversion” scenario at the San Francisco tide gauge). Thus, it is important to understand the anticipated project life of a structure and the associated planning horizon before starting an analysis for sea level rise concerns.

As explained in Chapters 5 and 6, the point of this step is not to specify exactly how long a project will exist (and be permitted for), but rather to identify a project life timeframe that is typical for the type of development in question so that the hazard analyses performed in subsequent steps will adequately consider the impacts that may occur over the entire life of the development.

Once the appropriate planning/project horizon has been identified, the associated projection for that time period can be identified using the projection tables from the 2018 OPC SLR Guidance. These tables include projections for each decade from 2030 to 2150.

As explained elsewhere in this Guidance, project characteristics (including its ability to withstand or adapt to different sea level rise amounts and the consequences associated with underestimating the amount of sea level rise that occurs) should guide users in choosing which scenario to assess for a particular planning horizon. As general guidance, the Coastal Commission continues to recommend that planners or project applicants take a precautionary approach by evaluating higher sea level rise amounts (for example, the medium-high risk aversion scenario for most development, or the extreme risk aversion scenario for critical infrastructure).

Step 2 – Determine tidal range and future inundation

One of the most basic examinations of changing sea level conditions has been to determine the new intersection of mean sea level or other tidal datums[99] with the shoreline. This is a basic "bathtub" analysis since it looks only at the expansion of areas that will be inundated (*i.e.*, regularly submerged under water) or subject to tidal or wave action. For example, future subtidal levels would be the current subtidal limit plus projected regional mean sea level rise. Future intertidal zones would be bounded by the future higher high tide level (current higher high water plus projected regional sea level rise) and future lower low tide levels (current lower low water plus projected regional sea level rise).[100] For some projects, such as wetland restoration, the identification of future inundation zones may be the only sea level analysis needed for project evaluation. However, if the shoreline is eroding, the location of this elevation would need to also incorporate the rate of erosion. So, if the shoreline is expected to erode due to increased wave attack, not only will the intertidal zone move up in elevation, it will be both higher than and inland of the current zone.

Future Water *Elevation* = Current Tidal Datum + Projected Sea Level Rise

OR

Future Water *Location* = Intersection of Future Water Elevation with Future Shore Location

Future water location will extend to the new inundation elevation on the future shoreline. On beaches with a gradual slope, this can move the inundation location significantly inland, based on the geometric conditions of the beach. (This type of analysis is often called the Bruun Rule). On a stable beach with a slope of 1:X (Vertical:Horizontal), every foot of vertical sea level rise will move the inundation area horizontally X feet inland. For a typical 1:60 beach, every foot of sea level would move the inundation zone inland by 60 ft. If the beach is eroding, the loss due to erosion will add to the loss resulting from inundation.

Figure B-2 shows the influence of tides and sea level rise on low-wave energy beaches. Table B-1 provides some useful resources for inundation studies. Local Tidal Elevations are available from tide gauges maintained by NOAA. Where there are no nearby gauges, NOAA recommends the VDatum software.

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99 Tidal datums are based on the latest National Tidal Datum Epoch (NTDE) published by NOAA and are the mean of the observed sea levels over a 19-year period. The latest published epoch is 1983-2001. This tidal epoch can be considered equivalent to the year 2000 baseline for the **OPC** projections.

100 Historical trends of high and low tide have changed differently than mean sea level (Flick *et al.* 2003). Based on historical trends, the changes to various tidal elements are likely to track closely with, but not identically with, changes to mean sea level. The future variability of changes to the tidal components, compared with changes to mean sea level will normally fall within the uncertainty for sea level rise projections and can be disregarded in almost all situations. As this phenomenon of tidal change is better understood and can be modeled, it may be appropriate in the future to include the changes in tidal components into the analysis of inundation and various water level projections.

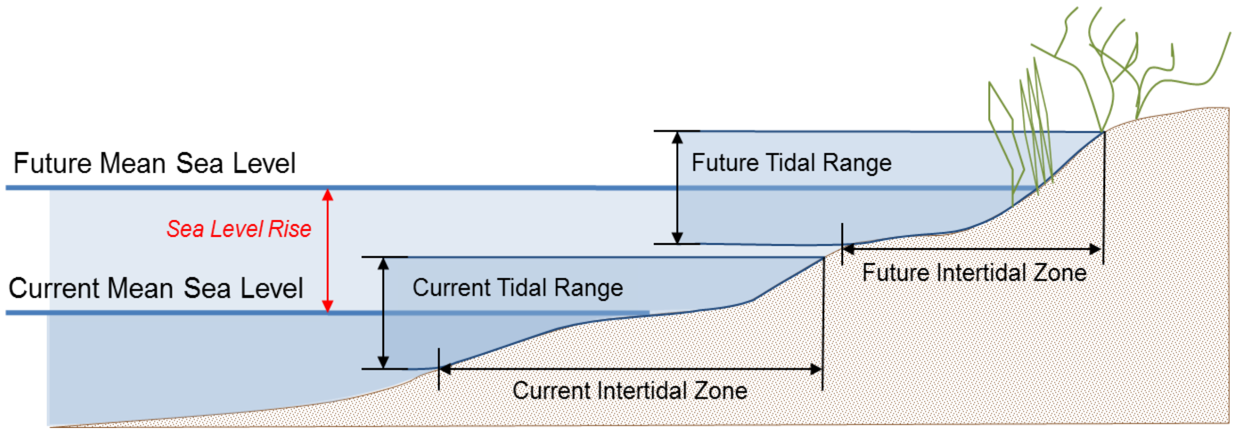

Figure B-2. Sea level rise and changes to tide range and intertidal zone. (*Source: L. Ewing, 2013*).

Table B-1. General Resources for Inundation Studies

Resource	Description	Link
Aerial Photographs	Useful for general information on shoreline trends; ortho-rectified photos can help quantify trends.	California Coastal Records Project, www.californiacoastline.org; Huntington Library; Local Libraries
LIDAR	Fairly detailed topography providing GIS layers for current conditions and comparable with LIDAR data sets for temporal changes.	NOAA Digital Coast, http://coast.noaa.gov/digitalcoast/data/coastallidar
Topographic Maps	Useful for basemaps to overlay site changes; often not at a scale to distinguish small changes in inundation or tidal action.	USGS Map Center, http://www.usgs.gov/pubprod/maps.html
NOAA Sea Level Rise and Coastal Flooding Impacts Viewer	Useful to show changes in water level location if there are no changes in the land due to erosion.	NOAA Digital Coast, https://coast.noaa.gov/digitalcoast/tools/slr.html
NOAA Tidal Data	Measured and predicted tidal components for locations along the open coast and in bays.	NOAA Center for Operational Oceanographic Products and Services, http://tidesandcurrents.noaa.gov/
NOAA Technical Report NOS 2010-01: *Technical Considerations for use of Geospatial Data in Sea Level Change Mapping and Assessment*	Provides technical guidance to agencies, practitioners, and decision makers seeking to use geospatial data to assist with sea level change assessments.	NOAA National Ocean Service http://www.tidesandcurrents.noaa.gov/publications/tech_rpt_57.pdf

VDatum Software	A Vertical Datum Transformation program that allows users to transform geospatial data among various geoidal, ellipsoidal and tidal vertical datums.	NOAA National Ocean Service, https://vdatum.noaa.gov/
Cal-Adapt – Exploring California's Climate	Represents inundation location and depth for the San Francisco Bay, the Sacramento-San Joaquin River Delta and California coast resulting from different increments of sea level rise coupled with extreme storm events. Incorporates real, time series water level data from past (near 100 year) storm events to capture the dynamic effect of storm surges in modeling inundation using a three dimensional hydrodynamic model (per Radke et al., 2017).	http://cal-adapt.org/tools/slr-calflod-3d/
Estimating Sea Level for Project Initiation Documents	Provides guidance on converting tidal datums and predicting future sea levels.	Caltrans Office of Land Surveys, http://www.dot.ca.gov/hq/row/landsurveys/SurveysManual/Estimating_Sea_Level_v1.pdf

Outcome from Step 2: *Provide information on the projected changes to the tidal range and future zones of inundation. For locations without any influence from erosion, storm surge, or wave energy, the identification of new inundation areas may be sufficient for project analysis and planning efforts. This projected new inundation area may also be useful for anticipating the likely migration of wetlands and low-energy water areas or as input for analysis of changes to groundwater salinity. For most open coast situations, this information will be used to inform further project planning and analysis that examines erosion, surge and storm wave conditions.*

Step 3 – Determine still water changes from surge, El Niño events, and PDOs

Estimates of surge, El Niño, and PDO water elevation changes are developed primarily from historical records. There are no state-wide resources for this information, although it may be included in some Regional Sediment Management Plan studies. General guidance on water level changes that can be expected from surge, El Niño events, and PDOs is provided in Table B-2.

The remaining discussion provides general information on some of these phenomena. It is provided to acquaint readers to the main issues associated with each phenomenon. Readers with a strong background in ocean-atmospheric conditions may want to skim or skip the rest of this section.

The Pacific Ocean is a complex system. Sea level in the Pacific Ocean responds to multiple oceanic and atmospheric forcing phenomena, occurring with different intensities and at different temporal and spatial scales. Some phenomena may reinforce each other, while others may act in opposition, reducing the net effect. Scientists and researchers are attempting to identify the various signals from the multiple phenomena, but these are nascent sciences and there is still much we need to learn.

Regional water levels can be influenced by surge as well as by high and low pressure systems. Surge is a short-term change in water elevation due to high wind, low atmospheric pressure, or both. It is most often associated with East Coast and Gulf Coast hurricanes that can cause up to 15 or 20 ft (4-6 m) or more of short-term water level rise over many miles of the coast. Along the West Coast, storm surge tends to be much smaller, and is rarely a coastal hazard, except in enclosed bays. In southern California, it rarely exceeds 1 ft (0.3 m) and in central California, it rarely exceeds 2 ft (0.6 m). Surge becomes a concern as one of several cumulative factors that cause a temporary rise in sea level. Each rise may be small, but when surge occurs during high tides and/or in combination with storms, it increases the threat of coastal flooding, wave impacts, and erosion.

Two of the more recognized phenomena that affect water temperature in the Pacific are the El Niño-Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO). ENSO cycles, which occur on inter-annual timescales (approximately 2-7 years), not only involve ocean-basin-spanning changes in sea surface temperature (SST) and in the depth of the mixed layer in the Equatorial Pacific, but also drive changes in ocean conditions and atmospheric circulation at higher latitudes. El Niño events result in the transfer of warm surface waters into the normally cool eastern equatorial Pacific, resulting in elevated SST and water levels along much of the west coast of the Americas. El Niños also tend to increase the strength and frequency of winter low pressure systems in the North Pacific. These events can persist for months or years at a time, and strongly influence local and regional sea level. For example, the pulse of warm water from the large 1982-83 El Niño caused water levels along California to be elevated by approximately 0.4-0.7 ft (0.12-0.21 m) for many months, with short-term water elevation peaks up to approximately 1 ft (0.3 m; Flick 1998). The opposite phase of ENSO, characterized by unusually cool SSTs and lower water elevations along the eastern Pacific margin, are called La Niña events. Between El Niños and La Niñas are periods of neutral SST and water elevation changes.

The PDO is an ENSO-like pattern of SST and atmospheric variability occurring over multiple decades. In contrast to ENSO, the PDO is more strongly expressed in the North Pacific than in the tropics. The positive or warm phase of the PDO is associated with unusually warm surface water throughout the eastern North Pacific (along the western US coast), while the negative or cool phase PDO is associated with colder than normal waters. As with the ENSO effects, the warm phase PDO has tended to cause elevated sea levels in the eastern Pacific and along the California coast, while the cool phase of the PDO tends to lower sea level in this region.

The PDO has basin-wide influence. Elevated water levels in one part of the Pacific are often accompanied by lowered water levels elsewhere. The cool phase PDO can result in a drop of water level along the eastern Pacific (western US Coast) and a rise in water level along the western Pacific. Recently, sea level along the western Pacific has been rising about three times faster than the global mean sea level rise rate, due in part to the PDO (Bromirski *et al.* 2011; Merrifield 2011). This does not mean the eastern Pacific will experience sea level rise that is three times faster than the global mean sea level rise when there is the next shift in the PDO, but does show that the PDO can have a major influence on basin-wide and regional sea level. The above discussion of El Niño and the PDO may suggest that they are well-understood phenomena, with easily anticipated changes in sea level. However, it is important to note that El Niños have varying strengths and intensities, resulting in different sea changes from one event to the next. Also, changes in regional mean sea level along the eastern Pacific have not always shown a strong connection to the PDO cycles. An apparent jump in regional mean sea level occurred after the mid-1970s shift to the warm phase of the PDO, yet the expected continued rise in sea level along the West Coast seems to have been suppressed by other forces. Tide gauge records for the Washington, Oregon, and California coasts have shown no significant inter-annual rise in sea level from 1983 to 2011 (Cayan *et al.* 2008; Bromirski *et al.* 2011; NOAA 2013). Bromirski *et al.* (2011, 2012) postulate that persistent alongshore winds have caused an extended period of offshore upwelling that has both drawn coastal waters offshore and replaced warm surface waters with cooler deep ocean water. Both of these factors could have caused a drop in sea level, canceling out the sea rise that would otherwise be expected from a warm phase PDO signal.

Water level changes from surge, atmospheric forcing, El Niño events and the PDO can occur in combination. The water elevation changes from each factor may be only about 1 ft (0.3 m) or less, but each can cause changes in the water level over a time period of days, months, or a few years – far more rapidly than sea level rise. In combination, they can potentially cause a significant localized increase in water level.

When high water conditions occur in combination with high tides, and with coastal storms, the threat of coastal flooding, wave impacts and erosion also increases. These conditions can be additive, as shown in Figure B-3. Also, these changes in water level will continue to be important to the overall water level conditions along the California coast and they need to be examined in conjunction with possible changes due to regional sea level rise.

As stated earlier, estimates of surge, El Niño and PDO water elevation changes are developed primarily from historical records. There are no state-wide resources for this information, although it may be included in one of the Regional Sediment Management Plans, available for many coastal areas (see http://www.dbw.ca.gov/csmw/). General guidance on water level changes, surge, and El Niño events is provided in Table B-2.

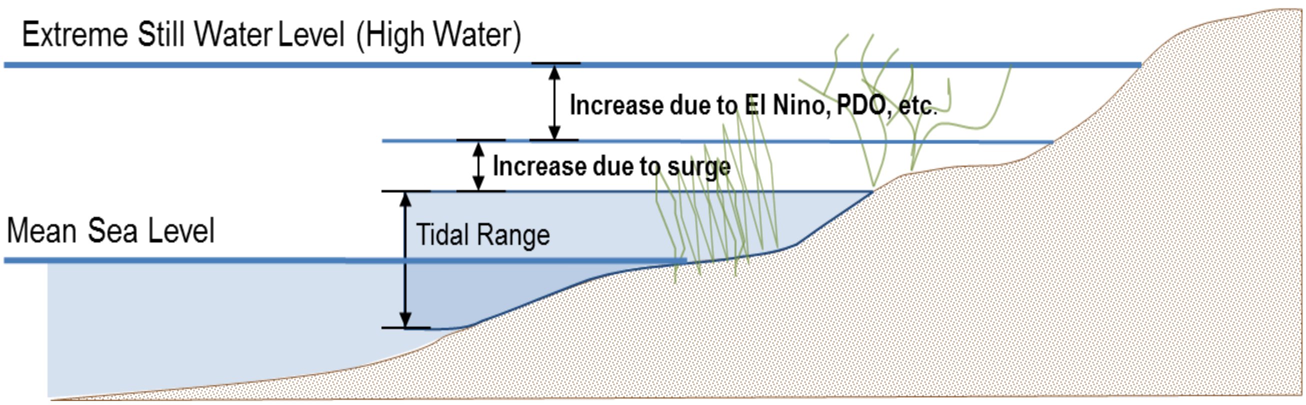

Figure B-3. Changes to extreme still water level due to surge, El Niño events, and PDOs. (*Source: L. Ewing, 2013*).

Table B-2. General Resources for Determining Still Water Elevation, Surge, El Niño events, and PDOs

Resource	Description	Link
NOAA Sea Level Rise and Coastal Flooding Impacts Viewer	Displays potential future sea levels within wetland areas, and provides visualizations for various amounts of sea level rise. For bays and estuaries, it also provides information on inland areas with the potential to flood if existing barriers to water connectivity are removed or overtopped. Communicates spatial uncertainty of mapped sea level rise, overlays social and economic data onto sea level rise maps, and models potential marsh migration due to sea level rise. Maps do not include any influence of beach or dune erosion.	NOAA Digital Coast, https://coast.noaa.gov/digitalcoast/tools/slr.html
Pacific Institute Sea Level Rise Maps	Downloadable PDF maps showing the coastal flood and erosion hazard zones from the 2009 study. Data are overlaid on aerial photographs and show major roads. Also available are an interactive online map and downloadable maps showing sea level rise and population and property at risk, miles of vulnerable roads and railroads, vulnerable power plants and wastewater treatment plants, and wetland migration potential.	http://www.pacinst.org/reports/sea_level_rise/maps/ For the 2009 report "The Impacts of Sea Level Rise on the California Coast" visit: http://pacinst.org/publication/the-impacts-of-sea-level-rise-on-the-california-coast/
Cal-Adapt – Exploring California's Climate	Represents inundation location and depth for the San Francisco Bay, the Sacramento-San Joaquin River Delta and California coast resulting from different increments of sea level rise coupled with extreme storm events. Incorporates real, time series water level data from past (near 100 year) storm events to capture the dynamic effect of	http://cal-adapt.org/tools/slr-calflod-3d/

	storm surges in modeling inundation using a three dimensional hydrodynamic model (per Radke et al., 2017).	
Regional Sediment Management Plans	Plans for regions of the state to identify how governance, outreach and technical approaches can support beneficial reuse of sediment resources within that region without causing environmental degradation or public nuisance.	http://www.dbw.ca.gov/csmw/

Outcome from Step 3*: Provide estimates of water elevations that can result from surge, El Niño events, and PDOs. When combined with the sea level changes to the tidal range, developed in Step 4, these can provide information on the extreme still water level. For most open coast situations, this information will be used to inform further project analysis and planning that examines erosion, surge and storm conditions.*

Step 4 – Estimate beach, bluff, and dune change from erosion

Predictions of future beach, bluff, and dune erosion are complicated by the uncertainty associated with future waves, storms and sediment supply. As a result, there is no single specific accepted method for predicting future beach erosion. At a minimum, projects should assume that there will be inundation of dry beach and that the beach will continue to experience seasonal and inter-annual changes comparable to historical amounts. When there is a range of erosion rates from historical trends, the high rate should be used to project future erosion with rising sea level conditions (unless future erosion will encounter more resistant materials, in which case lower erosion rates may be used). For beaches that have had a relatively stable long-term width, it would be prudent to also consider the potential for greater variability or even erosion as a future condition. For recent studies that provide some general guidance for including sea level rise in an evaluation of bluff and dune erosion, see, for example, Heberger *et al.* (2009) or Revell *et al.* (2011). Other approaches that recognize the influence of water levels in beach, bluff, or dune erosion can also be used. Table B-3, at the end of this section, provides some resources that can be used for projecting future erosion.

