Chapter 3

Sea Level Rise Science

This chapter provides information on sea level rise science and covers the following subjects:

- The best available science on sea level rise
- Using scenario-based analysis in response to sea level rise projection ranges
- The physical impacts of sea level rise
- Storms, extreme events, and abrupt change

Sea level rise science continues to evolve, and the discussion below reflects the best available science at the time this document was published.

BEST AVAILABLE SCIENCE ON SEA LEVEL RISE

Scientists widely agree that the climate is changing and that it has led to global increases in temperature and sea level. In the past century, global mean sea level (MSL) has increased by 7 to 8 in (17 to 21 cm; IPCC 2013). It is extremely likely (>95% probability of occurrence) that human influence has been the dominant cause of the observed warming of the atmosphere and the ocean since the mid-20th century (IPCC 2013).

There are a number of methods for projecting future changes in global sea level, including using extrapolations from historical trends and observations, estimations from physical models, and combinations of observations and modeling, known as semi-empirical methods. For a detailed description of these techniques, see Appendix A.

Scientists also measure sea level change at a variety of scales, from the global down to the local level. For example, the sea level rise projections in Intergovernmental Panel on Climate Change (IPCC) reports are based on large scale models that give global projections. But sea level does not change uniformly around the globe, so modifications for local conditions are necessary for adaptation planning.

In particular, global average sea level rise is driven by the expansion of ocean waters as they warm, the addition of freshwater to the ocean from melting land-based ice sheets and glaciers, and from extractions in groundwater (Figure 3). However, regional and local factors such as tectonics and ocean and atmospheric circulation patterns result in relative sea level rise rates that may be higher or lower than the global average. As such, global-scale models are often "downscaled" through a variety of methods to provide locally relevant data.

For California, the National Research Council (NRC) 2012 report, described below, provides sea level rise projections that have been refined for the regions North and South of Cape Mendocino. Except for Humboldt Bay and the Eel River Estuary, more detailed refinement of sea level rise projections is not considered necessary at this time. While some, more localized refinements are possible, these local refinements are highly technical and data-intensive, and local variation from the regional projections will often be quite small. It is important to note, though, that while the sea level rise projections are fairly similar throughout the state, the physical impacts may be quite different, and locally-specific analysis of impacts will be very important. Detail on physical impacts and how to assess them is provided in Section C of this chapter and in Appendix B.

