4. Climate & Sea Level Rise Science

4.1 Climate Cycles

Climate change as defined by general consensus among scientists is caused by the increase in human emitted greenhouse gases (GHGs), which differ from natural climate cycles observed in the Earth's geological record. Some of these climate cycles occur over long time periods and are related to the orbit of the earth around the sun, the tilt of the earth on its axis, and precession (subtle shift) of the earth's orbit and referred to as "Milankovitch cycles". These Milankovitch cycles occur at approximately 41,000, 120,000, and 400,000 years respectively, and are responsible for the glacial and interglacial periods observed in the geologic record.

Some of these climate cycles are shorter; the most commonly known cycle is the El Niño/La Niña cycle, which is related to changes in equatorial trade winds and shifts in ocean temperatures across the Pacific Ocean. An El Niño event brings warmer water to the Eastern Pacific, and this shift in ocean temperatures elevates sea levels by approximately 1.0 foot above predicted tides in the Santa Barbara Channel. These warmer ocean temperatures can increase evaporation, resulting in more atmospheric moisture and often substantially more precipitation. The 1982–1983, 1997–1998, and 2015-2017 El Niño events have caused flooding damages across the Carpinteria region. The January 1983 wave events are associated with one of the largest storms recorded in the Santa Barbara Channel.

Another climate cycle that regularly impacts the Carpinteria area is the Pacific Decadal Oscillation (PDO), which is an approximately 25–30-year cycle that changes the distribution of sea surface temperatures across the Pacific Ocean. Its effects were first noticed by fishery researchers in Washington (Mantua et al. 1997). The result of this ocean temperature shift is largely attributed to a shift in the jet stream. During the warm phase, the jet stream changes the storm track toward the south, affecting both the wave direction (resulting in an increase in wave energy into the Santa Barbara Channel) and precipitation. At present, the index has been on the cool side, which tends to lead to less precipitation in Carpinteria. One other implication of the PDO is that the rate of sea level rise is reduced in the Eastern Pacific Ocean (off the U.S. West Coast). Recent PDO research indicates that a shift in the PDO would likely result in a much more rapid rise in sea levels off the U.S. West Coast than has been seen in the last three decades (Bromirski et al. 2011).

4.2 Climate Change

Human-induced climate change is a consequence of increased GHG emissions from the burning of fossil fuels, the result of which is an increase in heat trapping gases in the atmosphere that serve to insulate the earth (like a blanket) from outgoing long-wave radiation (heat). As this atmospheric emissions blanket gets thicker, more heat is trapped in the earth's atmosphere, warming the earth and triggering a series of climate changes related to different feedback mechanisms. Once set in motion, many of the climate change feedbacks take centuries to millennium to stabilize.

Worldwide, there are multiple Global Climate Models (GCMs) which attempt to project future climate conditions by modeling key variables of the earth, ocean, and atmospheric dynamics, and interactions based on assumptions of global future population growth and global levels of GHG emissions. The modeling assumptions of future geopolitical responses to addressing GHG emissions are called the relative concentration pathways (RCP). The two RCP scenarios included in the climate projections for the *Fourth Climate Assessment* are RCP 4.5, which assumes global emissions peak in 2040 and then begins to decline, and the RCP 8.5, which assumes emissions peak around 2100 and then begins to decline. The RCP 4.5 scenario is a mid-range scenario, while RCP 8.5 is a high-end scenario that is often referred to as a "business-as-usual" scenario. The RCP 8.5 scenario is consistent with a future where there are few global efforts to limit or reduce emissions, and GHG emissions worldwide continue to follow the current "business-as-usual" trajectory. This Report considers primarily the RCP 8.5 emission scenarios.

4.3 Sea Level Rise

Globally, sea levels are rising as a result of two factors caused by human-induced climate change. The first factor is the thermal expansion of the oceans. As ocean temperatures warm, the water in the ocean expands and occupies more volume, resulting in a rise in sea levels. The second factor contributing to global sea level rise is the additional volume of water added to the oceans from the melting of mountain glaciers and ice sheets on land. It is predicted that if all of the ice on earth were to melt, ocean levels would rise by approximately 225-265 feet above present-day levels. The rate at which sea levels will rise is largely dependent on the feedback loop between the melting of the ice, which changes the land cover from a reflective ice surface, and the open ocean water, which absorbs more of the sun's energy and increases the rate of ice melt. The uncertainties associated with the rate at which ice melt occurs is largely responsible for the wide variation in sea level rise projections in the latter half of this century (i.e., between 2050 and 2100) and can help to explain the H++ scenario which could cause the analyzed approximately 5 feet of sea level rise by 2100 to occur as early as 2070.

The time scales for sea level rise are related to complex interactions between the atmosphere and the oceans, the lag times associated with the stabilization of GHGs in the atmosphere, and the dissolution of those gases into the ocean. The Intergovernmental Panel on Climate Change (IPCC) has published scientific evidence that demonstrates that due to the GHGs that have already been released into the atmosphere, sea levels will be rising for the next several thousand years. Given this long-term perspective, it is not a question of if sea level rise will happen, but the rate at which seas will rise.