The following sections discuss specific concerns associated with beach, bluff and dune erosion and are provided to acquaint readers to the main issues associated with each system. Readers with a strong background in coastal systems may want to skim or skip the rest of this section.

Beach Erosion

Beach erosion and accretion occur on an on-going basis due to regular variability in waves, currents and sand supply. The movement of sand on and off of beaches is an ongoing process. Along the California coast, periods of gradual, on-going beach change will be punctuated by rapid and dramatic changes, often during times of large waves or high streamflow events.

The overall dynamics of beach change have been described many times.[101] Sand moves on and off shore as well as along the shore. Normal sources of sand to a beach are from rivers and streams, bluff erosion or gullies, and offshore sand sources. Sand leaves a beach by being carried downcoast by waves and currents, either into submarine canyons or to locations too far offshore for waves to move it back onto shore. Beaches are part of the larger-scale sediment dynamics of the littoral cell, and in very simple terms, beaches accrete if more sand comes onto the beach than leaves and beaches erode if more sand leaves than is added. Changes in sand supply are a major aspect of beach change.

Beach changes are often classified as being either seasonal or long-term/inter-annual changes. Seasonal changes are the shifts in beach width that tend to occur throughout the year and are usually reversible. During late fall and winter, beaches tend to become narrower as more high energy waves carry sand away from the beach and deposit it in offshore bars. This is later followed by beach widening as gentler waves again bring sand landward, building up a wider dry-sand summer beach. These changes are considered seasonal changes, and if the beach widths return to the same seasonal width each year, then the beach experiences seasonal changes but no long-term or inter-annual changes. If the seasonal beach widths become progressively wider or narrower, these changes become long-term or inter-annual change, and suggest a long-term beach change trend – accretion if the beach is widening and erosion if the beach is narrowing.

If development is at or near beach level, erosion of the beach can expose the development to damage from waves, flooding, and foundation scour. Additionally, waves that hit the coast bring with them vegetation, floating debris, sand, cobbles, and other material which can act like projectiles, adding to the wave forces and flood damage.

At present, approximately 66% of the California beaches have experienced erosion over the last few decades, with the main concentration of eroding beaches occurring in southern California (Hapke *et al.* 2006). This erosion has been due to a combination of diminished sand supplies and increased removal of sand by waves and currents. With rising sea level, beach erosion is likely to increase due to both increased wave energy[102] that can carry sand offshore or away from the beach, and to decreased supply of new sediments to the coast.[103]

There are several factors that will contribute to the effects of sea level rise on seasonal and inter-annual beach change. There will be the changes to the beach due to inundation by rising water levels, as shown in Figure B-4 (see the discussion on inundation earlier in this Appendix for more information on how to determine this change). If the beach cannot migrate inland to accommodate these changes, then the inundation will result in a direct loss or erosion of beach width. This will result in a narrower seasonal beach as well as inter-annual loss of beach.

101 See for example, Bascom 1980, Komar 1998, and Griggs *et al.* 2005.

102 In shallow water, wave energy is proportional to the square of the water depth. As water depths increase with sea level rise, wave energy at the same location will likewise increase.

103 Many parts of the developed coast are already experiencing drops in sand supplies due to upstream impoundments of water and sediment, more impervious surfaces, and sand mining.

Seasonal and inter-annual beach conditions will also be affected by changes to waves and sediment supply. Since waves are sensitive to bottom bathymetry, changes in sea level may change the diffraction and refraction of waves as they approach the coast, thereby changing the resulting mixture of beach-accreting and beach-eroding waves. However, the influence of climate change (not just rising sea level) on wave conditions, through changes in wave height, wave direction, storm frequency, and storm intensity, will likely be far more significant than the slight changes from bathymetric changes. In addition, changing precipitation patterns will modify the amount and timing of sediment delivery to the beach.

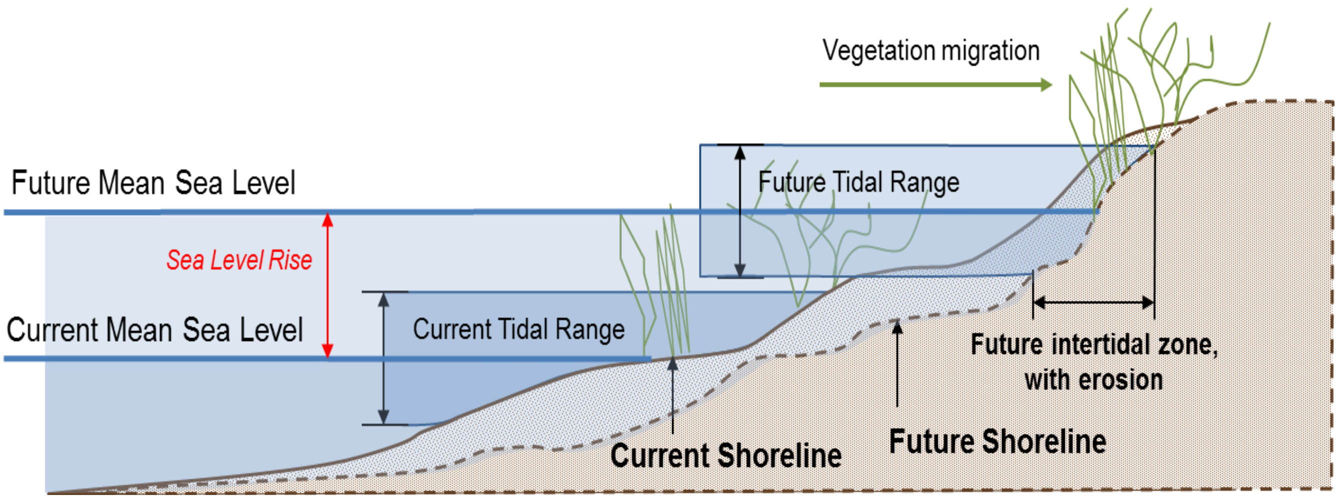

Figure B-4. Changes to the intertidal zone with sea level rise and erosion, without wave impacts. (*Source: L. Ewing, 2013*).

Bluff Erosion

A second type of erosion occurs on coastal bluffs.[104] There is no fully-accepted methodology for estimating future bluff erosion with sea level rise. Guidance for coastal analysts in Hawaii is to assume erosion will increase as a proportion of historical erosion (Hwang 2005). One approach used in the past by the Commission has been to apply one of the higher rates of historical erosion to represent average future trends. A more process-based methodology, used in the Pacific Institute study of erosion due to rising sea level, is to correlate future erosion rates of bluffs with a higher still water level that will allow waves to attack the bluff more frequently (Heberger *et al.* 2009; Revell *et al.* 2011). This approach assumes that all bluff erosion is due to wave impacts and that erosion rates will change over time as the beach or bluff experiences more frequent or more intense wave attack. Such an approach should be considered for examining bluff erosion with rising sea level. Other approaches that recognize the influence of water levels in beach, bluff, or dune erosion can also be used.

[104] Bluffs can be built or expanded during interglacial cycles or following seismic uplift. Many of the marine terraces that are visible along the California coast are remnants of past beach areas that have been uplifted to become bluffs and cliffs. However, natural bluff rebuilding is a millennial or multi-millennial process, and it will not occur during the time periods over which most development projects are evaluated.

Bluff retreat occurs via many different mechanisms. Landslides, slumps, block failures, gullies, and rilling are examples of bluff retreat. At the most basic level, bluff retreat or collapse occurs when the forces leading to collapse of the bluff face are stronger than the forces holding the bluff in place. Forces causing bluff retreat can include earthquakes, wind, burrowing animals, gravity, rain, surface runoff, groundwater, and sheet flow. Coastal bluffs have the added factor of wave attack. Resistance to collapse is mainly a characteristic of the bluff material. For example, granitic bluffs like those along the Big Sur coast retreat at a much slower rate than the soft sandstone and marine terrace bluffs of Pacifica.

Coastal bluff erosion can occur throughout the year, but it often occurs during or after storm periods, when the dry beach will be narrow or non-existent. When coastal bluffs are fronted by wide sand beaches, most waves break on the beach face and the beaches protect the bluffs from direct wave attack. When the beach is narrow, there is less buffering of the wave energy and waves can break directly against the bluffs. A general depiction of bluff retreat with rising sea level is provided in Figure B-5.

Bluff retreat is often episodic – the bluff may be stable for a number of years and then retreat by tens of feet in a few hours or a few days. If the changes to a bluff are examined through endpoint analysis (*i.e.*, looking first at the initial position of the bluff and then at the position of the bluff sometime in the future), researchers can determine the amount of retreat that has occurred during the time from the initial to final positions. This gives information on an average retreat rate that has occurred, but provides no insight about the conditions leading to the retreat, the size of retreat, frequency of retreat events, or the progression of retreat and no retreat. The average retreat rates can give some indication of likely future changes, but they provide little information about when the next retreat episode might occur or how large it might be.

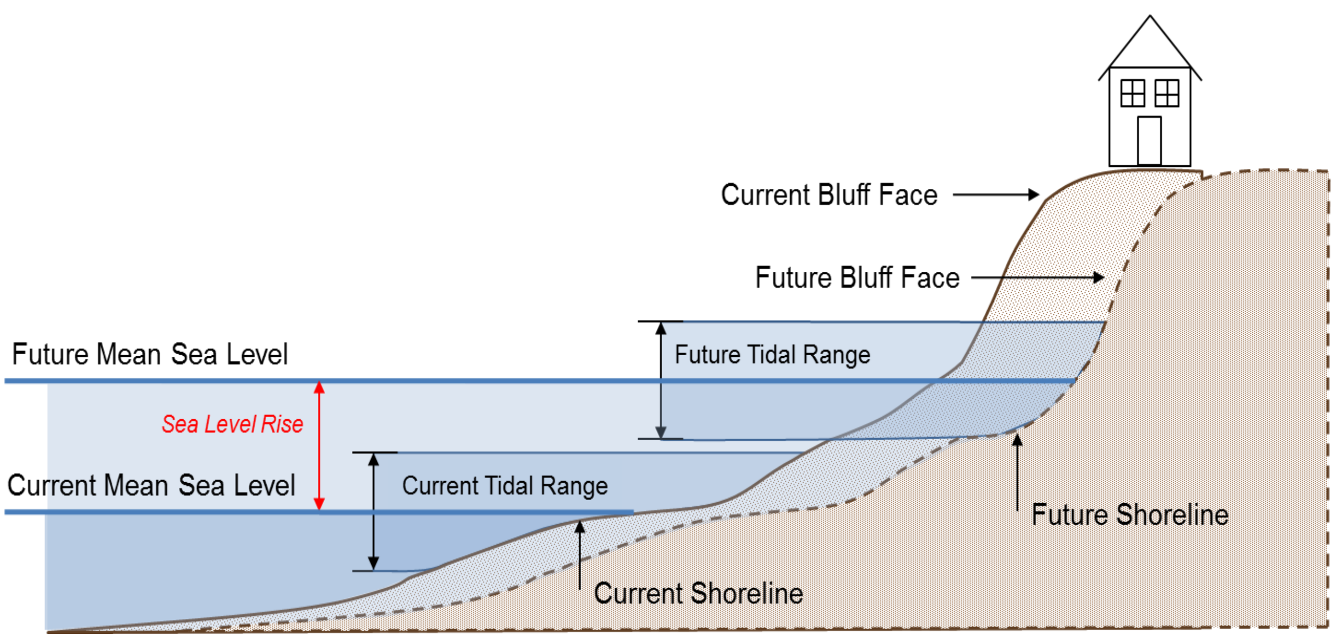

Figure B-5. Bluff erosion with changes in sea level. (*Source: L. Ewing, 2013*).

Dune Erosion

Just as there is no fully-accepted methodology for estimating changes to beach or bluff erosion with sea level rise, there is no fully-accepted methodology for dune erosion. A methodology somewhat similar to that for bluff erosion has been developed for dunes (Heberger *et al.* 2009; Revell *et al.* 2011), and such an approach should be considered for examining dune erosion with rising sea level. Other approaches that recognize the influence of water levels in beach, bluff, or dune erosion may also be used.

Dune erosion occurs when the waves break at or near the dunes, pulling sediment out of the dune. This process deposits sand onto the beach or in the nearshore area, but can result in short-term dune retreat. If sand is not returned to the dunes following these periods of short-term retreat, the sand losses will contribute to long-term dune erosion. Damage will occur to development located on dunes when the dune retreats back to the location of development, either through reversible, short-term retreat or long-term erosion.

For individual cases, determinations of future retreat risk are based on the site-specific conditions and professional analysis and judgment. However, the lack of information about the contributions of all the erosive forces to dunes and the beach-dune interactions makes it challenging to anticipate future changes to coastal dune retreat due to rising sea level and increased wave forces. As with beaches and bluffs for most situations, historical conditions provide a lower limit for future dune *retreat*, or the upper limit of dune *advance* for those sites that are now experiencing accretion or quasi-stability. Projections of future erosion should either: 1) use the high range of historical erosion; 2) develop a sea level rise influenced erosion rate, as done by Heberger *et al.* (2009) or Revell *et al.* (2011); or, 3) develop another approach that considers shoreline changes that are likely to occur under rising sea level conditions.

Table B-3. General Resources for Information on Beach, Bluff and Dune Erosion

Resource	Description	Link
Aerial Photographs	Useful for general information on shoreline trends; ortho-rectified photos can help quantify trends.	California Coastal Records Project, www.californiacoastline.org; Huntington Library; Local Libraries
LIDAR	Fairly detailed topography that can provide GIS layers for current conditions and is comparable with LIDAR data sets for temporal changes.	NOAA's Digital Coast, http://coast.noaa.gov/digitalcoast/data/coastallidar
USGS National Assessment of Shoreline Change with GIS Compilation of Vector Shorelines	Statewide inter-annual beach and bluff erosion; GIS shorelines available for sandy shorelines & cliff edge, showing historical changes for long-term (70 to 100 years) and short-term (25 to 50 years). No projections of future erosion rates available.	Sandy Shorelines – Open File Report 2006-1219, http://pubs.usgs.gov/of/2006/1219, and GIS Data in Open File 2006-1251, http://pubs.usgs.gov/of/2006/1251; Bluff Shorelines – Open File Report 2007-1133, http://pubs.usgs.gov/of/2007/1133, and GIS Data in Open File 2007-1251, http://pubs.usgs.gov/of/2007/1112

Regional Sediment Management Studies	Summaries of seasonal and long-term erosion studies	CSMW Website, http://dbw.ca.gov/csmw/default.aspx; California Beach Erosion Assessment Survey, http://dbw.ca.gov/csmw/library.aspx
US Army Corps of Engineers, Coast of California Studies	Summaries of seasonal and long-term erosion studies	Studies for many regions are available through an internet search (addresses are too numerous to list here)
Beach Profiles and Surveys	Detailed beach or bluff changes with time	NOAA's Digital Coast, https://coast.noaa.gov/digitalcoast/tools/ US Army Corps of Engineers; Regional Beach Studies; University Studies
The Impacts of Sea Level Rise on the California Coast (Pacific Institute Report)	Expected changes to bluff position over time for sea level rise of 4.6 ft (1.4 m) from 2000 to 2100 for California coast from Oregon border through Santa Barbara County.	Pacific Institute Website, http://www.pacinst.org/reports/sea_level_rise/maps/
CoSMoS	Currently available for Point Arena to the Mexico border, with a statewide expansion anticipated in 2018/2019. The Coastal Storm Modeling System (CoSMoS) is a dynamic modeling approach that allows detailed predictions of coastal flooding due to both future sea level rise and storms, and integrated with long-term coastal evolution (i.e., beach changes and cliff/bluff retreat)	https://walrus.wr.usgs.gov/coastal_processes/cosmos/ http://data.pointblue.org/apps/ocof/cms/
TNC Coastal Resilience	An online mapping tool showing potential impacts from sea level rise and coastal hazards designed to help communities develop and implement solutions that incorporate ecosystem-based adaptation approaches. Available statewide with more detailed modelling for Monterey Bay, Santa Barbara, Ventura, and Santa Monica.	http://maps.coastalresilience.org/california/

Outcome from Step 4: *Provide projections of future long-term beach, bluff or dune erosion that takes into account sea level rise. For locations without any influence from storm surge, or wave energy, the identification of the extent of beach, bluff or dune erosion may be sufficient for project analysis and planning efforts. This projected new erosion area may also be useful for anticipating the appropriate setback distance for otherwise stable land forms (If slope stability is a concern, refer to Commission guidance on setbacks (http://www.coastal.ca.gov/W-11.5-2mm3.pdf)). For most open coast situations, this information will be used to inform further project analysis and planning that examines erosion, surge and storm conditions.*

Step 5 – Determine wave, storm wave, wave runup, and flooding conditions

The main concerns with waves, storm waves, and runup are flooding and damage from wave impacts. Flooding is the temporary wetting of an area by waves, wave runup, surge, atmospheric forcing (such as water elevation during El Niño events) and, at river mouths, the combination of waves and river flows. Wave impacts occur when high-energy waves, often associated with storms, reach backshore areas or development. Coastal flooding and wave impacts are worst when they coincide with high water level events (high tide plus high inundation). As sea level rises, inundation will move inland, and so will flooding and wave impacts. Beach erosion will aggravate these conditions and add to the inland extent of impacts.

Flooding

In most situations, factors that result in high water conditions, such as tides, surge, El Niño events, and PDOs, should be used to determine flood levels and flood areas, as shown below. If the area is exposed to storm waves, these forces should be examined as well.

Future Flooding Level = Higher High Tide + Sea Level Rise + Surge + Forcing + Wave Runup

Flooding Areas = Flooding + Seasonal Eroded Beach + Long-Term Beach Erosion

Waves

Waves, like tides, cause constant changes to the water levels that are observed at the coast. The rhythmic lapping of waves on the beach during summer can be one of the joys of a beach visit. At other times of the year, waves can increase in size and energy and damage or destroy buildings, and cause erosion of bluffs and cliffs. Routine ocean waves are generated by wind blowing across the surface of the water and can travel far from their source, combining with waves generated from other locations to produce the rather erratic and choppy water levels that are seen in most of the ocean. As waves move into shallow water and approach land, they are strongly modified by the offshore bathymetry. They take on a more uniform appearance, aligning somewhat parallel to the shoreline through processes of refraction and diffraction. During most of the year, moderate short-period waves break once they are in water depths of approximately 1.3 times the wave height.

Wave impacts depend greatly upon storm activity – both the intensity and the duration of the storm. Normally projects have used design wave conditions comparable to the 100-year event. For critical infrastructure or development with a long life expectancy, it may be advisable to use a greater design standard, such as a 200-year or 500-year event. It may be suitable for some proposed projects to adjust design waves or the frequency of high energy waves to analyze the consequences of worsening wave impacts.