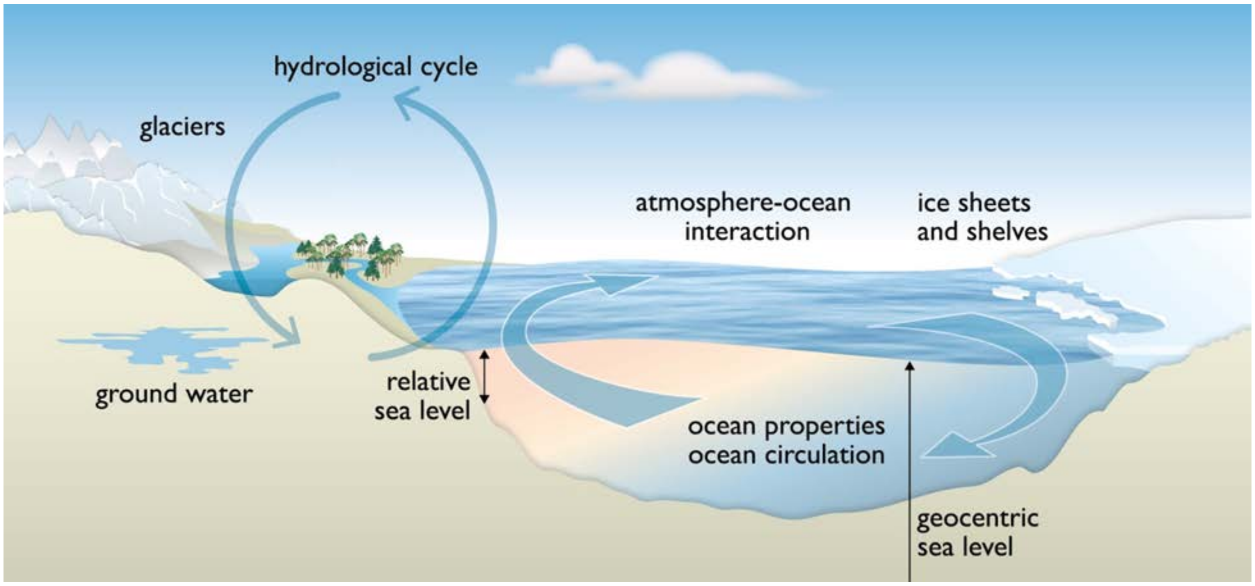

Figure 3. Climate-sensitive processes and components that can influence global and regional sea level. Changes in any one of the components or processes shown will result in a sea level change. The term "ocean properties" refers to aspects such as temperature, salinity, and density, which influence and are dependent on ocean circulation. (*Source*: IPCC 2013, Figure 13.1)

Global Sea Level Rise Projections

The IPCC 5th Assessment Report (AR5), which was released in September 2013, is the most recent global scale assessment of sea level rise. The report projects a rise in *global* average sea level by 10-39 in (26 to 98 cm) by the year 2100 (relative to mean sea level from 1985 to 2005) depending on the emissions scenario[14] (Figure 4). These projections are about 50% higher than the projections from the IPCC 4th Assessment Report (AR4, released in 2007). This is because the IPCC changed the climate model inputs between AR4 and AR5. In particular, much of the increase in the amount of sea level rise projected in the AR5 is due to the inclusion of sea level rise resulting from the loss of ice sheets. Ice sheet dynamics were not included in the AR4, but enhancements in physical models that account for such ice sheet dynamics have allowed for a better understanding and greater confidence in this input, and as such were included in the AR5[15].

[14] See Appendix A for more detail on emissions scenarios and the IPCC reports.

[15] Many of the other reports and studies cited in this Guidance used the AR4 as a reference (and for this reason detail on the AR4 is included in Appendix A). It is important to note, though, that while these other reports relied on the AR4 scenarios and model outputs for some climatic changes, many (*e.g.*, the *National Climate Assessment* (Melillo *et al*. 2014) and the NRC (2012) reports highlighted below) accounted for the loss of ice sheets through the use of semi-empirical models or other methods, further honing their results.

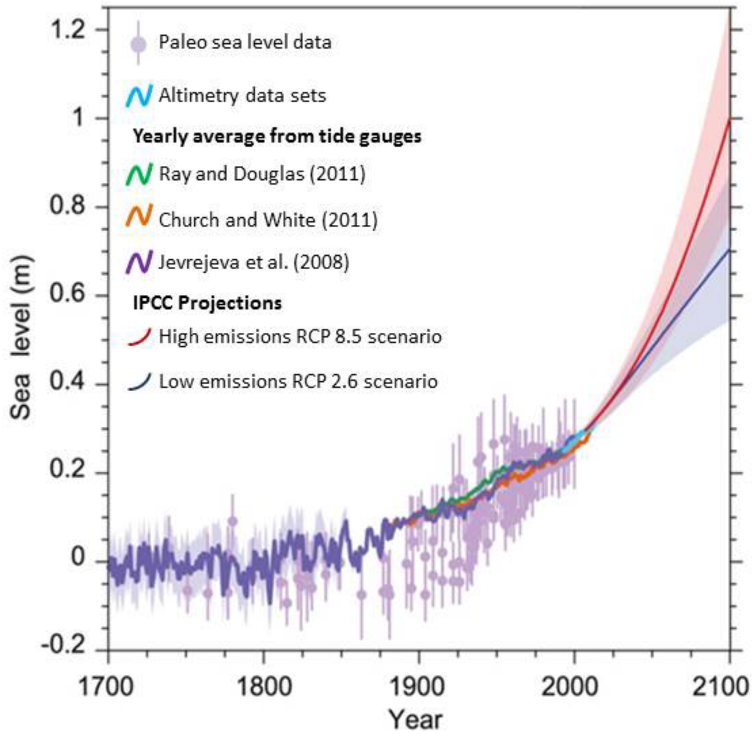

Figure 4. Past and projected future sea level trends (IPCC). Compilation of paleo sea level data, tide gauge data, altimeter data, and central estimates and likely ranges for projections of global mean sea level rise for low emissions RCP2.6 (blue) and high emissions RCP8.5 (red) scenarios, all relative to pre-industrial values. (*Source*: IPCC 2013, Figure 13.27)