Much of the scientific advancement in recent years has been in understanding the contribution and rate of ice melt to global sea levels. It has also revealed the potential for extreme sea level rise resulting from rapid acceleration of ice melt as noted above under the RCP 8.5 and H++ scenarios. In general, the higher the GHG emissions, the higher the temperature, the more rapid the ice melt, and the higher the rate of sea level rise.

Relative (Local) Sea Level Rise

Due to local differences in tectonic uplift/subsidence, subsidence caused by oil, gas, and groundwater extraction, and saltwater intrusion, as well as other factors such as near shore bathymetry, sea levels are rising at different rates in different regions of the world. Due to local variation and applicable factors, it is important that local sea level rise monitoring be conducted and that a baseline be established to assess future changes to local sea levels.

In southern Santa Barbara County, the offshore Ventura/Pitas Point and Red Mountain faults contribute to a wide range of vertical uplift and subsidence, while local groundwater, and oil and gas extraction accelerate subsidence. Other factors including near shore bathymetry are not applicable to the local setting. The difference between the local land motion and the global rise of sea level yields the relative sea level rise that will determine the magnitude of local sea level rise impacts.

The nearest tide gauge (Santa Barbara Tide Gauge) reports the local sea level rise rate at approximately 1.01 (+/-1.17) millimeters per year (mm/year) but has a sporadic historical record (Figure 4-1). Globally the average annual rate of sea level rise is estimated to be 3.2mm/year (Griggs et al 2017). The longest tide gauge in operation is near the mouth of San Francisco Bay and shows a 100-year sea level rise of about 7 inches. Since the Santa Barbara tide gauge was installed in the mid-1970s, nearly every major El Niño event has broken the gauge and consequently left a 7- to 10-year data gap, rendering the relative sea level rise trend calculations from the tide gauge unreliable. However, the gauge continues to be operated and should be used for future monitoring of rates and elevations of sea level rise that may support the development of policy triggers for adaptation.

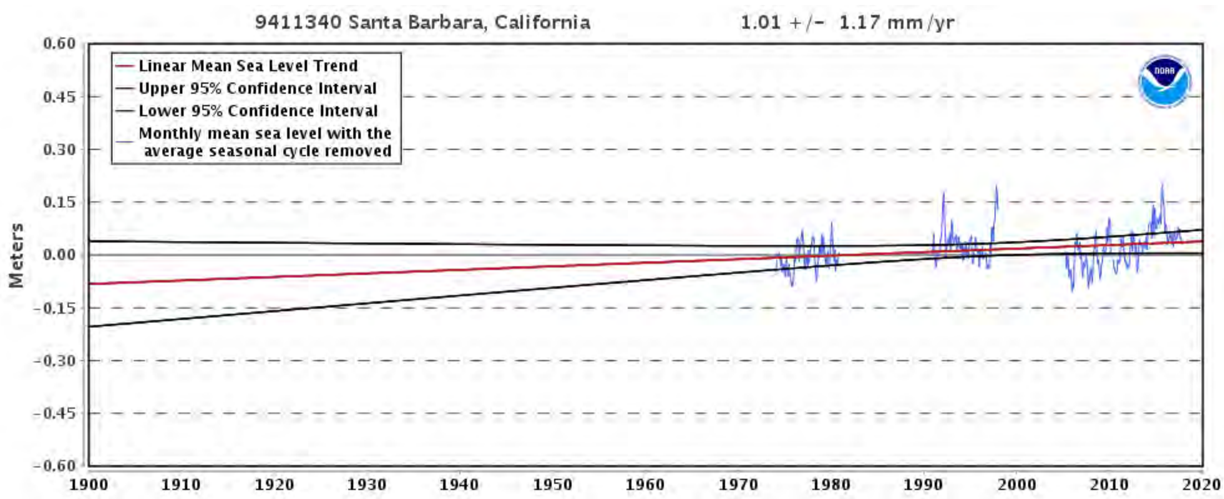

Figure 4-1. *Tide Record and Sea Level Rise Trend from Santa Barbara Tide Gauge (National Oceanic and Atmospheric Administration Station 9411340)*

4.4 State of Climate Science in California

Substantial research in California is currently underway to effectively downscale GCMs and to project various human-induced climate change impacts at a scale more relevant to California. Several of the key climate change impacts are likely to include increased temperature, uncertainty in precipitation changes, increased wildfire risk, and sea level rise. The following are recent scientific studies which form the basis of recent climate hazard understanding in Carpinteria.

2016-2018 California Fourth Climate Assessment

Biannually, the California Energy Commission (CEC) funds climate assessments to better understand the impacts of climate on various natural resource and urban settings. As an initial integral part of the *Fourth Climate Assessment*, Scripps Institution of Oceanography at the University of California, San Diego was commissioned to develop a new suite of climate projections reflecting the latest scientific publications and global level GHG emission reduction pledges made at the 2015 IPCC Paris climate change convention.