Waves also vary greatly with bathymetry; offshore reefs and sand bars can cause waves to break far from the coast and greatly reduce the energy of the waves that come onshore. Therefore, changes in offshore water depths can alter the nature of nearshore wave propagation and resultant onshore waves. For areas with complex offshore bathymetry, wave impact changes due to rising sea level may need to be examined in the context of both offshore and nearshore conditions.

Wave impacts to the coast, to coastal bluff erosion and inland development, should be analyzed under the conditions most likely to cause harm. Those conditions normally occur in winter when most of the sand has moved offshore leaving only a reduced dry sand beach to dissipate wave energy (this seasonal change in beach width is often referred to as short-term or seasonal erosion). On beaches that will experience long-term erosion, trends expected to occur over the entire expected life of the development should also be considered. Just as the beach conditions to analyze should be those least likely to protect from damage over the life of the development, the water level conditions considered should also be those most likely to contribute to damage over the life of the development. Waves that cause significant damage during high tide will be less damaging during low tide; all other things being equal, waves will cause more inland flooding and impact damage when water levels are higher. Since water levels will increase over the life of the development due to rising sea level, the development should be examined for the amount of sea level rise (or a scenario of sea level rise conditions) that is likely to occur throughout the expected life of the development. Then, the wave impact analysis should examine the consequences of a 100-year design storm event using the combined water levels that are likely to occur with high water conditions and sea level rise, as well as a long-term and seasonally eroded beach.

Eroded Beach Conditions = Seasonal Erosion + Long-Term Erosion*

High Water Conditions = High Tide + Relative Sea Level Rise* + Atmospheric Forcing

Wave Conditions = 100-year Design Storm + High Water + Eroded Beach

* The time period for both long-term erosion and relative sea level rise will be at least as long as the expected life of the development.

The remaining discussion provides general information about waves, the California wave climate, and coastal flooding. It is provided to acquaint readers to the main issues associated with waves and coastal flooding. Readers with a strong background in waves or coastal processes may want to skim or skip the rest of this section.

Storm Waves

During storm conditions, winds can transfer large amounts of energy into waves, increasing wave height, length, and period. Energy transfer to waves depends upon three conditions: the wind energy that is available to be transferred to the water (intensity); the length of time over which the wind blows (duration); and the area over which the wind blows (the fetch). As any of these conditions increases, the energy in the waves will increase, as will the energy that these waves bring to the coastline. Coastal scientists separate waves that are generated far from the coast (swell) from waves that are locally generated (seas). Storms in the mid-Pacific can cause storm-like wave conditions along the coast, even when there are no storms in the area. Likewise, a local storm can cause storm waves along one part of the coast while waves in other sections of the coast may be fairly mild.

Some of the worst storm wave conditions occur when there are intense storms along a large portion of the coast and when this large, distantly generated swell combines with local seas. The 1982/83 El Niño has been cited often as one of the more damaging storm seasons in recent times. In late January 1983, waves from a distant storm combined with locally generated waves and the highest tides of the year. This one storm caused substantial damage along much of the California Coast. The coast was not able to recover before a series of storms in February and March caused additional damage. The full 1982/83 El Niño storm season resulted in damage to approximately 3,000 homes and 900 businesses and destruction of 33 buildings. Damages exceeded $100 million to structures and $35 million to public recreational infrastructure (in 1982 dollars; Flick 1998).

Wave Runup

Wave runup, as depicted in Figure B-6, is the distance or extent to which water from a breaking wave will spread up the shoreline. Much of the wave energy will dissipate during breaking, but wave runup can also be damaging. The runup water moves quickly and can scour or erode the shoreline areas (including the beach), damage structures, and flood inland areas.

Damage from waves and wave runup may increase in the future, due both to rising sea level and to changes in storm intensity and frequency. Waves will break farther landward when water levels are higher. Therefore, increased water levels due to tides, surge, ENSO or PDO variability, or sea level rise will enable more wave energy to reach the beach, back shore, or inland development. The higher water levels do not change the waves. Rather, higher water levels change the point of impact, the extent of runup, and the frequency of wave impact. In locations where high waves now hit the coast, that frequency will increase; in locations where high waves rarely hit the coast, exposure to wave impacts will increase. Increased exposure to wave impacts or wave runup can cause a greater risk of flooding, erosion, bluff failure, and/or damage to development. But, since the focusing of wave energy is strongly influenced by offshore bathymetry, locations of wave exposure may also change with rising sea level and modifications in wave propagation might result from future differences in water depths.

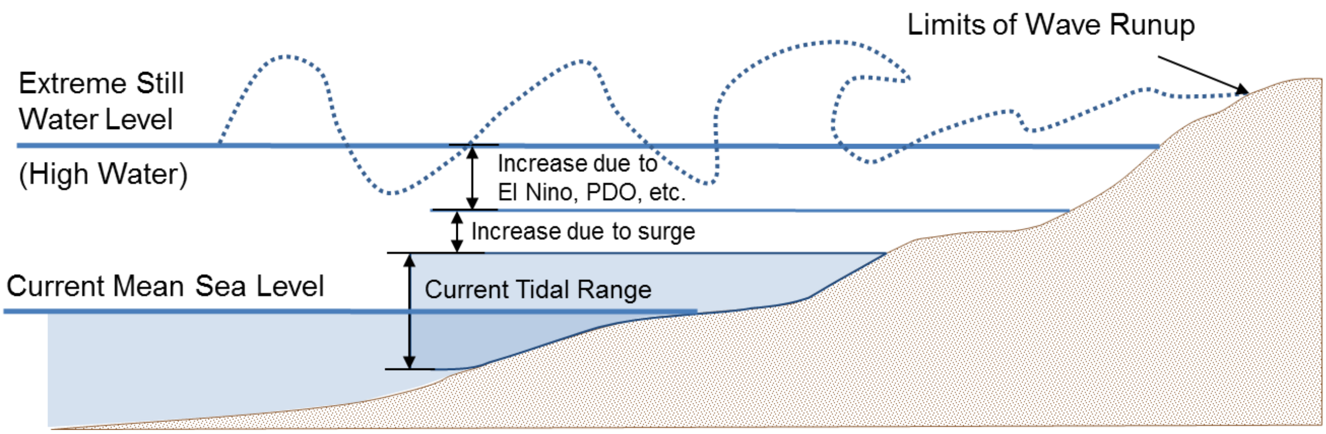

Figure B-6. Wave runup combined with extreme still water (High Water). (*Source: L. Ewing, 2013*).

Summary

Coastal flooding is a significant problem now and it will increase with rising sea level. At present, about 210,000 people in California are living in areas at risk from a 100-year flood event (Heberger *et al.* 2009). A rise in sea level of 55 in (1.4 m) with no change in development patterns or growth along the coast could put 418,000 to 480,000 people at risk from a 100-year flood (Cooley *et al.* 2012). An additional fraction of the California population that relies on critical infrastructure located in potentially hazardous areas is also vulnerable and increases in storm intensity or in the density of development in flood-prone areas will increase the number of people at risk from flooding.

The frequency and intensity of high wave events depends upon the storm conditions that generate the waves. There is less consistency in the output of climate models related to projections of future storm conditions than there has been for temperature projections. A recent report on coastal flooding from years 2000 to 2100 for the California coast has found that "storm activity is not projected to intensify or appreciably change the characteristics of winter nearshore wave activity of the twenty-first century" (Bromirski *et al.* 2012, p. 33). This continuation of current storm conditions is not, however, an indication that storms will not be a problem in the future. Storm damage is expected to continue, and, if sea level rise by the end of the twenty-first century reaches the high projections of about 55 in (1.4 m), "coastal managers can anticipate that coastal flooding events of much greater magnitude than those during the 1982-83 El Niño will occur annually." (Bromirski *et al.* 2012, p. 36)

For most situations, the 100-year storm event should be used as the design storm. This is equivalent to a storm with a 1% annual probability of occurrence. However, most development does outlast one year and this probability of occurrence grows over time such that there is a 22% probability of occurrence during a 25-year period and over 53% probability that this storm will occur at least once during a 75-year period. Even so, the 100-year storm event, like the 100-year flood event, is often used as a design standard for development. However, for structures with a very long projected life or for which storm protection is very critical, a larger, 200-year or 500-year event might be appropriate.

Table B-4 lists many of the resources that are available for finding regional or state-wide information on waves and flooding. Local communities may have records of major erosion episodes or flood events as well.

Table B-4. General Resources for Flooding and Wave Impacts

Resource	Description	Link
CDIP (Coastal Data Information Program)	Current and historical information on wind, waves, and water temperature, wave and swell models and forecasting. As of 2013, there are 19 active stations along the California coast.	http://cdip.ucsd.edu/
Flood Insurance Rate Maps (FIRMs)	FEMA is updating coastal flood maps. Existing FIRMs are based on 1980s topography; flooding includes seasonal beach change but not long-term erosion. Maps do not include sea level rise. Inclusion of a site shows a flood hazard; but exclusion does not necessarily indicate a lack of flood hazard.	FEMA Flood Map Service Center, https://msc.fema.gov/portal
FEMA Flood Hazard Mapping Guidance	*Subsection D.2.8* provides guidance for calculating wave runup and overtopping on barriers. There are special cases for steep slopes and where runup exceeds the barrier or bluff crest.	https://www.fema.gov/media-library/assets/documents/13948
Regional Sediment Management Studies	Some studies show elements of beach flooding and wave impacts.	http://dbw.ca.gov/csmw/default.aspx
Cal-Adapt – Exploring California's Climate	Represents inundation location and depth for the San Francisco Bay, the Sacramento-San Joaquin River Delta and California coast resulting from different increments of sea level rise coupled with extreme storm events. Incorporates real, time series water level data from past (near 100 year) storm events to capture the dynamic effect of storm surges in modeling inundation using a three dimensional hydrodynamic model (per Radke et al., 2017).	http://cal-adapt.org/tools/slr-calflod-3d/
US Army Corps of Engineers, Coastal Engineering Manual	Detailed information on all aspects of deep-water wave transformation, shoaling, runup, and overtopping.	https://www.publications.usace.army.mil/USACE-Publications/Engineer-Manuals/
European Overtopping Manual	Descriptions of available methods for assessing overtopping and its consequences. Provides techniques to predict wave overtopping at seawalls, flood embankments, breakwaters and other shoreline structures facing waves. Supported by web-based programs for the calculation of overtopping discharge and design details.	http://www.overtopping-manual.com/

CoSMoS	Currently available for Point Arena to the Mexico border, with a statewide expansion anticipated in 2018/2019. The Coastal Storm Modeling System (CoSMoS) is a dynamic modeling approach that allows detailed predictions of coastal flooding due to both future sea level rise and storms, and integrated with long-term coastal evolution (i.e., beach changes and cliff/bluff retreat)	https://walrus.wr.usgs.gov/coastal_processes/cosmos/ http://data.pointblue.org/apps/ocof/cms/
TNC Coastal Resilience	An online mapping tool showing potential impacts from sea level rise and coastal hazards designed to help communities develop and implement solutions that incorporate ecosystem-based adaptation approaches. Available statewide with more detailed modelling for Monterey Bay, Santa Barbara, Ventura, and Santa Monica.	http://maps.coastalresilience.org/california/

Outcome from Step 5: *Provide projections of future flooding and wave impacts resulting from waves, storm waves and runup, taking into account sea level rise.*

Step 6 – Examine potential flooding from extreme events

Extreme events[105], by their very nature, are those beyond the normal events that are considered in most shoreline studies. Examples of extreme events that might occur along the California coast include:

- An individual storm with an intensity at or above the 100-year event
- A series of large, long-duration storms during high tides
- A local storm that coincides with the arrival of distant swell and high tides
- Rapid subsidence, as might happen along the Northern California coast during a Cascadia Subduction Zone earthquake
- Global sea level rise greater than that projected to occur by 2100, when combined with a large storm during normal tides

Planning and project analysis need to consider and anticipate the consequences of these outlier events. In many situations, this assessment might be a qualitative consideration of consequences that could happen if an extreme event does occur. Analysis of the consequences of extreme events presents opportunities to address some of those potential impacts through design and adaptation.

[105] In its report on *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation*, the IPCC defines extreme events as "a facet of climate variability under stable or changing climate conditions. They are defined as the occurrence of a value or weather or climate variable above (or below) a threshold value near the upper (or lower) ends ("tails") of the range of observed values of the variable" (IPCC 2012).

In California, there may be some worsening of extreme precipitation and inland flooding from projected changes to atmospheric rivers, narrow bands of concentrated moisture in the atmosphere. In general, however, future extremes are likely to be comparable to the extremes of today, but with the added influence of sea level rise. Extreme storm waves or floods can be addressed with the guidance provided earlier, except that the extreme storm conditions would be used. For tsunamis it is recommended that, for most situations, the appropriate projection of sea level rise be added to the currently projected inundation level from tsunamis. This will provide a close approximation for future inundation from extreme tsunamis. If a detailed analysis of future tsunami impacts is needed, the analysis should be conducted by someone experienced in modeling tsunami waves.

Tsunamis

Tsunamis are large, long-period waves that can be generated by submarine landslides, subaerial landslides (slope failures from land into a water body), large submarine earthquakes, meteors, or volcanic eruptions. They are rare events, but can be extremely destructive when they occur. The extent of tsunami damage will increase as rising water levels allow tsunami waves to extend farther inland. Thus the tsunami inundation zone will expand inland with rising sea level. There has been no research that suggests that climate change will increase the intensity or frequency of seismically-generated tsunamis. However, the number and size of coastal subaerial landslides may increase because of increased coastal erosion due to sea level rise, which in turn may increase the potential for tsunamigenic landslides along the California coast (Highland 2004; Walder *et al.* 2003).

The detailed changes to the inundation zone with rising sea level need to be determined by modeling; however, modeling of long-waves, such as tsunamis, is a specialized area of coastal engineering, and will not be covered in this general Guidance. For most situations, it will be sufficient to get information on possible inundation from the most recent tsunami inundation maps (currently on the Department of Conservation website, http://www.conservation.ca.gov/cgs/geologic_hazards/Tsunami/Inundation_Maps/Pages/Statewide_Maps.aspx). The California Geological Survey and California Governor's Office of Emergency Services are creating new tsunami inundation maps based on probabilistic tsunami hazard analysis (CPTHAWG 2015). As a rough approximation, the change to the tsunami inundation level can be estimated as equal to the change in water elevation due to sea level; a 1-ft rise in sea level could be assumed to result in a 1-ft rise in the inundation elevation. However, in many places, particularly shallow bays, harbors, and estuaries, the change in tsunami inundation zone is likely to scale non-linearly with sea level rise and require careful modeling. California Geological Survey is also working to evaluate the impact of sea level rise with numerical tsunami modeling to verify that an additive approach (tsunami height + SLR) is the appropriate method for integrating SLR and tsunami inundation together. In areas with high tsunami hazards, or where critical resources are at risk, a site-specific analysis of sea level rise impacts on tsunami hazards is crucial, and someone experienced in modeling tsunami waves should be consulted.

Summary

Many different factors affect the actual water levels that occur along the coast and resulting hazards. In California, waves and tides have the largest routine effect on water levels. Tsunamis may have a very large, but infrequent effect on water levels. Sea level rise will affect water levels all along the coast. Until the mid-century, tides and storms are expected to have the biggest effects on local water levels, with sea level rise being a growing concern. After Year 2050, sea level rise is expected to become increasingly influential on water levels and in contributing to damages to inland areas from flooding, erosion and wave impacts. Table B-5 provides a general characterization of all the factors that can affect local water levels, with general estimates of their range and frequency of occurrence.

Outcome from Step 6: *Projections of potential flooding from extreme events including rapid subsidence, extreme precipitation, and tsunamis.*

Table B-5. Factors that Influence Local Water Level Conditions

Factors Affecting Water Level	Typical Range for CA Coast (ft)	Typical Range for CA Coast (m)	Period of Influence	Frequency
Tides	3 – 10	1 – 3	Hours	Twice daily
Low pressure	1.5	0.5	Days	Many times a year
Storm Surge	2 – 3	0.6 – 1.0	Days	Several times a year
Storm Waves	3 – 15	1 – 5	Hours	Several times a year
El Niño events (within the ENSO cycle)	<1.5	< 0.5	Months - Years	2 – 7 years
Tsunami waves	20 – 50 (max) 3 – 10 (typical)	6 – 15 (max) 1 – 3 (typical)	Minutes, Hours, Days	Infrequent but unpredictable
Historical Sea Level, over 100 years	0.7	0.2	Ongoing	Persistent
OPC Sea Level Projections 2000 – 2050 (SF tide gauge; see also App. G)	1.1 – 2.7	0.3 – 0.8	Ongoing	Persistent
OPC Sea Level Projections 2000 – 2100 (SF tide gauge; see also App. G)	3.4 – 10.2	1.0 – 3.1	Ongoing	Persistent

Note that all values are approximations. The conversions between feet and meters have been rounded to maintain the general ranges and they are not exact conversions. *Sources*: Flick 1998; OPC 2018; Personal communications from Dr. Robert Guza (Scripps Institution of Oceanography), Dr. William O'Reilly (Scripps Institution of Oceanography and University of California, Berkeley), and Rick Wilson, California Geological Survey; and professional judgment of staff.

REFERENCES: APPENDIX B

Bascom W. 1979. *Waves and Beaches: The Dynamics of the Ocean Surface.* Garden City, NY: Anchor Books. 366pp.

Bromirski PD, AJ Miller, RE Flick, G Auad. 2011. Dynamical suppression of sea level rise along the Pacific Coast of North America: Indications for imminent acceleration. *Journal of Geophysical Research-Oceans* 116: C07005. doi:10.1029/2010JC006759.

Bromirski PD, DR Cayan, N Graham, RE Flick, M Tyree. 2012. White Paper from the California Energy Commission. Prepared by Scripps Institution of Oceanography, CEC-500-2012-011. http://www.energy.ca.gov/2012publications/CEC-500-2012-011/CEC-500-2012-011.pdf.

California Probabilistic Tsunami Hazard Analysis Work Group (CPTHAWG). 2015. *Evaluation and Application of Probabilistic Tsunami Hazard Analysis in California – Phase 1: Work Group Review of Methods, Source Characterization, and Applications to the Crescent City Demonstration Project Results.* California Geological Survey Special Report 237. 33 pp. http://activetectonics.coas.oregonstate.edu/paper_files/reports/012615_CGS%20Special%20Report%20237-Evaluation%20of%20Probabilistic%20Tsunami%20Hazard%20Analysis%20in%20California-final.pdf.

Cayan DR, PD Bromirski, K Hayhoe, M Tyree, MD Dettinger, RE Flick. 2008. Climate change projections of sea level extremes along the California coast. *Climatic Change* 87(Suppl 1): S57-S73. doi:10.1007/s10584-007-9376-7.