National Sea Level Rise Projections

The third National Climate Assessment (NCA; Melillo *et al*.) was released in May 2014, and includes the current best-available science on climate change and sea level rise at the *national* scale. 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.* 2012). This report provides a set of four global sea level rise scenarios ranging from 8 in to 7 ft (0.2 to 2.0 m) by the year 2100 (using mean sea level in 1992 as a baseline) reflecting different amounts of future greenhouse gas emissions, ocean warming and ice sheet loss (Figure 5). The low and intermediate-low scenarios assume very significant reductions in greenhouse gas emissions, and limited changes in ocean warming and ice sheet loss. The intermediate-high scenario is based on the average of the high projections from semi-empirical models, which are based on the highest IPCC 4th Assessment Report (AR4; 2007) emissions scenario (A1FI).[16] The highest scenario (2.0 m) combines the IPCC AR4 projections with the maximum possible ice sheet melt that could occur by 2100. Given the recent studies that suggest that glacier and ice

[16] The IPCC emissions scenarios make assumptions about future changes in population growth, future economic growth and the introduction of clean and efficient technology. The A1FI scenario assumes continued intensive use of fossil fuels, high economic growth, and low population growth that peaks mid-century. The B1 scenario assumes significant reduction in fossil fuel use, an increase in clean technologies, and the same low population growth that peaks mid-century. The A1F1 yields the highest CO_2 emissions by 2100 and the B1 scenario yields the lowest.

sheet loss could contribute significantly to rising sea levels (*e.g.*, Rahmstorf 2007; Vermeer and Rahmstorf 2009; IPCC 2013; McMillan *et al*. 2014; Morlighem *et al*. 2014) and evidence that current greenhouse gas emissions are tracking with intermediate IPCC AR4 scenarios (Rahmstorf *et al*. 2012), the low and intermediate-low scenarios likely underrepresent future sea level rise unless demonstrable reductions in global greenhouse gas emissions occur soon.

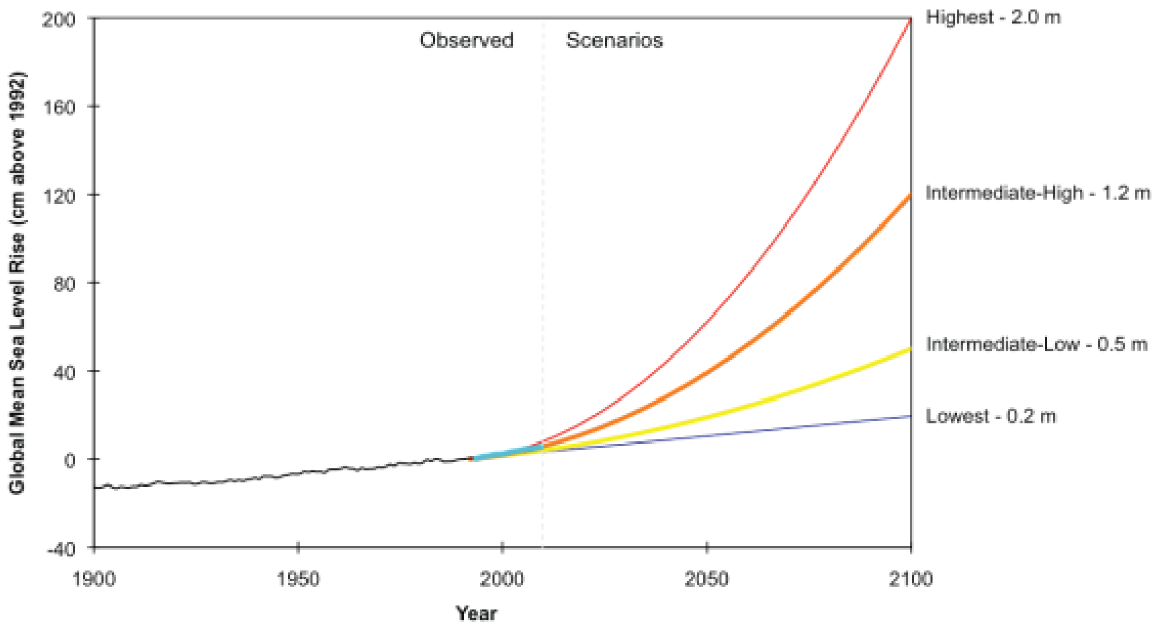

Figure 5. Observed and projected future sea level rise scenarios (Melillo *et al.* 2014). Global mean sea level rise scenarios used in the *US National Climate Assessment*. The Intermediate High Scenario is an average of the high end of ranges of global mean SLR reported by several studies using semi-empirical approaches. The Intermediate Low Scenario is the global mean SLR projection from the IPCC AR4 at 95% confidence interval. (*Source: Global Sea Level Rise Scenarios for the United States National Climate Assessment (*Parris *et al*. 2012))

Sea Level Rise Projections for California

Tide gauges and satellite observations show that in the past century, mean sea level in California has risen 8 in (20 cm), keeping pace with global rise. In the past 15 years or so, mean sea level in California has remained relatively constant, and may have been suppressed due to factors such as offshore winds and other oceanographic complexities. 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 offset the global sea level rise trend in this region. However, localized sea level suppression will not continue indefinitely. As the Pacific Decadal Oscillation, wind, and other conditions shift, California sea level will continue rising, likely at an accelerated rate (NRC 2012; Bromirski *et al.* 2011, 2012).

Over the coming decades, sea level is projected to increase by 17 to 66 in (42 to 167 cm) along much of the California coast by Year 2100, according to the 2012 National Research Council *Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future* report. In March 2013, the Ocean Protection Council adopted a revised *State of California Sea-*

Level Rise Guidance Document that established the NRC 2012 report as the best available science on sea level rise for California (OPC 2013).[17]

The Commission will periodically re-examine and update sea level rise projections as they evolve with the release of new scientific reports and information on local and regional sea level trends. For now, however, the Commission recommends that local governments and applicants use the 2012 NRC report for the best available projections of regional sea level rise in California, though equivalent resources may be used by local governments and applicants provided the sources are peer-reviewed, widely accepted within the scientific community, and locally relevant.

The full range of sea level rise projections from the NRC report is provided below in Table 3. The range of sea level rise projections reflects uncertainties in future greenhouse gas emissions, future changes in the rate of ice sheet melt, and uncertainties related to the data. The low end of the range is based on the lowest IPCC 4th Assessment Report (AR4) future CO_2 emissions scenario (B1) and the high end is based on the highest IPCC AR4 emissions scenario (A1FI) (2007). Note that these amounts are what the NRC report refers to as "ranges." The report also includes "projections" that are based on the A1B emissions scenario. Please refer to Appendix A for a greater description of the "ranges" and "projections"[18]. Again, given current greenhouse gas emission levels and projections of future ice sheet loss, the lowest range of the sea level rise projections likely underrepresents future sea level rise (Rahmstorf *et al*. 2012; Horton *et al*. 2014).

Table 3. Sea Level Rise Projections for California (NRC, 2012)

TIME PERIOD*	NORTH OF CAPE MENDOCINO[19]	SOUTH OF CAPE MENDOCINO
by 2030	-2 – 9 in (-4 – +23 cm)	2 – 12 in (4 – 30 cm)
by 2050	-1 – 19 in (-3 – + 48 cm)	5 – 24 in (12 – 61 cm)
by 2100	4 – 56 in (10 – 143 cm)	17 – 66 in (42 – 167 cm)

*with Year 2000 as a baseline

The NRC report breaks the California coast into two regions – South of Cape Mendocino and North of Cape Mendocino. South of Cape Mendocino, much of the land is experiencing

[17] Visit www.opc.ca.gov/climate-change/ for the *State Sea-Level Rise Guidance Document*.

[18] Table 5.3 from the NRC 2012 report uses the term "projections" to refer to sea level rise amounts for the A1B emission scenario (herein referred to as the NRC A1B projection). However, unless otherwise noted, this Guidance uses the term "projections" to refer more generally to sea level rise amounts from the broad set of emission scenarios.