Cooley H, HE Moore, M Heberger, L Allen. 2012. *Social Vulnerability to Climate Change in California*. White paper from the California Energy Commission. Prepared by the Pacific Institute. CEC-500-2012-013. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.260.471&rep=rep1&type=pdf.

Flick RE. 1998. Comparison of California tides, storm surges, and mean sea level during the El Niño winters of 1982–1983 and 1997–1998. *Shore & Beach* 66(3): 7-11.

Flick R, J Murray, L Ewing. 2003. Trends in U.S. Tidal Datum Statistics and Tide Range. *ASCE Journal of Waterway, Port, Coast and Ocean Engineering* 129(4): 155-164. http://dsp.ucsd.edu/~jfmurray/publications/Flick2003.pdf.

Gallien TW, PL Barnard, M van Ormondt, AC Foxgrover, BF Sanders. 2012. A parcel-scale coastal flood forecasting prototype for a southern California urbanized embayment. *Journal of Coastal Research* 29(3): 642-656. doi: 10.2112/JCOASTRES-D-12-00114.1.

Gallien TW, JE Schubert, BF Sanders. 2011. Predicting tidal flooding of urbanized embayments: A modeling framework and data requirements. *Coastal Engineering* 58(6): 567-577. doi:10.1016/j.coastaleng.2011.01.011.

Griggs G, K Patsch, L Savoy (Eds.). 2005. *Living with the Changing California Coast*. Berkeley and LA, CA: University of California Press. 551 pp.

Grinsted A, J Moore, S Jevrejeva. 2009. Reconstructing sea level from paleo and projected temperatures 200 to 2100 AD. *Climate Dynamics* 34: 461-472. doi:10.1007/s00382008-0507-2.

Hapke CJ, D Reid, BM Richmond, P Ruggiero, J List. 2006. *National Assessment of Shoreline Change Part 3: Historical Shore Change and Associated Coastal Land Loss Along Sandy Shorelines of the California Coast*. USGS Open File Report 2006-1219.

Heberger M, H Cooley, P Herrera, PH Gleick, E Moore. 2009. *The Impacts of Sea-Level Rise on the California Coast*. Prepared by the Pacific Institute for the California Climate Change Center. http://dev.cakex.org/sites/default/files/CA%20Sea%20Level%20Rise%20Report.pdf.

Highland L. 2004. *Landslide Types and Processes*. US Geological Survey Fact Sheet 2004-3072: 1-4, Reston, VA.

Hwang DJ. 2005. *Hawaii Coastal Hazard Mitigation Guidebook*. University of Hawaii Sea Grant College Program. 216 pp.

Intergovernmental Panel on Climate Change (IPCC). 2007. *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change.* [S Solomon, D Qin, M Manning, M Marquis, K Averyt, MMB Tignor, HL Miller, Jr., Z Chen (eds.)], Cambridge University Press: Cambridge, UK and New York, NY, USA. 91 pp. https://www.ipcc.ch/report/ar4/

Intergovernmental Panel on Climate Change (IPCC). 2012. *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation.* A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change [CB Field, V Barros, TF Stocker, D Qin, DJ Dokken, KL Ebi, MD Mastrandrea, KJ Mach, GK Plattner, SK Allen, M Tignor, PM Midgley (Eds.)]. Cambridge University Press, Cambridge, UK, and New York, NY, USA. 582 pp. http://ipcc-wg2.gov/SREX/report/.

Jevrejeva S, JC Moore, A Grinsted. 2012. Sea level projections to AD2500 with a new generation of climate change scenarios. *Global and Planetary Change* 80-81: 14-20. doi:10.1016/j.gloplacha.2011.09.006.

Komar PD. 1998. *Beach Processes and Sedimentation*. 2nd Ed. Upper Saddle River, NJ: Prentice Hall. 544pp.

Kopp R, F Simons, J Mitrovica, A Maloof, M Oppenheimer. 2009. Probabilistic assessment of sea level during the last interglacial stage. *Nature* 462: 863-867. doi:10.1038/nature08686.

Merrifield MA. 2011. A shift in western tropical Pacific sea level trends during the 1990s. *Journal of Climate* 24(15): 4126-4138. doi:10.1175/2011JCLI3932.1.

National Research Council (NRC). 2012. *Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future*. Report by the Committee on Sea Level Rise in California, Oregon, and Washington. National Academies Press, Washington, DC. 250 pp. http://www.nap.edu/catalog/13389/sea-level-rise-for-the-coasts-of-california-oregon-and-washington.

Nicholls RJ, N Marinova, JA Lowe, S Brown, P Vellinga, D de Gusmao, J Hinkel, RSJ Tol. 2011. Sea-level rise and its possible impacts given a 'beyond 4°C world' in the twenty-first century. *Philosophical Transactions of the Royal Society* 369(1934): 161-181. doi:10.1098/rsta.2010.0291.

National Oceanic and Atmospheric Administration (NOAA) Tides and Currents. 2013. *Center for Operational Oceanographic Products and Services.* Retrieved 19 July, 2013, from http://tidesandcurrents.noaa.gov/.

Ocean Protection Council (OPC). 2018. *State of California Sea-Level Rise Guidance: 2018 Update.* *http://www.opc.ca.gov/webmaster/ftp/pdf/agenda_items/20180314/Item3_Exhibit-A_OPC_SLR_Guidance-rd3.pdf*

Pfeffer WT, JT Harper, S O'Neel. 2008. Kinematic constraints on glacier contributions to 21st century sea-level rise. *Science* 321(5894): 1340 -1343. doi:10.1126/science.1159099.

Rahmstorf S. 2007. A semi-empirical approach to projecting future sea-level rise. *Science* 315(5810): 368-370. doi:10.1126/science.1135456.

Revell DL, R Battalio, B Spear, P Ruggiero, J Vandever. 2011. A methodology for predicting future coastal hazards due to sea-level rise on the California Coast. *Climatic Change* 109(Suppl 1): 251-276. doi:10.1007/s10584-011-0315-2.

Rohling E, K Grant, C Hemleben, M Siddall, B Hoogakker, M Bolshaw, M Kucera. 2008. High rates of sea-level rise during the last interglacial period. *Nature Geoscience* 1: 38-42. doi:10.1038/ngeo.2007.28.

Schaeffer M, W Hare, S Rahmstorf, M Vermeer. 2012. Long-term sea-level rise implied by 1.5˚C and 2˚C warming levels. *Nature Climate Change* 2: 867-870. doi:10.1038/nclimate1584.

Schubert JE, BF Sanders. 2012. Building treatments for urban flood inundation models and implications for predictive skill and modeling efficiency. *Advances in Water Resources* 41: 49-64. doi:10.1016/j.advwatres.2012.02.012.

Vellinga P, C Katsman, A Sterl, J Beersma, W Hazeleger, J Church, R Kopp, D Kroon, M Oppenheimer, H Plag, S Rahmstorf, J Lowe, J Ridley, H von Storch, D Vaughan, R van de Wal, R Weisse, J Kwadijk, R Lammersen, N Marinova. 2009. *Exploring high-end climate change scenarios for flood protection of the Netherlands. International Scientific Assessment*, Prepared for the Delta Committee. Scientific Report WR-2009-05. KNMI, Alterra, The Netherlands. 150pp. http://edepot.wur.nl/191831.

Vermeer M, S Rahmstorf. 2009. Global sea level linked to global temperature. *Proceedings of the National Academy of Science* 108: 21527-21532. doi:10.1073/pnas.0907765106.

Walder JS, P Watts, OE Sorensen, K Janssen. 2003. Tsunamis generated by subaerial mass flows. *Journal of Geophysical Research: Solid Earth (1978–2012)* 108: B5. doi: 10.1029/2001JB000707.

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Appendix C

Resources for Addressing Sea Level Rise

This section contains lists of sea level rise viewers, guidebooks, guidance documents, and state agency-produced resources, and data clearing houses related to sea level rise. These resources will be particularly relevant for informing Steps 1-6 of the LCP planning process (Chapter 5). Tables include:

- Table C-1 – Sea Level Rise Mapping Tools.
  This may be particularly relevant for Steps 1-3.

- Table C-2 – Sea Level Rise Data and Resource Clearinghouses.
  This may be particularly relevant for Steps 1-4.

- Table C-3 – Adaptation Planning Guidebooks.
  This may be particularly relevant for Steps 1-3.

- Table C-4 – Resources for Assessing Adaptation Measures.
  This may be particularly relevant for Step 4.

- Table C-5 – Examples of Sea Level Rise Vulnerability Assessments in California.
  This may be particularly relevant for Steps 1-3.

- Table C-6 – California Climate Adaptation Plans that Address Sea Level Rise.
  This may be particularly relevant for Steps 1-4.

- Table C-7 – California State Agency Resources

Table C-1. Sea Level Rise Mapping Tools

Tool	Description	Link
Statewide		
NOAA Digital Coast Sea Level Rise and Coastal Flooding Impacts Viewer	Displays potential future sea levels with a slider bar. Communicates spatial uncertainty of mapped sea level rise, overlays social and economic data onto sea level rise maps, and models potential marsh migration due to sea level rise. Maps do not include any influence of beach or dune erosion.	https://coast.noaa.gov/digitalcoast/tools/slr.html
Cal-Adapt – Exploring California's Climate	Represents inundation location and depth for the San Francisco Bay, the Sacramento-San Joaquin River Delta and California coast resulting from different increments of sea level rise coupled with extreme storm events. Incorporates real, time series water level data from past (near 100 year) storm events to capture the dynamic effect of storm surges in modeling inundation using a three dimensional hydrodynamic model (per Radke et al., 2017).	http://cal-adapt.org/tools/slr-calflod-3d/
Climate Central Surging Seas	Overlays sea level rise data with socio-economic information and ability to analyze property values, population, socio-economic status, ethnicity, and income or areas at risk. Can compare exposure across the whole state or selected county.	http://sealevel.climatecentral.org/ssrf/california
Pacific Institute Sea Level Rise Maps (Heberger *et al.* 2009)	Downloadable PDF maps showing the coastal flood and erosion hazard zones from the 2009 study. Data are overlaid on aerial photographs and show major roads. Also available are an interactive online map and downloadable maps showing sea level rise and population and property at risk, miles of vulnerable roads and railroads, vulnerable power plants and wastewater treatment plants, and wetland migration potential.	http://www.pacinst.org/reports/sea_level_rise/maps/ For the 2009 report *The Impacts of Sea-Level Rise on the California Coast*, see: http://pacinst.org/publication/the-impacts-of-sea-level-rise-on-the-california-coast/

Sea Level Affecting Marshes Model (SLAMM)	Simulates the dominant processes involved in wetland conversions and shoreline modifications during long-term sea level rise. Map distributions of wetlands are predicted under conditions of accelerated sea level rise, and results are summarized in tabular and graphical form.	http://www.warrenpinnacle.com/prof/SLAMM
Coastal Storm Modeling System (CoSMoS); tool hosted by Our Coast Our Future	Currently available for Point Arena to the Mexico border, with a statewide expansion anticipated in 2018/2019. The Coastal Storm Modeling System (CoSMoS) is a dynamic modeling approach that allows detailed predictions of coastal flooding due to both future sea level rise and storms, and integrated with long-term coastal evolution (i.e., beach changes and cliff/bluff retreat)	https://walrus.wr.usgs.gov/coastal_processes/cosmos/ http://data.pointblue.org/apps/ocof/cms/
TNC Coastal Resilience	An online mapping tool showing potential impacts from sea level rise and coastal hazards designed to help communities develop and implement solutions that incorporate ecosystem-based adaptation approaches. Available statewide with more detailed modelling for Monterey Bay, Santa Barbara, Ventura, and Santa Monica.	http://maps.coastalresilience.org/california/
Humboldt Bay Sea Level Rise Adaptation Project	This project is a multi-phased, regional collaboration. Phase I produced the *Humboldt Bay Shoreline Inventory, Mapping, and Sea Level Rise Vulnerability Assessment* which describes current shoreline conditions and vulnerabilities under the current tidal regime. Phase II included hydrodynamic modeling to develop vulnerability maps of areas surrounding Humboldt Bay vulnerable to inundation from existing and future sea levels. Phase II produced the *Humboldt Bay Sea Level Rise Modeling Inundation Mapping Report* and the *Humboldt Bay Sea Level Rise Conceptual Groundwater Model*.	All reports are available at: http://humboldtbay.org/humboldt-bay-sea-level-rise-adaptation-planning-project

Table C-2. Sea Level Rise Data and Resource Clearinghouses

Resource	Description	Link
California State Adaptation Clearinghouse	Hosted by the OPR Integrated Climate Adaptation and Resiliency Program (ICARP), a centralized source of information that provides the resources necessary to guide decision makers at the state, regional, and local levels when planning for and implementing climate adaptation projects to promote resiliency to climate change in California.	http://opr.ca.gov/clearinghouse/adaptation/ or https://resilientca.org/
California Climate Commons	Offers a point of access to climate change data and related resources, information about the science that produced it, and the opportunity to communicate with others about applying climate change science to conservation in California.	http://climate.calcommons.org/
Climate Adaptation Knowledge Exchange (CAKE)	Provides an online library of climate adaptation case studies and resources, plus ways to connect with an online climate adaptation community/ network.	http://www.cakex.org/
Ecosystem Based Management Tools Network Database	Provides a searchable database of tools available for climate adaptation, conservation planning, sea level rise impact assessment, *etc.*	http://www.ebmtools.org/about_ebm_tools.html
Climate.Data.gov	Recently launched federal government data portal that includes a number of data sets on climate change, including sea level rise impacts.	http://www.data.gov/climate/
NOAA Digital Coast	This NOAA-sponsored website is focused on helping communities address coastal issues. The Digital Coast provides coastal data, tools, training, and information from reputable sources.	http://coast.noaa.gov/digitalcoast/

Table C-3. Adaptation Planning Guidebooks

Title	Description	Link
Scanning the Conservation Horizon (National Wildlife Federation 2011)	Designed to assist conservation and resource professionals to better plan, execute, and interpret climate change vulnerability assessments.	https://www.nwf.org/~/media/pdfs/global-warming/climate-smart-conservation/nwfscanningtheconservationhorizonfinal92311.ashx
Adapting to Sea Level Rise: A Guide for California's Coastal Communities (Russell and Griggs 2012)	Intended to assist California's coastal managers and community planners in developing adaptation plans for sea level rise that are suited to their local conditions and communities.	http://seymourcenter.ucsc.edu/OOB/Adapting%20to%20Sea%20Level%20Rise.pdf
California Adaptation Planning Guide (APG) (Cal EMA/CNRA 2012)	Provides guidance to support regional and local communities in proactively addressing the unavoidable consequences of climate change. Includes a step-by-step process for local and regional climate vulnerability assessment and adaptation strategy development.	http://resources.ca.gov/climate/safeguarding/local-action/
Preparing for Climate Change: A Guidebook for Regional and State Governments (Snover *et al.* 2007)	Assists decision makers in a local, regional, or state government prepare for climate change by recommending a detailed, easy-to-understand process for climate change preparedness based on familiar resources and tools.	http://cses.washington.edu/db/pdf/snoveretalgb574.pdf
Adapting to Climate Change: a Planning Guide for State Coastal Managers (NOAA 2010)	Guide offers a framework for state coastal managers to follow as they develop and implement climate change adaptation plans in their own states.	https://coast.noaa.gov/czm/media/adaptationguide.pdf

Using Scenarios to Explore Climate Change: A Handbook for Practitioners (NPS 2013)	Describes the five-step process for developing multivariate climate change scenarios taught by the Global Business Network (GBN). Detailed instructions are provided on how to accomplish each step. Appendices include a hypothetical scenario exercise that demonstrates how to implement the process and some early examples of how national parks are using climate change scenarios to inform planning and decision making.	http://www.nps.gov/subjects/climatechange/upload/CCScenariosHandbookJuly2013.pdf
Scenario Planning for Climate Change Adaptation: A Guidance for Resource Managers (Moore *et al.* 2013)	Step-by-step guide to using scenarios to plan for climate change adaptation for natural resource managers, planners, scientists, and other stakeholders working at a local or regional scale to develop resource management approaches that take future climate change impacts and other important uncertainties into account.	http://scc.ca.gov/files/2013/07/Scen-planning_17july2013_FINAL-3.pdf

Table C-4. Resources for Assessing Adaptation Measures

Resource	Description	Link
General		
Georgetown Climate Center's Climate Adaptation Toolkit – Sea Level Rise and Coastal Land Use	Explores 18 different land-use tools that can be used to preemptively respond to the threats posed by sea level rise to both public and private coastal development and infrastructure, and strives to assist governments in determining which tools to employ to meet their unique socio-economic and political contexts.	http://www.georgetownclimate.org/resources/adaptation-tool-kit-sea-level-rise-and-coastal-land-use
What Will Adaptation Cost? (ERGI 2013)	"This report provides a framework that community leaders and planners can use to make more economically informed decisions about adapting to sea level rise and storm flooding. The four-step framework can be used to perform a holistic assessment of costs and benefits of different adaptation approaches across a community, or to focus in on select infrastructure. The report also discusses the expertise needed at each step in the process."	https://coast.noaa.gov/data/digitalcoast/pdf/adaptation-report.pdf
Center for Ocean Solutions: Adaptation in Action: Examples from the Field	Provides case studies of various adaptation strategies including overlay zones, non-conformities, setbacks, buffers, development conditions, shoreline protection devices, managed retreat, capital improvement programs, acquisition programs, conservation easements, rolling easements, tax incentives, transfer development rights, and real estate disclosures.	http://www.centerforoceansolutions.org/sites/default/files/Application%20of%20Land%20Use%20Practices%20and%20Tools%20to%20Prepare.pdf

Combatting Sea Level Rise in Southern California: How Local Government Can Seize Adaptation Opportunities While Minimizing Legal Risk (Herzog and Hecht 2013)	Identifies how local governments can harness legal doctrines to support aggressive, innovative strategies to achieve successful sea level rise adaptation outcomes for Southern California while minimizing legal risk. Broadly outlines likely sea level rise impacts in Southern California, and evaluates the risks and opportunities of potential protection, accommodation, and retreat adaptation strategies that local governments could deploy.	http://www.law.ucla.edu/~/media/Files/UCLA/Law/Pages/Publications/CEN_EMM_PUB%20Combatting%20Sea-Level%20Rise.ashx
Strategies for Erosion-Related Impacts		
Evaluation of Erosion Mitigation Alternatives for Southern Monterey Bay	Provides a technical evaluation of various erosion mitigation measures, conducts a cost benefit analysis of some of the more promising measures, and includes recommendations for addressing coastal erosion in Southern Monterey Bay. The report is intended to be relevant for other areas of California as well.	https://montereybay.noaa.gov/research/techreports/tresapwa2012.html
Rolling Easements		
Rolling Easements- A Primer (Titus 2011)	Examines more than a dozen different legal approaches to rolling easements. It differentiates opportunities for legislatures, regulators, land trusts, developers, and individual landowners. Considers different shoreline environments (*e.g.*, wetlands, barrier islands) and different objectives (*e.g.*, public access, wetland migration)	http://papers.risingsea.net/rolling-easements.html
No Day at the Beach: Sea Level Rise, Ecosystem Loss, and Public Access Along the California Coast (Caldwell and Segall 2007)	Provides a description of sea level rise impacts to ecosystems and public access, strategies to address these impacts, and case study examples of rolling easement strategies for the California coast.	http://scholarship.law.berkeley.edu/cgi/viewcontent.cgi?article=1833&context=elq