[19] Since portions of Humboldt Bay are experiencing subsidence, and thus differ from the regional uplift conditions, the projections for north of Cape Mendocino may not be appropriate for use within parts of Humboldt Bay. See Appendix B for additional discussion about vertical land movement and relative sea level rise.

subsidence, which will augment the consequences of rising sea level. For much of the area north of Cape Mendocino, the consequences of rising sea level are being reduced by the vertical land uplift along much of the Cascadia Subduction Zone. However, much of this vertical uplift could change rapidly during the next large Cascadian earthquake. During such an earthquake, areas north of Cape Mendocino could experience rapid subsidence of up to about 6 ft (2 m), which means relative sea level in the area would correspondingly rise (NRC 2012).

In contrast to the vertical uplift occurring throughout the majority of the area north of Cape Mendocino, Humboldt Bay's North Spit and the Eel River Estuary are subsiding and experiencing the highest rate of sea level rise in the state: a rate of 18.6 in over the last century (NOAA 2013). As a result, the projections for north of Cape Mendocino will not be appropriate for use in or near Humboldt Bay and the Eel River Estuary and will instead need to be modified to account for local vertical land movement. Please see *Humboldt Bay: Sea Level Rise Hydrodynamic Modeling, and Inundation Vulnerability Mapping* (Northern Hydrology and Engineering 2015) for additional information on sea level rise projections for the Humboldt Bay region.

The NRC report (2012) only provides estimated sea level rise ranges through the year 2100, though sea level will continue to rise, possibly at an accelerating rate, beyond the end of the century (IPCC 2013; Horton *et al*. 2014). Additionally, sea level rise in a particular location along the coast will likely vary from these regional projections due to changes in vertical land motion and ocean circulation, though such variation may be insignificant in places other than Humboldt Bay and the Eel River regions. Regardless, local governments, applicants, and staff may choose to modify these projections to account for local conditions and/or specific time periods, using the steps provided in Appendix B.

The Coastal Commission will be using and recommends that local governments and applicants use best available science, currently identified as the projections provided in the NRC 2012 report (Table 3), in all relevant local coastal planning and coastal development permitting decisions.

USING SCENARIO-BASED ANALYSIS IN RESPONSE TO SEA LEVEL RISE PROJECTION RANGES

Despite the recent advances in sea level rise science, sea level rise projections, including those in the 2012 NRC Report (Table 3) and the 2013 IPCC AR5, are typically presented in ranges due to several sources of significant uncertainty.

The two primary sources of uncertainty in *global* sea level projections include:

1) Uncertainty about future greenhouse gas emissions and concentrations of sulfate aerosols, which will depend on future human behavior and decision making, and
2) Uncertainty about future rates of land ice loss (NRC 2012; McMillan *et al*. 2014; Morlighem *et al*. 2014).

The NRC report (2012) also notes additional sources of uncertainty when projecting *regional* sea level for California, Oregon, and Washington, including:

1) Uncertainty in the influence of thermal expansion on local sea level, and
2) Uncertainty in future vertical land motion.

Additionally, the further into the future sea level rise is projected, the greater the uncertainty becomes. This occurs because the longer the projection period, the greater the likelihood that models will deviate from the actual impacts of climate change (NRC 2012).

This Guidance recommends using scenario-based analysis to address the uncertainty in sea level projections. Scenario-based analysis (or planning) refers to the idea of developing multiple scenarios from which to analyze vulnerabilities, generate new ideas and adaptation options, and/or test strategies. In the context of this Guidance, scenario-based analysis includes choosing several possible sea level rise amounts as a starting point to evaluate impacts to coastal resources and potential risks to development over time. This type of scenario-based approach is useful because it reveals the full range of possible consequences of sea level rise that can be reasonably expected for particular regions or sites according to the best available science. Additionally, a scenario-based analysis helps to reveal the tipping points indicating if or when sea level rise will become a serious issue in a particular location. In many cases, using multiple sea level rise scenarios will help to hone in on the types of hazards for which to prepare.

In general, the Coastal Commission recommends using best available science (currently the 2012 NRC report) to identify a range of sea level rise scenarios including the high projection, low projection, and one or more intermediate projections[20]. An even higher value than the NRC range might also be considered if there is the potential for severe impacts to coastal resources and human health and safety from sea level rise impacts. In practice, the process for choosing scenarios and performing scenario-based analysis will be slightly different for LCP planning and CDP applications due to the different planning goals and levels of technical detail required for each.

For a Local Coastal Program (LCP), the general goal is to assess the potential impacts from sea level rise over the entire planning area and over a range of time horizons so that both short and long term adaptation strategies can be identified and implemented. Another important facet of LCP planning is identifying locations that are particularly vulnerable so that additional, more detailed studies can be performed if necessary, and adaption options and actions can be prioritized. Scenario-based analysis in the context of LCP planning includes choosing a range of sea level rise projections to analyze so as to understand the best and worst case scenarios and to identify amounts of sea level rise and related conditions that would trigger severe impacts and the associated time period for when such impacts might occur. Choosing sea level rise scenarios in the context of LCP planning is described in greater detail in Chapter 5.

[20] Similar to the recommendation in the OPC's 2011 *State Sea-Level Rise Resolution*, the Commission does not recommend using values solely in the lower third of the NRC's projections as this does not give a full picture of the risks. Looking instead at both the high and low projections allows users to build an understanding of the overall risk sea level rise poses to the region or site.

In the context of a Coastal Development Permit (CDP) application, the goal is to understand how sea level rise will impact a specific site and a specific project over its expected lifetime so as to ensure that the proposed development is safe from hazards and avoids impacts to coastal resources. Thus, in the context of a CDP, it is important to identify the amounts of sea level rise that could result in effects to a particular site as well as the time period(s) over which those effects could occur so that the proposed development can be safely sited and designed to avoid resource and development impacts. However, some sites will be completely safe from sea level rise under even the highest projection scenarios, while others will depend on the timing and magnitude of sea level rise to determine safety. Therefore, scenario-based planning analysis can be used as a screening process to identify if and when sea level rise might become a problem. Identifying sea level rise scenarios in the context of CDPs is described in greater detail in Chapter 6.

Overall, scenario-based planning should help planners make reasonable and informed decisions about whether their projects or plans are compatible with the local hazards influenced by sea level rise, and identify the types of adaptation measures that might be appropriate given the local circumstances and requirements of the Coastal Act. By exploring the range of future scenarios based on the best available science, users of this document can make decisions based on full understanding of possible future hazards, ultimately achieve outcomes that are safer for both development and coastal resources, and avoid costly damages to projects.

For more information on scenario-based planning in the context of LCPs and CDPs see Chapters 5 and 6, respectively. A number of additional resources related to scenario-based planning are available, including a handbook from the National Park Service (2013) and guidance from Point Blue Conservation Science and the California Coastal Conservancy (Moore *et al*. 2013). See Appendix C for these and other resources related to scenario-based analysis and adaptation planning.

PHYSICAL EFFECTS OF SEA LEVEL RISE

Continued and accelerated sea level rise will have widespread adverse consequences for California's coastal resources (See summary in Figure 8). The main physical effects of sea level rise include increased flooding, inundation, wave impacts, coastal erosion, changes in sediment dynamics, and saltwater intrusion. These impacts are interrelated and often occur together. Absent any preparatory action, an increase in sea level may have serious implications for coastal resources and development, as described in Chapter 4. In addition, these physical effects could have disproportionate impacts on vulnerable communities that have lower capacity to adapt.

Physical effects from sea level rise to the coastal zone include the following:

- **Flooding and inundation:** Low lying coastal areas may experience more frequent flooding (temporary wetting) or inundation (permanent wetting), and the inland extents of 100-year floods may increase. Riverine and coastal waters come together at river mouths, coastal lagoons, and estuaries, and higher water levels at the coast may cause water to back up and increase upstream flooding (Heberger *et al*. 2009). Drainage systems that discharge close to sea level could have similar problems, and inland areas may become flooded if outfall pipes back up with salt water. In addition, other climate change impacts such as increases in the amount of precipitation falling as rain rather than snow will add to river flooding in some areas.