Natural Resources		
PRBO Climate Smart Conservation	Lists science-based, climate-smart conservation planning and management tools and methods, including restoration projects designed for climate change and extremes.	http://www.pointblue.org/priorities/climate-smart-conservation/
US Forest Service System for Assessing Vulnerability of Species- Climate Change Tool	Quantifies the relative impact of expected climate change effects for terrestrial vertebrate species.	http://www.fs.fed.us/rm/grassland-shrubland-desert/products/species-vulnerability/savs-climate-change-tool/
The Nature Conservancy: Reducing Climate Risk with Natural Infrastructure report	Presents a series of nine case studies in which natural, "green" infrastructure was successfully used to mitigate climate impacts. The economic costs and benefits of the green infrastructure are compared with traditional "gray" approaches.	http://www.nature.org/ourinitiatives/regions/northamerica/unitedstates/california/ca-green-vs-gray-report-2.pdf
CDFW Essential Habitat Connectivity Project	"The California Department of Fish and Wildlife and the California Department of Transportation (Caltrans) commissioned a team of consultants to produce a statewide assessment of essential habitat connectivity by February of 2010, using the best available science, datasets, spatial analyses, and modeling techniques. The goal was to identify large remaining blocks of intact habitat or natural landscape and model linkages between them that need to be maintained, particularly as corridors for wildlife."	https://www.wildlife.ca.gov/Conservation/Planning/Connectivity
CDFW Areas of Conservation Emphasis tool	Provides a mapping tool and reports on the best available statewide, spatial information on California's biological richness, including species diversity, rarity, and sensitive habitats, as well as recreational needs and opportunities throughout the state, including fishing, hunting and wildlife-viewing.	http://www.dfg.ca.gov/biogeodata/ace/

Table C-5. Examples of Sea Level Rise Vulnerability Assessments in California

Title	Description	Link
Humboldt Bay Sea Level Rise Adaptation Planning Project	Multiphase project to assess vulnerability of Humboldt Bay shoreline and adjacent areas to sea level rise and coastal hazards.	http://humboldtbay.org/humboldt-bay-sea-level-rise-adaptation-planning-project
Marin Ocean Coast Sea Level Rise Vulnerability Assessment (2018)	Assesses vulnerability of Marin County's ocean coastal areas to sea level rise, specifically evaluating 5 SLR and storm scenarios through approximately 2100. Findings are organized both by asset type and community.	https://www.marincounty.org/depts/cd/divisions/planning/csmart-sea-level-rise/csmart-publications-csmart-infospot
San Francisco Sea Level Rise Existing Data and Analyses Technical Memorandum (2016)	Summarizes existing data and analyses of SLR vulnerability within the Coastal Zone and lays the foundation for San Francisco's proposed LCP amendment.	http://default.sfplanning.org/plans-and-programs/local_coastal_prgm/20160506.SFLCP_SLR_Tech_Memo.FINAL.pdf
Plan Half Moon Bay Sea Level Rise Vulnerability Assessment (2016)	Identifies the primary vulnerabilities within Half Moon Bay and sets forth next steps that the City and other involved agencies may take to further assess and address these vulnerabilities.	http://nebula.wsimg.com/0849a308eecc c2c58ce202e2851bade?AccessKeyId=06ACEAA5216D33A5C3B0&disposition=0&alloworigin=1
City of Monterey Final Sea Level Rise and Vulnerability Analyses, Existing Conditions and Issues Report (2016)	Provides a science-based assessment of climate change vulnerabilities that includes extensive field data gathering, and compilation of existing data and information.	https://www.monterey.org/Portals/0/Policies-Procedures/Planning/WorkProgram/LCP/16_0316_FINAL_Monterey_ExistingConditions_wAppendixA_WEB.pdf
City of Pacific Grove Climate Change Vulnerability Assessment (2015)	Provides an evaluation of potential significant impacts of climate change for the city's coastal zone with an emphasis on how anticipated climate change may affect people, resources, and infrastructure along the coast.	http://www.cityofpacificgrove.org/sites/default/files/general-documents/local-coastal-program/pg-lcp-final-vulnerability-assessment-011515.pdf
City of Morro Bay Community Vulnerability and Resilience Assessment (2017)	Provides a best estimate of likely future conditions, based on local demographic projections and the most recently available scientific projections of future climate conditions, given current trends.	http://www.morrobayca.gov/DocumentCenter/View/10676/Final-Draft--Revised-Community-Vulnerability-and-Resilience-Assessment-3-6-17?bidId=

City of Goleta Coastal Hazards Vulnerability Assessment and Fiscal Impact Report (2015)	Provides a science-based assessment that includes extensive field data gathering, compilation of existing data and information, and the participation of stakeholders such as citizens, business owners, local organizations, and community leaders. Enhances community planning by identifying coastal hazards and associated vulnerabilities that are in balance with fiscal resources.	https://www.conservationgateway.org/ConservationPractices/Marine/crr/library/Documents/GoletaCoastalVulnerability.pdf
City of Oxnard Sea Level Rise Atlas (2016)	Maps and identifies areas and assets at risk to existing and future conditions, including sea level rise.	http://nebula.wsimg.com/64b81b1805381307f1e6492bf187b6d9?AccessKeyId=D91312DA8FC16C8BCDB9&disposition=0&alloworigin=1
County of San Diego Climate Change Vulnerability Assessment (2017)	Identifies the primary threats from a changing climate facing the unincorporated areas of San Diego county, and its vulnerability to these threats.	https://www.sandiegocounty.gov/content/dam/sdc/pds/advance/cap/publicreviewdocuments/PostBOSDocs/CAP%20Appendix%20D%20-%20Climate%20Change%20Vulnerability%20Assessment.pdf
City of Imperial Beach Sea Level Rise Assessment (2016)	Identifies vulnerabilities from sea level rise and coastal hazards; a range of adaptation strategies including tradeoffs and economics; and recommends strategies over time that are politically digestible and economically feasible.	http://www.imperialbeachca.gov/vertical/sites/%7B6283CA4C-E2BD-4DFA-A7F7-8D4ECD543E0F%7D/uploads/100516_IB_Sea_Level_Rise_Assessment_FINAL.pdf
Santa Barbara Sea Level Rise Vulnerability Study (Russell and Griggs 2012)	Assesses the vulnerability of the City of Santa Barbara to future sea level rise and related coastal hazards (by Years 2050 and 2100) based upon past events, shoreline topography, and exposure to sea level rise and wave attack. It also evaluates the likely impacts of coastal hazards to specific areas of the City, analyzes their risks and the City's ability to respond, and recommends potential adaptation responses.	http://www.energy.ca.gov/2012publications/CEC-500-2012-039/CEC-500-2012-039.pdf

City of Santa Cruz Climate Change Vulnerability Assessment (Griggs and Haddad 2011)	Delineates and evaluates the likely impacts of future climate change on the city of Santa Cruz, analyzes the risks that these hazards pose for the city, and then recommends potential adaptation responses to reduce the risk and exposure from these hazards in the future.	http://seymourcenter.ucsc.edu/OOB/SCClimateChangeVulnerabilityAssessment.pdf
Developing Climate Adaptation Strategies for San Luis Obispo County: Preliminary Vulnerability Assessment for Social Systems (Moser 2012)	Describes the likely impacts of climate change on the resources and social systems of San Luis Obispo County, and assesses key areas of vulnerability. Sea level rise is identified as a major source of risk to fishing, coastal tourism, coastal development, and infrastructure.	http://www.energy.ca.gov/2012publications/CEC-500-2012-054/CEC-500-2012-054.pdf
Monterey Bay Sea Level Rise Vulnerability Study (Monterey Bay National Marine Sanctuary and PWA ESA; In progress)	Will assess potential future impacts from sea level rise for the Monterey Bay region. The project will estimate the extent of future coastal erosion in Monterey Bay due to accelerated sea level rise and evaluate areas subjected to coastal flooding by inundation from wave action and/or storm surges. The project will update and refine existing Monterey Bay coastal hazard zones maps (erosion and flooding).	Project scope and grant details: http://scc.ca.gov/webmaster/ftp/pdf/sccbb/2012/1201/20120119Board03D_Monterey_Bay_Sea_Level_Rise.pdf
Sea Level Rise Vulnerability Study for the City of LA (Adapt LA) (USC Sea Grant 2013)	This report provides a summary of the initial research on the potential impacts of sea level rise and associated flooding from storms for coastal communities in the City of L.A. The study concentrates on the City's three coastal regions: Pacific Palisades from Malibu to Santa Monica; Venice and Playa del Rey; and San Pedro, Wilmington and the Port of Los Angeles.	http://dornsife.usc.edu/uscseagrant/la-slr/

** See also the Coastal Commission's LCP Grant website for a status chart of sea level rise work completed by grantees (updated on an approximately quarterly basis).*

Table C-6. California Climate Adaptation Plans that Address Sea Level Rise

Title	Description	Link
Marin Ocean Coast Sea Level Rise Adaptation Report (2018)	Presents near-, medium-, and long-term options to accommodate, protect against, or retreat from the threats of SLR and extreme events and is intended to inform Marin County's Local Coastal Program (LCP), coastal permitting, and other county goals related to SLR preparation.	https://www.marincounty.org/depts/cd/divisions/planning/csmart-sea-level-rise/csmart-publications-csmart-infospot
Morro Bay Sea Level Rise Adaptation Strategy Report (2018)	Presents adaptation strategies for three sites within the City, selected to represent the general exposure of a type of hazard or asset.	http://www.morro-bay.ca.us/DocumentCenter/View/11753/Sea-Level-Rise-Adaptation-Report-January-2018
Adapting to Rising Tides (ART) Project	The ART project is a collaborative planning effort led by the San Francisco Bay Conservation and Development Commission to help SF Bay Area communities adapt to rising sea levels. The project has started with a vulnerability assessment for a portion of the Alameda County shoreline.	http://www.adaptingtorisingtides.org/
Santa Cruz Climate Adaptation Plan	An update to the 2007 Hazard Mitigation Plan, the adaptation plan includes strategies and best available science for integrating climate change impacts into City of Santa Cruz operations.	Complete plan is available: http://www.cityofsantacruz.com/home/showdocument?id=23644
San Diego Bay Sea Level Rise Adaptation Strategy	The strategy provides measures to evaluate and manage risks from sea level rise and other climate change impacts, and includes a vulnerability assessment of community assets at risk, and broad recommendations to increase resilience of these assets.	http://icleiusa.org/wp-content/uploads/2015/08/San-Diego-Sea-Level-Rise.pdf

** See also the Coastal Commission's LCP Grant website for a status chart of sea level rise work completed by grantees (updated on an approximately quarterly basis).*

Table C-7. California State Agency Resources

Agency	Document	Description and Link
California Natural Resources Agency	*Safeguarding California Plan: 2018 Update (2018)*	An update to the 2014 Safeguarding document: http://resources.ca.gov/docs/climate/safeguarding/update2018/safeguarding-california-plan-2018-update.pdf
	Safeguarding California from Climate Change (2014)	An update to the 2009 *California Climate Adaptation Strategy*: http://resources.ca.gov/docs/climate/Final_Safeguarding_CA_Plan_July_31_2014.pdf
	California Climate Adaptation Strategy (2009)	Summarizes climate change impacts and recommends adaptation strategies across seven sectors: Public Health, Biodiversity and Habitat, Oceans and Coastal Resources, Water, Agriculture, Forestry, and Transportation and Energy: http://resources.ca.gov/docs/climate/Statewide_Adaptation_Strategy.pdf
Office of the Governor	*Executive Order S-13-08* (2008)	This 2008 Executive Order required the CA Natural Resources Agency to develop a statewide climate adaptation strategy, and requested that the National Academy of Sciences convene an independent scientific panel to assess sea level rise in California. http://www.climatechange.ca.gov/state/executive_orders.html
	Executive Order B-30-15 (2015)	This 2015 Executive Order established an interim greenhouse gas reduction target of 40 percent below 1990 levels by 2030 to expand upon the targets already included in AB32 and emphasized the need for adaptation in line with the actions identified in the *Safeguarding California* document. http://gov.ca.gov/news.php?id=18938
Governor's Office of Planning and Research	*Defining Vulnerable Communities in the Context of Climate Adaptation*	Resource guide developed by the Integrated Climate Adaptation and Resiliency Program (ICARP) as a starting point for practitioners to use when first considering how to define vulnerable communities in an adaptation context. http://opr.ca.gov/planning/icarp/vulnerable-communities.html
California Ocean Protection Council (and the Coasts &	*State of California Sea-Level Rise Guidance: 2018 Update (2018)*	Provides guidance for incorporating sea level rise projections into planning and decision making. Updated to include *Rising Seas* science, 2018: http://www.opc.ca.gov/updating-californias-sea-level-rise-guidance/

Oceans Climate Action Team, or CO-CAT)	*Rising Seas in California: An Update on Sea-Level Rise Science*	Provides a synthesis of the state of the science on sea-level rise and forms the scientific foundation for the updated OPC SLR Guidance. http://www.opc.ca.gov/webmaster/ftp/pdf/docs/rising-seas-in-california-an-update-on-sea-level-rise-science.pdf
	Resolution on Implementation of the Safeguarding California Plan for Reducing Climate Risks (2014)	Resolves that OPC staff and the State Coastal Leadership Group on SLR will develop an action plan to implement the *Safeguarding California* plan. http://www.opc.ca.gov/webmaster/ftp/pdf/agenda_items/20140827/Item5_OPC_Aug2014_Exhibit_1_Safeguarding_Resolution_ADOPTED.pdf
	Resolution on Sea Level Rise (2011)	Recognizes that state agencies should address SLR through various actions such as the consideration of SLR risks in decision making, investment of public funds, stakeholder engagement, state SLR guidance updates, *etc*. http://www.opc.ca.gov/webmaster/ftp/pdf/docs/OPC_SeaLevelRise_Resolution_Adopted031111.pdf
	California State Sea-Level Rise Guidance Document (2013)	Provides guidance for incorporating sea level rise projections into planning and decision making for projects in California. Updated to include NRC projections March 2013: http://www.opc.ca.gov/webmaster/ftp/pdf/docs/2013_SLR_Guidance_Update_FINAL1.pdf
California Coastal Conservancy	*Climate Change Policy* (2010)	Includes policies on 1) consideration of climate change in project evaluation, 2) consideration of sea level rise impacts in vulnerability assessments, 3) collaboration to support adaptation strategies, and 4) encouragement of adaptation strategies in project applications mitigation and adaptation: http://scc.ca.gov/2009/01/21/coastal-conservancy-climate-change-policy-and-project-selection-criteria/
	Project Selection Criteria (2011)	Adds sea level rise vulnerability to project selection criteria: http://scc.ca.gov/2009/01/21/coastal-conservancy-climate-change-policy-and-project-selection-criteria/

	Guidance for addressing climate change in CA Coastal Conservancy projects (2012)	Includes the following steps: 1) conduct initial vulnerability assessment, 2) conduct more comprehensive vulnerability assessment, 3) reduce risks and increase adaptive capacity, and 4) identify adaptation options: http://scc.ca.gov/2013/04/24/guidance-for-grantees
San Francisco Bay Conservation and Development Commission (BCDC)	*Climate Change Bay Plan Amendment* (2011)	Amends *Bay Plan* to include policies on climate change and sea level rise. Policies require: 1) a sea level rise risk assessment for shoreline planning and larger shoreline projects, and 2) if risks exist, the project must be designed to cope with flood levels by mid-century, and include a plan to address flood risks at end of century. Assessments are required to "identify all types of potential flooding, degrees of uncertainty, consequences of defense failure, and risks to existing habitat from proposed flood protection devices": http://www.bcdc.ca.gov/proposed_bay_plan/bp_amend_1-08.shtml
	Living with a Rising Bay: Vulnerability and Adaptation in San Francisco Bay and on its Shoreline (2011)	Provides the background staff report identifying vulnerabilities in the Bay Area's economic and environmental systems, as well as the potential impacts of climate change on public health and safety. The report provides the basis for all versions of the proposed findings and policies concerning climate change: http://www.bcdc.ca.gov/BPA/LivingWithRisingBay.pdf
California Department of Transportation (Caltrans)	*Estimating Sea Level for Project Initiation Documents* (2012)	Provides guidance on converting tidal datums and predicting future sea levels. http://www.dot.ca.gov/hq/row/landsurveys/SurveysManual/Estimating_Sea_Level_v1.pdf

	Guidance on Incorporating Sea Level Rise (2011)	Provides guidance on how to incorporate sea level rise concerns into programming and design of Caltrans projects. Includes screening criteria for determining whether to include SLR and steps for evaluating degree of potential impacts, developing adaptation alternatives, and implementing the adaptation strategies: http://www.dot.ca.gov/ser/downloads/sealevel/guide_incorp_slr.pdf
	Addressing Climate Change in Adaptation Regional Transportation Plans: A Guide for MPOs and RTPAs (2013)	Provides a clear methodology for regional agencies to address climate change impacts through adaptation of transportation infrastructure: http://www.dot.ca.gov/hq/tpp/offices/orip/climate_change/documents/FR3_CA_Climate_Change_Adaptation_Guide_2013-02-26_.pdf
	District-wide Vulnerability Assessments (2018, ongoing)	Caltrans is currently in the process of completing climate change and sea level rise vulnerability assessments for each of its Districts. http://www.dot.ca.gov/transplanning/ocp/vulnerability-assessment.html
Cal OES	*California Multi-Hazard Mitigation Plan* (Draft SHMP 2018)	The California (CA) State Hazard Mitigation Plan (SHMP) represents the state's primary hazard mitigation guidance document - providing an updated analysis of the state's historical and current hazards, hazard mitigation goals and objectives, and hazard mitigation strategies and actions. The plan represents the state's overall commitment to supporting a comprehensive mitigation strategy to reduce or eliminate potential risks and impacts of disasters in order to promote faster recovery after disasters and, overall, a more resilient state: http://www.caloes.ca.gov/for-individuals-families/hazard-mitigation-planning/state-hazard-mitigation-plan
State Lands Commission	Application for Lease of State Lands	Requires assessment of climate change risks, and preference is given to projects that reduce climate change risks: http://www.slc.ca.gov/Forms/LMDApplication/LeaseApp.pdf

California State Parks	Sea level rise guidance (*in development*)	Will provide guidance to Park staff on how to assess impacts to parklands.
Groups of state agencies	California Climate Change Center's 3rd Assessment	Explores local and statewide vulnerabilities to climate change, highlighting opportunities for taking concrete actions to reduce climate-change impacts: http://climatechange.ca.gov/climate_action_team/reports/third_assessment/
	California Climate Adaptation Planning Guide (APG)	Provides a decision-making framework intended for use by local and regional stakeholders to aid in the interpretation of climate science and to develop a systematic rationale for reducing risks caused, or exacerbated, by climate change (2012): http://resources.ca.gov/climate/safeguarding/local-action/

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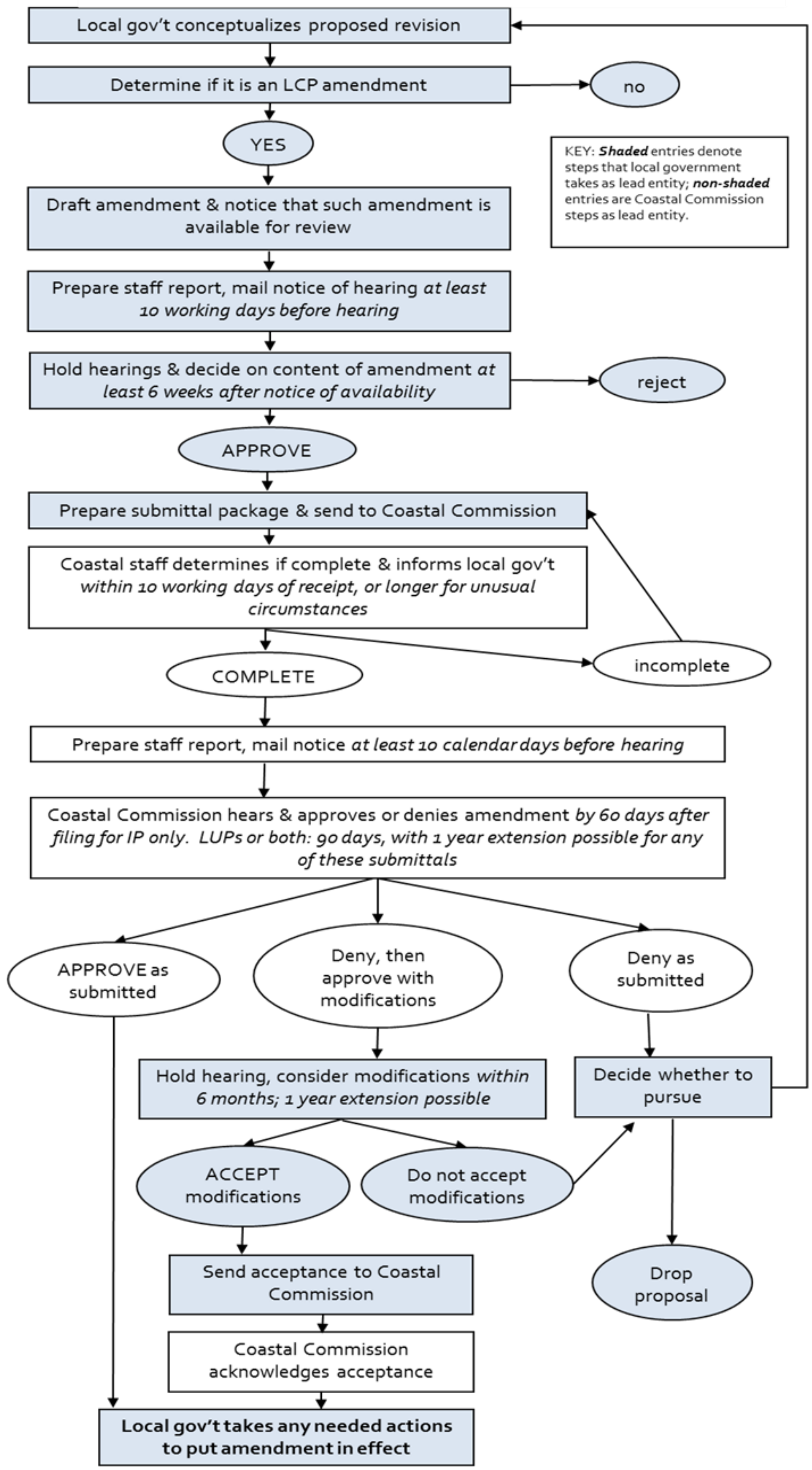
Appendix D

General LCP Amendment Processing Steps and Best Practices

Sea level rise is one of many topics that should be addressed in a Local Coastal Program (LCP) or LCP amendment. The Coastal Commission offers a *Local Coastal Program (LCP) Update Guide* that outlines the broad process for amending or certifying an LCP, including guidance for both Land Use Plans and Implementation Plans. It addresses major Coastal Act concerns, including public access, recreation and visitor serving facilities, water quality protection, ESHA and natural resources, agricultural resources, new development, archaeological and cultural resources, scenic and visual resources, coastal hazards, shoreline erosion and protective devices, energy and industrial development, and timberlands. Therefore, this *Sea Level Rise Policy Guidance* should be used in conjunction with the LCP Update Guide to perform complete LCP amendments or certifications. The following figure depicts the general LCP amendment process.

Figure I: General LCP Amendment Processing Steps



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Appendix E

Funding Opportunities for LCP Planning and Implementation

Project Implementation Funds

The following table includes a list of grant funding available for implementation of sea level rise adaptation projects and programs. Much of this information was compiled by the Governor's Office of Emergency Services (Cal OES).

Grant Name	Agency	Purpose	Contact
Proposition 1 & Proposition 84 Competitive Grant Programs	Ocean Protection Council	Funding from Prop 1 is intended to fund projects that provide more reliable water supplies, restore important species and habitat, and develop a more resilient and sustainably managed water system (water supply, water quality, flood protection, and environment) that can better withstand inevitable and unforeseen pressures in the coming decades. Proposition 84 funds may be used for a wide range of purposes including scientific research, adaptive management, and conservation of marine resources.	OPC http://www.opc.ca.gov/category/funding-opportunities/
Proposition 68 Funds **Proposition 1 Grants** **Climate Ready Grants**	California Coastal Conservancy	Proposition 68 grants for a variety of purposes including creating parks, protecting coastal forests and wetlands, and climate adaptation Proposition 1 Grants for multi-benefit ecosystem and watershed protection and restoration projects. Climate Ready Grants are focused on supporting planning, project implementation and multi-agency coordination to advance actions that will increase the resilience of coastal communities and ecosystems	Coastal Conservancy http://scc.ca.gov/2018/10/10/proposition-68-draft-guidelines/ http://scc.ca.gov/grants/proposition-1-grants/ http://scc.ca.gov/climate-change/climate-ready-program/
SB 1 Adaptation Planning Grants	Caltrans	Support actions at the local and regional level to advance climate change adaptation efforts on the state transportation system	Caltrans http://www.dot.ca.gov/hq/tpp/grants.html

Proposition 68	Ocean Protection Council	Provide funding for projects that plan, develop, and implement climate adaptation and resiliency projects, including projects that assist coastal communities with adaptation to sea level rise. These funds can also support technical assistance and community access projects.	Ocean Protection Council (*website to come*)
Hazard Mitigation Grant (HMG) Program	Administered by: Cal OES Funded by: US Department of Homeland Security, Federal Emergency Management Agency (FEMA)	Provides grants to states and local governments to implement long-term hazard mitigation measures after a major disaster declaration. The purpose of the HMGP is to reduce the loss of life and property due to natural disasters and to enable mitigation measures to be implemented during the immediate recovery from a disaster.	Cal OES http://www.caloes.ca.gov/cal-oes-divisions/recovery/disaster-mitigation-technical-support/404-hazard-mitigation-grant-program FEMA https://www.fema.gov/hazard-mitigation-grant-program
Flood Mitigation Assistance (FMA) Program	Administered by: Cal OES Funded by: US Department of Homeland Security, Federal Emergency Management Agency (FEMA)	Provides grants to assist states and communities in implementing measures to reduce or eliminate the long-term risk of flood damage to buildings, manufactured homes, and other structures insurable under the NFIP.	Cal OES http://www.caloes.ca.gov/cal-oes-divisions/hazard-mitigation/pre-disaster-flood-mitigation FEMA https://www.fema.gov/flood-mitigation-assistance-program
Public Assistance (PA) Program	US Department of Homeland Security, Federal Emergency Management Agency (FEMA)	To provide supplemental Federal disaster grant assistance for debris removal, emergency protective measures, and the repair, replacement, or restoration of disaster-damaged, publicly owned facilities and the facilities of certain Private Non-Profit (PNP) organizations. The PA Program also encourages protection of these damaged facilities from future events by providing assistance for hazard mitigation measures during the recovery process.	FEMA https://www.fema.gov/public-assistance-local-state-tribal-and-non-profit
Community Development Block Grant (CDBG) Program	US Department of Housing and Urban Development	Program works to ensure decent affordable housing, to provide services to the most vulnerable in our communities, and to create jobs through the expansion and retention of businesses.	HUD http://portal.hud.gov/hudportal/HUD?src=/program_offices/comm_planning/communitydevelopment/programs

Watershed Surveys and Planning	US Department of Agriculture, Natural Resource Conservation Service	To provide planning assistance to Federal, state and local agencies for the development or coordination of water and related land resources and programs in watersheds and river basins.	NRCS http://www.nrcs.usda.gov/wps/portal/nrcs/main/national/programs/landscape/wsp/
Watershed Protection and Flood Prevention	US Department of Agriculture, Natural Resource Conservation Service	To provide technical and financial assistance in planning and executing works of improvement to protect, develop, and use of land and water resources in small watersheds.	NRCS http://www.nrcs.usda.gov/wps/portal/nrcs/main/national/programs/landscape/wfpo/
Land and Water Conservation Fund Grants	US Department of the Interior, National Park Service	To acquire and develop outdoor recreation areas and facilities for the general public, to meet current and future needs.	NPS http://www.nps.gov/lwcf/index.htm
SBA Disaster Loan Program	US Small Business Administration	SBA provides low-interest disaster loans to businesses of all sizes, private non-profit organizations, homeowners, and renters. SBA disaster loans can be used to repair or replace the following items damaged or destroyed in a declared disaster: real estate, personal property, machinery and equipment, and inventory and business assets.	SBA https://www.sba.gov/content/disaster-loan-program
Clean Water Act Section 319 Grants	US Environmental Protection Agency	To implement state and tribal non-point source pollution management programs, including support for non-structural watershed resource restoration activities.	EPA https://www.epa.gov/nps/319-grant-program-states-and-territories
Flood Control Works/ Emergency Rehabilitation	US Department of Defense, Army Corps of Engineers	To assist in the repairs and restoration of public works damaged by flood, extraordinary wind, wave or water action.	USACE http://www.usace.army.mil/Missions/EmergencyOperations/NationalResponseFramework/FloodControl.aspx
Emergency Streambank and Shoreline Protection	US Department of Defense, Army Corps of Engineers	To prevent erosion damages to public facilities by the emergency construction or repair of streambank and shoreline protection works (33 CFR 263.25)	USACE http://www.mvr.usace.army.mil/BusinessWithUs/OutreachCustomerService/FloodRiskManagement/Section14.aspx
Small Flood Control Projects	US Department of Defense, Army Corps of Engineers	To reduce flood damages through small flood control projects not specifically authorized by Congress.	USACE www.usace.army.mil See also: https://www.cfda.gov/index?s=program&mode=form&tab=core&id=2216ee03c69db437c431036a5585ede6

Appendix F

Primary Coastal Act Policies Related to Sea Level Rise and Coastal Hazards

Legislative Findings Relating to Sea Level Rise

Section 30006.5 of the Coastal Act states (Legislative findings and declarations; technical advice and recommendations) states (emphasis added):

> *The Legislature further finds and declares that sound and timely scientific recommendations are necessary for many coastal planning, conservation, and development decisions and that the commission should, in addition to developing its own expertise in significant applicable fields of science, interact with members of the scientific and academic communities in the social, physical, and natural sciences so that the commission may receive technical advice and recommendations with regard to its decisionmaking, especially with regard to issues such as coastal erosion and geology, marine biodiversity, wetland restoration, the question of sea level rise, desalination plants, and the cumulative impact of coastal zone developments.*

Public Access and Recreation

Section 30210 of the Coastal Act (Access; recreational opportunities; posting) states:

> *In carrying out the requirement of Section 4 of Article X of the California Constitution, maximum access, which shall be conspicuously posted, and recreational opportunities shall be provided for all the people consistent with public safety needs and the need to protect public rights, rights of private property owners, and natural resource areas from overuse.*

Section 30211 of the Coastal Act (Development not to interfere with access) states:

> *Development shall not interfere with the public's right of access to the sea where acquired through use or legislative authorization, including, but not limited to, the use of dry sand and rocky coastal beaches to the first line of terrestrial vegetation.*

Section 30212 of the Coastal Act (New development projects) states:

> *(a) Public access from the nearest public roadway to the shoreline and along the coast shall be provided in new development projects except where: (1) it is inconsistent with public safety, military security needs, or the protection of fragile coastal resources, (2) adequate access exists nearby, or (3) agriculture would be adversely affected. Dedicated accessway shall not be required to be opened to public use until a public agency or private association agrees to accept responsibility for maintenance and liability of the accessway.*

Section 30214 of the Coastal Act (Implementation of public access policies; legislative intent) states:

> *(a) The public access policies of this article shall be implemented in a manner that takes into account the need to regulate the time, place, and manner of public access depending on the facts and circumstances in each case including, but not limited to, the following:*
>
> *(1) Topographic and geologic site characteristics.*
>
> *(2) The capacity of the site to sustain use and at what level of intensity.*

> *(3) The appropriateness of limiting public access to the right to pass and repass depending on such factors as the fragility of the natural resources in the area and the proximity of the access area to adjacent residential uses.*
>
> *(4) The need to provide for the management of access areas so as to protect the privacy of adjacent property owners and to protect the aesthetic values of the area by providing for the collection of litter.*
>
> *(b) It is the intent of the Legislature that the public access policies of this article be carried out in a reasonable manner that considers the equities and that balances the rights of the individual property owner with the public's constitutional right of access pursuant to Section 4 of Article X of the California Constitution. Nothing in this section or any amendment thereto shall be construed as a limitation on the rights guaranteed to the public under Section 4 of Article X of the California Constitution.*
>
> *(c) In carrying out the public access policies of this article, the commission and any other responsible public agency shall consider and encourage the utilization of innovative access management techniques, including, but not limited to, agreements with private organizations which would minimize management costs and encourage the use of volunteer programs.*

Section 30220 of the Coastal Act (Protection of certain water-oriented activities) states:

> *Coastal areas suited for water-oriented recreational activities that cannot readily be provided at inland water areas shall be protected for such uses.*

Section 30221 of the Coastal Act (Oceanfront land; protection for recreational use and development**)** states:

> *Oceanfront land suitable for recreational use shall be protected for recreational use and development unless present and foreseeable future demand for public or commercial recreational activities that could be accommodated on the property is already adequately provided for in the area.*

Section 30223 of the Coastal Act (Upland areas) states:

> *Upland areas necessary to support coastal recreational uses shall be reserved for such uses, where feasible.*

Wetlands and Environmentally Sensitive Resources

Section 30231 of the Coastal Act (Biological productivity; water quality) states in part:

> *The biological productivity and the quality of coastal waters, streams, wetlands, estuaries, and lakes appropriate to maintain optimum populations of marine organisms and for the protection of human health shall be maintained and, where feasible, restored…*

Section 30233 of the Coastal Act (Diking, filling or dredging; continued movement of sediment and nutrients) states:

> *(a) The diking, filling, or dredging of open coastal waters, wetlands, estuaries, and lakes shall be permitted in accordance with other applicable provisions of this division, where there is no feasible less environmentally damaging alternative, and where feasible mitigation measures have been provided to minimize adverse environmental effects, and shall be limited to the following:*

Section 30240 of the Coastal Act (Environmentally sensitive habitat areas; adjacent developments) states:

> *(a) Environmentally sensitive habitat areas shall be protected against any significant disruption of habitat values, and only uses dependent on those resources shall be allowed within those areas.*
>
> *(b) Development in areas adjacent to environmentally sensitive habitat areas and parks and recreation areas shall be sited and designed to prevent impacts which would significantly degrade those areas, and shall be compatible with the continuance of those habitat and recreation areas.*

Coastal Act Section 30121 defines "Wetland" as follows:

> *"Wetland" means lands within the coastal zone which may be covered periodically or permanently with shallow water and include saltwater marshes, freshwater marshes, open or closed brackish water marshes, swamps, mudflats, and fens.*

The California Code of Regulations Section 13577(b) of Title 14, Division 5.5, Article 18 defines "Wetland" as follows:

> *(1) Measure 100 feet landward from the upland limit of the wetland. Wetland shall be defined as land where the water table is at, near, or above the land surface long enough to promote the formation of hydric soils or to support the growth of hydrophytes, and shall also include those types of wetlands where vegetation is lacking and soil is poorly developed or absent as a result of frequent and drastic fluctuations of surface water levels, wave action, water flow, turbidity or high concentrations of salts or other substances in the substrate. Such wetlands can be recognized by the presence of surface water or saturated substrate at some time during each year and their location within, or adjacent to, vegetated wetlands or deep-water habitats. For purposes of this section, the upland limit of a wetland shall be defined as:*
>
> > *(A) the boundary between land with predominantly hydrophytic cover and land with predominantly mesophytic or xerophytic cover;*
> >
> > *(B) the boundary between soil that is predominantly hydric and soil that is predominantly nonhydric; or*
> >
> > *(C) in the case of wetlands without vegetation or soils, the boundary between land that is flooded or saturated at some time during years of normal precipitation, and land that is not.*
>
> *(2) For the purposes of this section, the term "wetland" shall not include wetland habitat created by the presence of and associated with agricultural ponds and reservoirs where:*

> *(A) the pond or reservoir was in fact constructed by a farmer or rancher for agricultural purposes; and*
>
> *(B) there is no evidence (e.g., aerial photographs, historical survey, etc.) showing that wetland habitat pre-dated the existence of the pond or reservoir. Areas with drained hydric soils that are no longer capable of supporting hydrophytes shall not be considered wetlands.*

In addition, Coastal Act Section 30107.5 defines “Environmentally sensitive area" as follows:

> *"Environmentally sensitive area" means any area in which plant or animal life or their habitats are either rare or especially valuable because of their special nature or role in an ecosystem and which could be easily disturbed or degraded by human activities and developments.*

Agricultural and Timber Lands

Section 30241 of the Coastal Act (Prime agricultural land; maintenance in agricultural production) states:

> *The maximum amount of prime agricultural land shall be maintained in agricultural production to assure the protection of the areas' agricultural economy, and conflicts shall be minimized between agricultural and urban land uses…*

Section 30242 of the Coastal Act (Lands suitable for agricultural use; conversion) states:

> *All other lands suitable for agricultural use shall not be converted to nonagricultural uses unless (1) continued or renewed agriculture use is not feasible, or (2) such conversion would preserve prime agricultural land or concentrate development consistent with Section 30250. Any such permitted conversion shall be compatible with continue agricultural use on surrounding lands.*