- **Wave impacts:** Wave impacts can cause some of the more long-lasting consequences of coastal storms, resulting in high amounts of erosion and damage or destruction of structures. The increase in the extent and elevation of flood waters from sea level rise will also increase wave impacts and move the wave impacts farther inland. Erosion rates of coastal cliffs, beaches, and dunes will increase with rising sea level and are likely to further increase if waves become larger or more frequent (NRC 2012).
- **Erosion:** Large sections of the California coast consist of oceanfront bluffs that are often highly susceptible to erosion. With higher sea levels, the amount of time that bluffs are pounded by waves would increase, causing greater erosion (NRC 2012). This erosion could lead to landslides and loss of structural and geologic stability of bluff top development such as homes, infrastructure, the California Coastal Trail, Highway 1, and other roads and public utilities. The Pacific Institute (Heberger *et al*. 2009) estimated that 41 square miles (106 square km) of coastal land from the California-Oregon border through Santa Barbara County could be lost due to increased erosion with 4.6 ft (1.4 m) of sea level rise by the year 2100, and approximately 14,000 people now live in those vulnerable areas. Increased erosion will not occur uniformly throughout the state. Mendocino and Humboldt Counties have the greatest areas projected to be lost by erosion. For example, dunes in Humboldt County could erode a distance of approximately 2000 ft (nearly 600 m) by the year 2100 (Heberger *et al*. 2009; Revell *et al*. 2011). Man-made structures like dikes and levees may also be impacted by erosion, increasing flooding risk of the areas protected by those structures, such as low-lying agricultural land. Over the long term, rising sea levels will also cause landward migration of beaches due to the combined effects inundation and loss of sediment due to erosion (NRC 2012).

Figure 6. Photo of Esplanade Apartments threatened by cliff erosion in 2013 in Pacifica, CA. (*Source: California Coastal Records Project*)

- **Changes in sediment supply and movement:** Sediment is important to coastal systems in, for example, forming beaches and mudflats and as the substrate for wetlands. Sea level rise will result in changes to sediment availability. Higher water levels and changing precipitation patterns could change erosion and deposition patterns. Loss of sediment could worsen beach erosion and possibly increase the need for beach nourishment projects (adding sand to a beach or other coastal area), as well as decrease the effectiveness and long-term viability of beach nourishment if sand is quickly washed away after being placed on a beach (Griggs 2010). Sediment supplies in wetland areas will also be important for long-term marsh survival. Higher water levels due to sea level rise, however, may outpace the ability of wetlands to trap sediment and grow vertically (Titus 1988; Ranasinghe *et al*. 2012; Van Dyke 2012).
- **Saltwater intrusion:** An increase in sea level could cause saltwater to enter into groundwater resources, or aquifers. Existing research suggests that rising sea level is likely to degrade fresh groundwater resources in certain areas, but the degree of impact will vary greatly due to local hydrogeological conditions. Generally, the most vulnerable hydrogeological systems are unconfined aquifers along low-lying coasts, or aquifers that have already experienced overdraft and saline intrusion. In California, saline intrusion into groundwater resources is a problem in multiple areas, including but not limited to the Pajaro Valley (Hanson 2003), Salinas Valley (Hanson *et al*. 2002a; MCWRA 2012), Oxnard Plain (Izbicki 1996; Hanson *et al*. 2002b), and the heavily urbanized coastal plains of Los Angeles and Orange Counties (Edwards and Evans 2002; Ponti *et al*. 2007; Nishikawa *et al*. 2009; Barlow and Reichard 2010). Groundwater sources for coastal agricultural lands may also be susceptible to saltwater intrusion. Additional research is needed to understand the site-specific consequences of sea level rise and saltwater intrusion to these and other coastal aquifers in California.

Storms, Extreme Events, and Abrupt Change

Much of the California coast is currently vulnerable to flooding and wave damage during large storm events, and even more of the coast is vulnerable to storm impacts when they occur during times of heightened water levels, such as high tides, El Niño events, a warm phase of the Pacific Decadal Oscillation, or a combination of these factors. Sea level rise will increase coastal vulnerability to storms even more because rising water levels will result in more areas being impacted.

Climate change will likely modify or change much more than just sea level. One potential climate change-related impact that will interact most directly with sea level rise hazards is a change in frequency or intensity of coastal storms (storminess) and extreme events. The extremes associated with high-intensity events may be particularly devastating since they have the potential to cause broad-scale damage, as seen from recent events such as Hurricanes Katrina and Rita, Superstorm Sandy, and the Tohoku tsunami. Abrupt change in sea levels is another potential impact of climate change. Both potential impacts are described below.