Section 30243 of the Coastal Act (Productivity of soils and timberlands; conversions) states:

> *The long-term productivity of soils and timberlands shall be protected, and conversions of coastal commercial timberlands in units of commercial size to other uses or their division into units of noncommercial size shall be limited to providing for necessary timber processing and related facilities.*

Archaeological and Paleontological Resources

Section 30244 of the Coastal Act (Archaeological or paleontological resources) states:

> *Where development would adversely impact archaeological or paleontological resources as identified by the State Historic Preservation Officer, reasonable mitigation measures shall be required.*

Marine Resources

Section 30230 of the Coastal Act (Marine resources; maintenance) states:

> *Marine resources shall be maintained, enhanced, and where feasible, restored. Special protection shall be given to areas and species of special biological or economic significance. Uses of the marine environment shall be carried out in a manner that will sustain the biological productivity of coastal waters and that will maintain healthy populations of all species of marine organisms adequate for long-term commercial, recreational, scientific, and educational purposes.*

Section 30231 of the Coastal Act (Biological productivity; water quality) states:

> *The biological productivity and the quality of coastal waters, streams, wetlands, estuaries, and lakes appropriate to maintain optimum populations of marine organisms and for the protection of human health shall be maintained and, where feasible, restored through, among other means, minimizing adverse effects of waste water discharges and entrainment, controlling runoff, preventing depletion of ground water supplies and substantial interference with surface waterflow, encouraging waste water reclamation, maintaining natural vegetation buffer areas that protect riparian habitats, and minimizing alteration of natural streams.*

Section 30233 of the Coastal Act (Diking, filling or dredging; continued movement of sediment and nutrients) states:

> *(a) The diking, filling, or dredging of open coastal waters, wetlands, estuaries, and lakes shall be permitted in accordance with other applicable provisions of this division, where there is no feasible less environmentally damaging alternative, and where feasible mitigation measures have been provided to minimize adverse environmental effects…*
>
> *(d) Erosion control and flood control facilities constructed on watercourses can impede the movement of sediment and nutrients that would otherwise be carried by storm runoff into coastal waters. To facilitate the continued delivery of these sediments to the littoral zone, whenever feasible, the material removed from these facilities may be placed at appropriate points on the shoreline in accordance with other applicable provisions of this division, where feasible mitigation measures have been provided to minimize adverse environmental effects. Aspects that shall be considered before issuing a Coastal Development Permit for these purposes are the method of placement, time of year of placement, and sensitivity of the placement area.*

Section 30234 of the Coastal Act (Commercial fishing and recreational boating facilities**)** states:

> *Facilities serving the commercial fishing and recreational boating industries shall be protected and, where feasible, upgraded. Existing commercial fishing and recreational boating harbor space shall not be reduced unless the demand for those facilities no longer exists or adequate substitute space has been provided. Proposed recreational boating facilities shall, where feasible, be designed and located in such a fashion as not to interfere with the needs of the commercial fishing industry.*

Section 30234.5 of the Coastal Act (Economic, commercial, and recreational importance of fishing) states:

> *The economic, commercial, and recreational importance of fishing activities shall be recognized and protected.*

Coastal Development

Section 30250 of the Coastal Act (Location; existing developed area) states:

> *(a) New residential, commercial, or industrial development, except as otherwise provided in this division, shall be located within, contiguous with, or in close proximity to, existing developed areas able to accommodate it or, where such areas are not able to accommodate it, in other areas with adequate public services and where it will not have significant adverse effects, either individually or cumulatively, on coastal resources. In addition, land divisions, other than leases for agricultural uses, outside existing developed areas shall be permitted only where 50 percent of the usable parcels in the area have been developed and the created parcels would be no smaller than the average size of surrounding parcels.*
>
> *(b) Where feasible, new hazardous industrial development shall be located away from existing developed areas.*
>
> *(c) Visitor-serving facilities that cannot feasibly be located in existing developed areas shall be located in existing isolated developments or at selected points of attraction for visitors.*

Section 30251 of the Coastal Act (Scenic and visual qualities) states:

> *The scenic and visual qualities of coastal areas shall be considered and protected as a resource of public importance. Permitted development shall be sited and designed to protect views to and along the ocean and scenic coastal areas, to minimize the alteration of natural land forms, to be visually compatible with the character of surrounding areas, and, where feasible, to restore and enhance visual quality in visually degraded areas...*

Section 30253 the Coastal Act (Minimization of adverse impacts) states in part:

> *New development shall do all of the following:*
>
> *(a) Minimize risks to life and property in areas of high geologic, flood, and fire hazard.*
>
> *(b) Assure stability and structural integrity, and neither create nor contribute significantly to erosion, geologic instability, or destruction of the site or surrounding area or in any way require the construction of protective devices that would substantially alter natural landforms along bluffs and cliffs...*

Section 30235 of the Coastal Act (Construction altering natural shoreline) states:

> *Revetments, breakwaters, groins, harbor channels, seawalls, cliff retaining walls, and other such construction that alters natural shoreline processes shall be permitted when required to serve coastal-dependent uses or to protect existing structures or public*

> *beaches in danger from erosion, and when designed to eliminate or mitigate adverse impacts on local shoreline sand supply. Existing marine structures causing water stagnation contributing to pollution problems and fishkills should be phased out or upgraded where feasible.*

Section 30236 of the Coastal Act (Water supply and flood control) states:

> *Channelizations, dams, or other substantial alterations of rivers and streams shall incorporate the best mitigation measures feasible, and be limited to (l) necessary water supply projects, (2) flood control projects where no other method for protecting existing structures in the flood plain is feasible and where such protection is necessary for public safety or to protect existing development, or (3) developments where the primary function is the improvement of fish and wildlife habitat.*

Ports

Section 30705 of the Coastal Act (Diking, filling or dredging water areas) states:

> *(a) Water areas may be diked, filled, or dredged when consistent with a certified port master plan only for the following: …*
>
> *(b) The design and location of new or expanded facilities shall, to the extent practicable, take advantage of existing water depths, water circulation, siltation patterns, and means available to reduce controllable sedimentation so as to diminish the need for future dredging.*
>
> *(c) Dredging shall be planned, scheduled, and carried out to minimize disruption to fish and bird breeding and migrations, marine habitats, and water circulation. Bottom sediments or sediment elutriate shall be analyzed for toxicants prior to dredging or mining, and where water quality standards are met, dredge spoils may be deposited in open coastal water sites designated to minimize potential adverse impacts on marine organisms, or in confined coastal waters designated as fill sites by the master plan where such spoil can be isolated and contained, or in fill basins on upland sites. Dredge material shall not be transported from coastal waters into estuarine or fresh water areas for disposal.*

Section 30706 of the Coastal Act (Fill) states:

> *In addition to the other provisions of this chapter, the policies contained in this section shall govern filling seaward of the mean high tide line within the jurisdiction of ports:*
>
> > *(a) The water area to be filled shall be the minimum necessary to achieve the purpose of the fill.*
> >
> > *(b) The nature, location, and extent of any fill, including the disposal of dredge spoils within an area designated for fill, shall minimize harmful effects to coastal resources, such as water quality, fish or wildlife resources, recreational resources, or sand transport systems, and shall minimize reductions of the volume, surface area, or circulation of water.*

(c) The fill is constructed in accordance with sound safety standards which will afford reasonable protection to persons and property against the hazards of unstable geologic or soil conditions or of flood or storm waters.

(d) The fill is consistent with navigational safety.

Section 30708 of the Coastal Act (Location, design and construction of port related developments) states:

All port-related developments shall be located, designed, and constructed so as to:

(a) Minimize substantial adverse environmental impacts.

(b) Minimize potential traffic conflicts between vessels.

(c) Give highest priority to the use of existing land space within harbors for port purposes, including, but not limited to, navigational facilities, shipping industries, and necessary support and access facilities.

(d) Provide for other beneficial uses consistent with the public trust, including, but not limited to, recreation and wildlife habitat uses, to the extent feasible.

(e) Encourage rail service to port areas and multicompany use of facilities.

Public Works Facilities

According to Coastal Act Section 30114, public works facilities include:

(a) All production, storage, transmission, and recovery facilities for water, sewerage, telephone, and other similar utilities owned or operated by any public agency or by any utility subject to the jurisdiction of the Public Utilities Commission, except for energy facilities.

(b) All public transportation facilities, including streets, roads, highways, public parking lots and structures, ports, harbors, airports, railroads, and mass transit facilities and stations, bridges, trolley wires, and other related facilities. For purposes of this division, neither the Ports of Hueneme, Long Beach, Los Angeles, nor San Diego Unified Port District nor any of the developments within these ports shall be considered public works.

(c) All publicly financed recreational facilities, all projects of the State Coastal Conservancy, and any development by a special district.

(d) All community college facilities.

Greenhouse Gas Emissions Reduction

Section 30250(a) of the Coastal Act (Location, existing developed areas states) in part:

(a) New residential, commercial, or industrial development, except as otherwise provided in this division, shall be located within, contiguous with, or in close proximity to, existing developed areas able to accommodate it or, where such areas are not able to accommodate it, in other areas with adequate public services and where it will not have

> *significant adverse effects, either individually or cumulatively, on coastal resources. In addition, land divisions, other than leases for agricultural uses, outside existing developed areas shall be permitted only where 50 percent of the usable parcels in the area have been developed and the created parcels would be no smaller than the average size of surrounding parcels.*

Section 30252 of the Coastal Act (Maintenance and enhancement of public access) states:

> *The location and amount of new development should maintain and enhance public access to the coast by (1) facilitating the provision or extension of transit service, (2) providing commercial facilities within or adjoining residential development or in other areas that will minimize the use of coastal access roads, (3) providing nonautomobile circulation within the development, (4) providing adequate parking facilities or providing substitute means of serving the development with public transportation, (5) assuring the potential for public transit for high intensity uses such as high-rise office buildings, and by (6) assuring that the recreational needs of new residents will not overload nearby coastal recreation areas by correlating the amount of development with local park acquisition and development plans with the provision of onsite recreational facilities to serve the new development.*

Section 30253(d) of the Coastal Act (Minimization of adverse impacts) states in part:

> *New Development shall:*
>
> > *(d) Minimize energy consumption and vehicle miles traveled….*

Appendix G

Sea Level Rise Projections for 12 California Tide Gauges

Map of Tide Gauge Locations

Figure G-1. Map of tide gauge locations (from OPC 2018)

Table G-1. Sea Level Rise Projections for the Crescent City Tide Gauge[106] (OPC 2018)

Projected Sea Level Rise (in feet): *Crescent City*			
	Probabilistic Projections (in feet) (based on Kopp et al. 2014)		H++ Scenario (Sweet et al. 2017)
	Low Risk Aversion	**Medium-High Risk Aversion**	**Extreme Risk Aversion**
	Upper limit of "likely range" (~17% probability SLR exceeds...)	*1-in-200 chance (0.5% probability SLR exceeds...)*	*Single scenario (no associated probability)*
2030	0.3	0.5	0.8
2040	0.4	0.9	1.4
2050	0.7	1.5	2.3
2060	0.9	2.1	3.3
2070	1.2	2.8	4.5
2080	1.6	3.7	5.9
2090	2.0	4.7	7.4
2100	2.5	5.9	9.3
2110*	2.5	6.2	11.0
2120	3.0	7.4	13.1
2130	3.4	8.7	15.3
2140	3.9	10.1	17.8
2150	4.4	11.6	20.6

**Most of the available climate model experiments do not extend beyond 2100. The resulting reduction in model availability causes a small dip in projections between 2100 and 2110, as well as a shift in uncertainty estimates (see Kopp et al., 2014). Use of 2110 projections should be done with caution and acknowledgement of increased uncertainty around these projections.*

[106] Probabilistic projections for the height of sea level rise and the H++ scenario are presented. The H++ projection is a single scenario and does not have an associated likelihood of occurrence. Projections are with respect to a baseline year of 2000 (or more specifically, the average relative sea level over 1991-2009). Table is adapted from the 2018 OPC SLR Guidance to present only the three scenarios OPC recommends evaluating. Additionally, while the OPC tables include low emissions scenarios, only high emissions scenarios, which represent RCP 8.5, are included here because global greenhouse gas emissions are currently tracking along this trajectory. The Coastal Commission will continue to update best available science as necessary, including if emissions trajectories change.

Table G-2. Sea Level Rise Projections for the North Spit Tide Gauge[107] (OPC 2018)

Projected Sea Level Rise (in feet): *North Spit*			
	Probabilistic Projections (based on Kopp et al. 2014)		H++ Scenario (Sweet et al. 2017)
	Low Risk Aversion	**Medium-High Risk Aversion**	**Extreme Risk Aversion**
	Upper limit of "likely range" (~17% probability SLR exceeds...)	*1-in-200 chance (0.5% probability SLR exceeds...)*	*Single scenario (no associated probability)*
2030	0.7	1.0	1.2
2040	1.1	1.6	2.0
2050	1.5	2.3	3.1
2060	1.9	3.1	4.3
2070	2.4	4.0	5.6
2080	2.9	5.1	7.2
2090	3.5	6.2	8.9
2100	4.1	7.6	10.9
2110*	4.3	8.0	12.7
2120	4.9	9.4	15.0
2130	5.5	10.9	17.4
2140	6.2	12.5	20.1
2150	6.8	14.1	23.0

**Most of the available climate model experiments do not extend beyond 2100. The resulting reduction in model availability causes a small dip in projections between 2100 and 2110, as well as a shift in uncertainty estimates (see Kopp et al., 2014). Use of 2110 projections should be done with caution and acknowledgement of increased uncertainty around these projections.*

[107] Probabilistic projections for the height of sea level rise and the H++ scenario are presented. The H++ projection is a single scenario and does not have an associated likelihood of occurrence. Projections are with respect to a baseline year of 2000 (or more specifically, the average relative sea level over 1991-2009). Table is adapted from the 2018 OPC SLR Guidance to present only the three scenarios OPC recommends evaluating. Additionally, while the OPC tables include low emissions scenarios, only high emissions scenarios, which represent RCP 8.5, are included here because global greenhouse gas emissions are currently tracking along this trajectory. The Coastal Commission will continue to update best available science as necessary, including if emissions trajectories change.

Table G-3. Sea Level Rise Projections for the Arena Cove Tide Gauge[108] (OPC 2018)

Projected Sea Level Rise (in feet): *Arena Cove*			
	Probabilistic Projections (in feet) (based on Kopp et al. 2014)		H++ Scenario (Sweet et al. 2017)
	Low Risk Aversion	**Medium-High Risk Aversion**	**Extreme Risk Aversion**
	Upper limit of "likely range" (~17% probability SLR exceeds...)	*1-in-200 chance (0.5% probability SLR exceeds...)*	*Single scenario (no associated probability)*
2030	0.5	0.7	1.0
2040	0.7	1.2	1.6
2050	1.0	1.8	2.6
2060	1.3	2.5	3.7
2070	1.7	3.3	5.0
2080	2.2	4.3	6.4
2090	2.6	5.4	8.0
2100	3.1	6.7	9.9
2110*	3.2	7.0	11.6
2120	3.8	8.2	13.9
2130	4.3	9.7	16.2
2140	4.8	11.1	18.7
2150	5.4	12.6	21.5

**Most of the available climate model experiments do not extend beyond 2100. The resulting reduction in model availability causes a small dip in projections between 2100 and 2110, as well as a shift in uncertainty estimates (see Kopp et al., 2014). Use of 2110 projections should be done with caution and acknowledgement of increased uncertainty around these projections.*

[108] Probabilistic projections for the height of sea level rise and the H++ scenario are presented. The H++ projection is a single scenario and does not have an associated likelihood of occurrence. Projections are with respect to a baseline year of 2000 (or more specifically, the average relative sea level over 1991-2009). Table is adapted from the 2018 OPC SLR Guidance to present only the three scenarios OPC recommends evaluating. Additionally, while the OPC tables include low emissions scenarios, only high emissions scenarios, which represent RCP 8.5, are included here because global greenhouse gas emissions are currently tracking along this trajectory. The Coastal Commission will continue to update best available science as necessary, including if emissions trajectories change.

Table G-4. Sea Level Rise Projections for the Point Reyes Tide Gauge[109] (OPC 2018)

Projected Sea Level Rise (in feet): *Point Reyes*			
	Probabilistic Projections (in feet) (based on Kopp et al. 2014)		H++ Scenario (Sweet et al. 2017)
	Low Risk Aversion	**Medium-High Risk Aversion**	**Extreme Risk Aversion**
	Upper limit of "likely range" (~17% probability SLR exceeds...)	*1-in-200 chance (0.5% probability SLR exceeds...)*	*Single scenario (no associated probability)*
2030	0.6	0.8	1.0
2040	0.8	1.3	1.8
2050	1.1	2.0	2.8
2060	1.5	2.7	3.9
2070	1.9	3.5	5.2
2080	2.4	4.6	6.7
2090	2.9	5.6	8.3
2100	3.5	7.0	10.3
2110*	3.6	7.3	12.0
2120	4.2	8.6	14.3
2130	4.7	10.1	16.6
2140	5.3	11.5	19.2
2150	5.9	13.1	22.0

**Most of the available climate model experiments do not extend beyond 2100. The resulting reduction in model availability causes a small dip in projections between 2100 and 2110, as well as a shift in uncertainty estimates (see Kopp et al., 2014). Use of 2110 projections should be done with caution and acknowledgement of increased uncertainty around these projections.*

[109] Probabilistic projections for the height of sea level rise and the H++ scenario are presented. The H++ projection is a single scenario and does not have an associated likelihood of occurrence. Projections are with respect to a baseline year of 2000 (or more specifically, the average relative sea level over 1991-2009). Table is adapted from the 2018 OPC SLR Guidance to present only the three scenarios OPC recommends evaluating. Additionally, while the OPC tables include low emissions scenarios, only high emissions scenarios, which represent RCP 8.5, are included here because global greenhouse gas emissions are currently tracking along this trajectory. The Coastal Commission will continue to update best available science as necessary, including if emissions trajectories change.

Table G-5. Sea Level Rise Projections for the San Francisco Tide Gauge[110] (OPC 2018)

Projected Sea Level Rise (in feet): *San Francisco*			
	Probabilistic Projections (in feet) (based on Kopp et al. 2014)		H++ Scenario (Sweet et al. 2017)
	Low Risk Aversion	**Medium-High Risk Aversion**	**Extreme Risk Aversion**
	Upper limit of "likely range" (~17% probability SLR exceeds...)	*1-in-200 chance (0.5% probability SLR exceeds...)*	*Single scenario (no associated probability)*
2030	0.5	0.8	1.0
2040	0.8	1.3	1.8
2050	1.1	1.9	2.7
2060	1.5	2.6	3.9
2070	1.9	3.5	5.2
2080	2.4	4.5	6.6
2090	2.9	5.6	8.3
2100	3.4	6.9	10.2
2110*	3.5	7.3	11.9
2120	4.1	8.6	14.2
2130	4.6	10.0	16.6
2140	5.2	11.4	19.1
2150	5.8	13.0	21.9

**Most of the available climate model experiments do not extend beyond 2100. The resulting reduction in model availability causes a small dip in projections between 2100 and 2110, as well as a shift in uncertainty estimates (see Kopp et al., 2014). Use of 2110 projections should be done with caution and acknowledgement of increased uncertainty around these projections.*

[110] Probabilistic projections for the height of sea level rise and the H++ scenario are presented. The H++ projection is a single scenario and does not have an associated likelihood of occurrence. Projections are with respect to a baseline year of 2000 (or more specifically, the average relative sea level over 1991-2009). Table is adapted from the 2018 OPC SLR Guidance to present only the three scenarios OPC recommends evaluating. Additionally, while the OPC tables include low emissions scenarios, only high emissions scenarios, which represent RCP 8.5, are included here because global greenhouse gas emissions are currently tracking along this trajectory. The Coastal Commission will continue to update best available science as necessary, including if emissions trajectories change.

Table G-6. Sea Level Rise Projections for the Monterey Tide Gauge[111] (OPC 2018)

Projected Sea Level Rise (in feet): *Monterey*			
	Probabilistic Projections (in feet) (based on Kopp et al. 2014)		H++ Scenario (Sweet et al. 2017)
	Low Risk Aversion	**Medium-High Risk Aversion**	**Extreme Risk Aversion**
	Upper limit of "likely range" (~17% probability SLR exceeds...)	*1-in-200 chance (0.5% probability SLR exceeds...)*	*Single scenario (no associated probability)*
2030	0.5	0.8	1.0
2040	0.8	1.2	1.7
2050	1.1	1.9	2.7
2060	1.4	2.6	3.8
2070	1.8	3.4	5.1
2080	2.3	4.4	6.6
2090	2.8	5.5	8.2
2100	3.3	6.9	10.1
2110*	3.4	7.2	11.8
2120	4.0	8.5	14.0
2130	4.5	9.9	16.4
2140	5.1	11.3	18.9
2150	5.7	12.9	21.8

**Most of the available climate model experiments do not extend beyond 2100. The resulting reduction in model availability causes a small dip in projections between 2100 and 2110, as well as a shift in uncertainty estimates (see Kopp et al., 2014). Use of 2110 projections should be done with caution and acknowledgement of increased uncertainty around these projections.*

[111] Probabilistic projections for the height of sea level rise and the H++ scenario are presented. The H++ projection is a single scenario and does not have an associated likelihood of occurrence. Projections are with respect to a baseline year of 2000 (or more specifically, the average relative sea level over 1991-2009). Table is adapted from the 2018 OPC SLR Guidance to present only the three scenarios OPC recommends evaluating. Additionally, while the OPC tables include low emissions scenarios, only high emissions scenarios, which represent RCP 8.5, are included here because global greenhouse gas emissions are currently tracking along this trajectory. The Coastal Commission will continue to update best available science as necessary, including if emissions trajectories change.

Table G-7. Sea Level Rise Projections for the Port San Luis Tide Gauge[112] (OPC 2018)

Projected Sea Level Rise (in feet): *Port San Luis*			
	Probabilistic Projections (in feet) (based on Kopp et al. 2014)		H++ Scenario (Sweet et al. 2017)
	Low Risk Aversion	**Medium-High Risk Aversion**	**Extreme Risk Aversion**
	Upper limit of "likely range" (~17% probability SLR exceeds...)	*1-in-200 chance (0.5% probability SLR exceeds...)*	*Single scenario (no associated probability)*
2030	0.5	0.7	1.0
2040	0.7	1.2	1.6
2050	1.0	1.8	2.6
2060	1.3	2.5	3.7
2070	1.7	3.3	5.0
2080	2.1	4.3	6.4
2090	2.6	5.3	8.0
2100	3.1	6.7	9.9
2110*	3.2	7.0	11.6
2120	3.7	8.2	13.8
2130	4.3	9.6	16.2
2140	4.8	11.1	18.7
2150	5.4	12.6	21.5

**Most of the available climate model experiments do not extend beyond 2100. The resulting reduction in model availability causes a small dip in projections between 2100 and 2110, as well as a shift in uncertainty estimates (see Kopp et al., 2014). Use of 2110 projections should be done with caution and acknowledgement of increased uncertainty around these projections.*

[112] Probabilistic projections for the height of sea level rise and the H++ scenario are presented. The H++ projection is a single scenario and does not have an associated likelihood of occurrence. Projections are with respect to a baseline year of 2000 (or more specifically, the average relative sea level over 1991-2009). Table is adapted from the 2018 OPC SLR Guidance to present only the three scenarios OPC recommends evaluating. Additionally, while the OPC tables include low emissions scenarios, only high emissions scenarios, which represent RCP 8.5, are included here because global greenhouse gas emissions are currently tracking along this trajectory. The Coastal Commission will continue to update best available science as necessary, including if emissions trajectories change.

Table G-8. Sea Level Rise Projections for the Santa Barbara Tide Gauge[113] (OPC 2018)

Projected Sea Level Rise (in feet): *Santa Barbara*			
	Probabilistic Projections (in feet) (based on Kopp et al. 2014)		H++ Scenario (Sweet et al. 2017)
	Low Risk Aversion	**Medium-High Risk Aversion**	**Extreme Risk Aversion**
	Upper limit of "likely range" (~17% probability SLR exceeds...)	*1-in-200 chance (0.5% probability SLR exceeds...)*	*Single scenario (no associated probability)*
2030	0.4	0.7	1.0
2040	0.7	1.1	1.6
2050	1.0	1.8	2.5
2060	1.3	2.5	3.6
2070	1.7	3.3	4.9
2080	2.1	4.3	6.3
2090	2.6	5.3	7.9
2100	3.1	6.6	9.8
2110*	3.2	6.9	11.5
2120	3.7	8.2	13.7
2130	4.2	9.5	16.0
2140	4.8	11.0	18.6
2150	5.3	12.6	21.4

**Most of the available climate model experiments do not extend beyond 2100. The resulting reduction in model availability causes a small dip in projections between 2100 and 2110, as well as a shift in uncertainty estimates (see Kopp et al., 2014). Use of 2110 projections should be done with caution and acknowledgement of increased uncertainty around these projections.*

113 Probabilistic projections for the height of sea level rise and the H++ scenario are presented. The H++ projection is a single scenario and does not have an associated likelihood of occurrence. Projections are with respect to a baseline year of 2000 (or more specifically, the average relative sea level over 1991-2009). Table is adapted from the 2018 OPC SLR Guidance to present only the three scenarios OPC recommends evaluating. Additionally, while the OPC tables include low emissions scenarios, only high emissions scenarios, which represent RCP 8.5, are included here because global greenhouse gas emissions are currently tracking along this trajectory. The Coastal Commission will continue to update best available science as necessary, including if emissions trajectories change.

Table G-9. Sea Level Rise Projections for the Santa Monica Tide Gauge[114] (OPC 2018)

Projected Sea Level Rise (in feet): *Santa Monica*			
	Probabilistic Projections (in feet) (based on Kopp et al. 2014)		H++ Scenario (Sweet et al. 2017)
	Low Risk Aversion	**Medium-High Risk Aversion**	**Extreme Risk Aversion**
	Upper limit of "likely range" (~17% probability SLR exceeds...)	*1-in-200 chance (0.5% probability SLR exceeds...)*	*Single scenario (no associated probability)*
2030	0.5	0.8	1.0
2040	0.8	1.2	1.7
2050	1.1	1.9	2.6
2060	1.4	2.6	3.8
2070	1.8	3.4	5.1
2080	2.3	4.4	6.5
2090	2.8	5.5	8.1
2100	3.3	6.8	10.0
2110*	3.5	7.2	11.7
2120	4.0	8.5	14.0
2130	4.5	9.8	16.3
2140	5.1	11.3	18.9
2150	5.7	12.9	21.7

**Most of the available climate model experiments do not extend beyond 2100. The resulting reduction in model availability causes a small dip in projections between 2100 and 2110, as well as a shift in uncertainty estimates (see Kopp et al., 2014). Use of 2110 projections should be done with caution and acknowledgement of increased uncertainty around these projections.*

[114] Probabilistic projections for the height of sea level rise and the H++ scenario are presented. The H++ projection is a single scenario and does not have an associated likelihood of occurrence. Projections are with respect to a baseline year of 2000 (or more specifically, the average relative sea level over 1991-2009). Table is adapted from the 2018 OPC SLR Guidance to present only the three scenarios OPC recommends evaluating. Additionally, while the OPC tables include low emissions scenarios, only high emissions scenarios, which represent RCP 8.5, are included here because global greenhouse gas emissions are currently tracking along this trajectory. The Coastal Commission will continue to update best available science as necessary, including if emissions trajectories change.

Table G-10. Sea Level Rise Projections for the Los Angeles Tide Gauge[115] (OPC 2018)

Projected Sea Level Rise (in feet): *Los Angeles*			
	Probabilistic Projections (in feet) (based on Kopp et al. 2014)		H++ Scenario (Sweet et al. 2017)
	Low Risk Aversion	**Medium-High Risk Aversion**	**Extreme Risk Aversion**
	Upper limit of "likely range" (~17% probability SLR exceeds...)	*1-in-200 chance (0.5% probability SLR exceeds...)*	*Single scenario (no associated probability)*
2030	0.5	0.7	1.0
2040	0.7	1.2	1.7
2050	1.0	1.8	2.6
2060	1.3	2.5	3.7
2070	1.7	3.3	5.0
2080	2.2	4.3	6.4
2090	2.7	5.3	8.0
2100	3.2	6.7	9.9
2110*	3.3	7.1	11.5
2120	3.8	8.3	13.8
2130	4.3	9.7	16.1
2140	4.9	11.1	18.7
2150	5.4	12.7	21.5

**Most of the available climate model experiments do not extend beyond 2100. The resulting reduction in model availability causes a small dip in projections between 2100 and 2110, as well as a shift in uncertainty estimates (see Kopp et al., 2014). Use of 2110 projections should be done with caution and acknowledgement of increased uncertainty around these projections.*

[115] Probabilistic projections for the height of sea level rise and the H++ scenario are presented. The H++ projection is a single scenario and does not have an associated likelihood of occurrence. Projections are with respect to a baseline year of 2000 (or more specifically, the average relative sea level over 1991-2009). Table is adapted from the 2018 OPC SLR Guidance to present only the three scenarios OPC recommends evaluating. Additionally, while the OPC tables include low emissions scenarios, only high emissions scenarios, which represent RCP 8.5, are included here because global greenhouse gas emissions are currently tracking along this trajectory. The Coastal Commission will continue to update best available science as necessary, including if emissions trajectories change.

Table G-11. Sea Level Rise Projections for the La Jolla Tide Gauge[116] (OPC 2018)

Projected Sea Level Rise (in feet): *La Jolla*			
	Probabilistic Projections (in feet) (based on Kopp et al. 2014)		H++ Scenario (Sweet et al. 2017)
	Low Risk Aversion	**Medium-High Risk Aversion**	**Extreme Risk Aversion**
	Upper limit of "likely range" (~17% probability SLR exceeds...)	*1-in-200 chance (0.5% probability SLR exceeds...)*	*Single scenario (no associated probability)*
2030	0.6	0.9	1.1
2040	0.9	1.3	1.8
2050	1.2	2.0	2.8
2060	1.6	2.7	3.9
2070	2.0	3.6	5.2
2080	2.5	4.6	6.7
2090	3.0	5.7	8.3
2100	3.6	7.1	10.2
2110*	3.7	7.5	12.0
2120	4.3	8.8	14.3
2130	4.9	10.2	16.6
2140	5.4	11.7	19.2
2150	6.1	13.3	22.0

**Most of the available climate model experiments do not extend beyond 2100. The resulting reduction in model availability causes a small dip in projections between 2100 and 2110, as well as a shift in uncertainty estimates (see Kopp et al., 2014). Use of 2110 projections should be done with caution and acknowledgement of increased uncertainty around these projections.*

[116] Probabilistic projections for the height of sea level rise and the H++ scenario are presented. The H++ projection is a single scenario and does not have an associated likelihood of occurrence. Projections are with respect to a baseline year of 2000 (or more specifically, the average relative sea level over 1991-2009). Table is adapted from the 2018 OPC SLR Guidance to present only the three scenarios OPC recommends evaluating. Additionally, while the OPC tables include low emissions scenarios, only high emissions scenarios, which represent RCP 8.5, are included here because global greenhouse gas emissions are currently tracking along this trajectory. The Coastal Commission will continue to update best available science as necessary, including if emissions trajectories change.

Table G-12. Sea Level Rise Projections for the San Diego Tide Gauge[117] (OPC 2018)

Projected Sea Level Rise (in feet): *San Diego*			
	Probabilistic Projections (in feet) (based on Kopp et al. 2014)		H++ Scenario (Sweet et al. 2017)
	Low Risk Aversion	**Medium-High Risk Aversion**	**Extreme Risk Aversion**
	Upper limit of "likely range" (~17% probability SLR exceeds...)	*1-in-200 chance (0.5% probability SLR exceeds...)*	*Single scenario (no associated probability)*
2030	0.6	0.9	1.1
2040	0.9	1.3	1.8
2050	1.2	2.0	2.8
2060	1.6	2.7	3.9
2070	2.0	3.6	5.2
2080	2.5	4.6	6.7
2090	3.0	5.7	8.3
2100	3.6	7.0	10.2
2110*	3.7	7.5	12.0
2120	4.3	8.8	14.3
2130	4.9	10.2	16.6
2140	5.4	11.7	19.2
2150	6.1	13.3	22.0

**Most of the available climate model experiments do not extend beyond 2100. The resulting reduction in model availability causes a small dip in projections between 2100 and 2110, as well as a shift in uncertainty estimates (see Kopp et al., 2014). Use of 2110 projections should be done with caution and acknowledgement of increased uncertainty around these projections.*

[117] Probabilistic projections for the height of sea level rise and the H++ scenario are presented. The H++ projection is a single scenario and does not have an associated likelihood of occurrence. Projections are with respect to a baseline year of 2000 (or more specifically, the average relative sea level over 1991-2009). Table is adapted from the 2018 OPC SLR Guidance to present only the three scenarios OPC recommends evaluating. Additionally, while the OPC tables include low emissions scenarios, only high emissions scenarios, which represent RCP 8.5, are included here because global greenhouse gas emissions are currently tracking along this trajectory. The Coastal Commission will continue to update best available science as necessary, including if emissions trajectories change.

Appendix H

Coastal Commission Contact Information

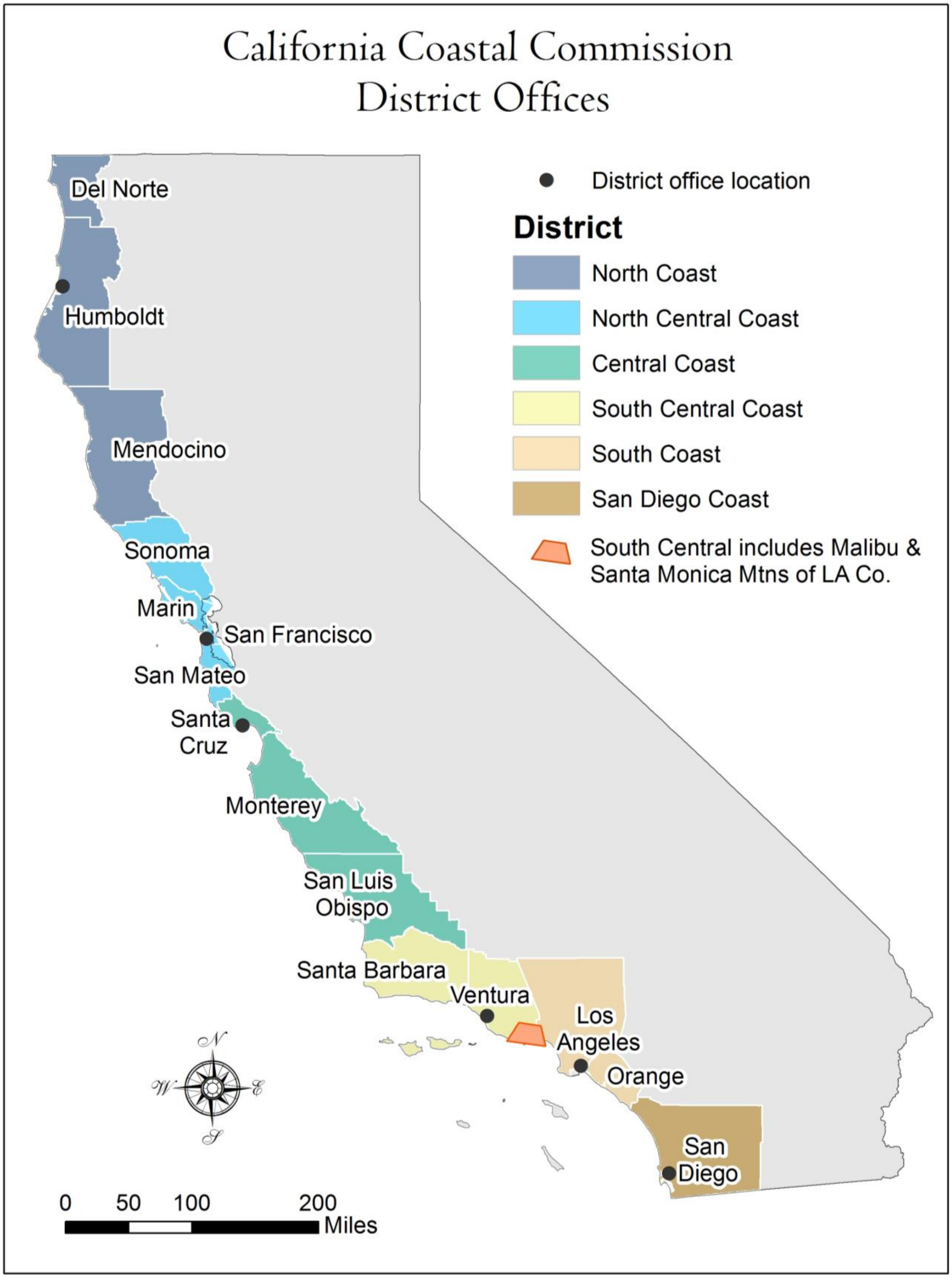

Figure H-1. Location of Coastal Commission Offices

Coastal Commission District Office Contact Information

North Coast (Del Norte, Humboldt, Mendocino Counties)
(707) 826-8950

Headquarters and North Central Coast (Sonoma, Marin, San Francisco, San Mateo Counties)
(415)-904-5200

Central Coast (Santa Cruz, Monterey, San Luis Obispo Counties)
(831) 427-4863

South Central Coast (Santa Barbara and Ventura Counties, and the Malibu portion of Los Angeles County)
(805) 585-1800

South Coast (Los Angeles (except Malibu) and Orange Counties)
(562) 590-5071

San Diego (San Diego County)
(619) 767-2370

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