Extreme Events and Storms

There are several ways to describe extreme events, and most definitions tend to frame these events in terms of consequences or past observations. Kruk *et al*. 2013 define extreme events as "the floods that displace us from our homes, the high waves that wash out coastal roads, or the toppling of trees and power poles from a passing storm." The IPCC defines climate extremes as "the occurrence of a value of a weather or climate variable above (or below) a threshold value near the upper (or lower) ends of the range of observed values of the variables" (IPCC 2012, p. 5). In general, extreme events, by their very nature, are those beyond the normal events that are considered in most shoreline studies. For example, for storm waves and flood conditions, an extreme event will normally be anything worse than the 100-year event.

Extreme events are of particular concern to the examination of coastal vulnerability and damage because they tend to cause the greatest community upheaval and can result in irreversible changes to the coastal landscape. In the El Niño winter of 1982-1983, for example, a series of storms, several of which coincided with high tide, caused more than $200 million in damage (in 2010 dollars) to coastal California (OPC 2013). The 2012 NRC report notes that "waves riding on these higher water levels will cause increased coastal damage and erosion—more than that expected by sea level rise alone" (NRC 2012, p.107). These impacts result because a rise in sea level will mean that flooding and damage will likely reach further inland. The IPCC *Fifth Assessment Report* (2013) states that it is very likely[21] that there will be a significant increase in the occurrence of future sea level extremes primarily as a result of an increase in mean sea level, with the frequency of a particular sea level extreme increasing by an order of magnitude or more in some regions by the end of the 21st century.

According to the 2012 NRC report, if the frequency or intensity of storms changes, then so will the frequency and intensity of extreme sea level events. However, the evidence that storminess will change in the North Pacific Ocean is conflicting and inconclusive (Cayan *et al*. 2009; Lowe *et al*. 2010; Dettinger 2011). Still, even if storminess does not change, sea level rise will exacerbate storm surge and high waves, magnifying their impact on the coastline. For this reason, it is important to include these factors in the analysis of sea level rise hazards. Methodologies for these analyses are included in Appendix B.

Abrupt change

Currently, the best available science is inconclusive as to whether sea level could change abruptly. Thermal expansion and direct melting of land ice is expected to be gradual, leading to slow and steady sea level rise. However, rapid collapse of land-based ice sheets could lead to sudden acceleration of sea level rise. Still, the likelihood of such collapses is uncertain (but probably low) and remains an area in need of future research (NRC 2013).

[21] The IPCC has assigned quantitative levels to various terms of confidence and likelihood. High confidence means there is about an 8 out of 10 chance of being correct. Very likely has a greater than 90% probability of occurrence. Other terms that will be used later in this discussion are likely (> 66% probability of occurrence), medium confidence (about a 5 out of 10 chance), low confidence (about a 2 out of 10 chance). *Source of terms*: http://www.ipcc.ch/pdf/supporting-material/uncertainty-guidance-note_ar4.pdf

Rapid change in land elevation during an earthquake is another potential cause of an abrupt sea level change in a localized area. A large earthquake in the Cascadia Subduction Zone could cause land in northern California, Oregon, and Washington to suddenly subside relative to sea level, causing a sudden rise in relative sea level by 3-6.5 ft (1-2 m; NRC 2012). Large earthquakes in this zone are expected to occur about every several hundred to one thousand years, and the most recent such earthquake occurred in 1700. The sudden rise or drop in land elevation would occur in a matter of minutes. If the land were to subside, the relative rise in sea level would be rapid and it would add to sea level rise already occurring from climate-related forcing.

There is also potential for oceanographic conditions to lead to a relatively rapid rate of sea level rise in California. Examination of the tidal gauge records indicate that there was no significant interannual rise in California's sea level from 1983 to 2011, despite a rise in global sea level over the same time period. One explanation, presented by Bromirski *et al*. (2011, 2012), links this suppression of sea level rise with persistent alongshore winds and an extended period of offshore upwelling that has both drawn coastal waters offshore and replaced warm surface waters with cooler deep ocean water. However, this suppression will not continue indefinitely and as the Pacific Decadal Oscillation, wind, and other conditions shift, California sea level will continue rising, likely at an accelerated rate (NRC 2012; Bromirski *et al.* 2011, 2012).