The downscaled climate model projections include the entire suite of climate variables including temperature, wildfire risk, precipitation, and sea levels. The modeling included assumptions on population growth, and future global political responses to addressing GHGs called the RCP. The modeling included assumptions on population growth and future global political response to addressing GHGs and used RCP 4.5 and RCP 8.5 as described above. Future climate scenarios are compared to the historic period from 1961-1990. Four (4) GCMs were identified by the State for use in the *Fourth Climate Assessment* work.

- HADGEM2-ES (Warm/Dry)

- CNRM-CM5 (Cool/Wet)
- CanESM2 (Average)
- MIROC5 (Compliment)

Results for key climate variables for the Carpinteria area were extracted from the downscaled California models (Table 4-1). The results shown in Table 4-1 are the average of all four of the State-prioritized GCMs and assume the Business as Usual (BAU) emissions scenario (RCP 8.5) and a medium population growth. RCP 8.5 is considered an extreme scenario with a low probability (0.5 percent chance) of occurring by 2100 as shown in Table 4-2 below. A brief discussion of the implications to Carpinteria is included below.

Table 4-1. Results from the California Fourth Climate Assessment for Key Climate Variables

Category	Threshold	Units	Historical Record (1961-1990)	2030	2060	2100
Extreme Heat	>90.1°F	days	4.3	5	9	10
Temperature	Maximum	°F	71.2	73.7	76.3	79
Temperature	Minimum	°F	49	51.6	53.9	56.7
Precipitation	Annual Total	inches	19.9	24	24.1	24.3
Wildfire	Annual average	hectares	28.9	33.8	44.4	39.5

Temperature

Overall average maximum temperatures in Carpinteria are projected to rise by 7.8°F by 2100 as shown in Table 4-1. These projections differ depending on the time of year and the type of measurement (highs vs. lows), all of which have different potential effects on the state's ecosystem health, agricultural production, water use and availability, and energy demand. Extreme heat has been defined for the Carpinteria area as 90.1°F for the time of year between April and October. Extreme heat during this baseline period averaged 4.3 days per year. There are wide ranges between the available climate models, however in general, the extreme heat projections show not only an increase in the number of days expected to exceed the extreme heat threshold, but also their occurrence both earlier and later in the season.

Precipitation

In Carpinteria, the average of the models' precipitation projections show an increase in total annual precipitation. However, among the current models, precipitation projections are not consistent over the next 100 years. Some individual models show a decrease and others show an increase. Uncertainty around the future trend of precipitation is high. The Mediterranean seasonal precipitation pattern is expected to continue, with most precipitation falling during the winter season from North Pacific storms. However, even modest changes could have a significant impact because California ecosystems are conditioned to historical precipitation levels and water resources are nearly fully utilized.

Wildfire Risk

As the devastating Thomas Fire in December 2017 attests, wildfire is a serious hazard in California and in Carpinteria. Several studies have indicated that the risk of wildfire will increase with climate change. While the models differ, there is a general pattern for wildfires to start earlier in the season and continue later in the year.

Sea Level Rise

The *Fourth Climate Assessment* scenarios take a new approach and carefully quantify each contributing factor to global sea level rise and assign a probability of occurrence based on the scientific uncertainties associated with each factor. The new resulting sea level rise projections for California are the first to identify probabilities for future levels of sea level rise (Cayan et al 2016). The new sea level rise numbers are summarized in a scientific summary which was written to be more approachable for policy making (Griggs et al 2017). Overall, the future sea level rise projections from 2016 are lower than those projections from the National Research Council (NRC) 2012 report, except for the high emissions (RCP 8.5) 2100 scenario. In addition, recent scientific work has identified the potential for an extreme sea level rise scenario caused by runaway ice melt. This scenario is called the H++ scenario and projects 9.8 feet of sea level rise by 2100.

Ocean Protection Council (OPC) has used these scientific updates to develop revised sea level rise planning guidance and has included the associated probabilities of sea level rise for the Santa Barbara tide gauge. These are summarized in Table 4-2 below.

Table 4-2. Probabilistic Projections of Sea Level Rise for Santa Barbara (OPC 2018)

		Probabilistic Projections (ft/yr) (based on Kopp et al. 2014)				H++ Scenario (Sweet et at. 2017) *Single High-Emissions Scenario
		Median	Likely Range	1-in-20 Chance	1-in-200 Chance	
Scenario	Year	50% Probability Sea-level Rise Meets or Exceeds…	66% Probability Sea-level Rise is Between…	5% Probability Sea-level Rise Meets or Exceeds…	0.5% Probability Sea-level Rise Meets or Exceeds	
High Emissions	2030 – 2050	0.3 – 0.7	0.2 – 1.0	0.5 – 1.2	0.7 – 1.8	1.0 – 2.5
Low Emissions	2060 – 2080	0.7 – 1.0	0.4 – 1.5	1.4 – 2.0	2.2 – 3.6	3.6 – 6.3
High Emissions	2060 – 2080	0.9 – 1.4	0.6 – 2.1	1.6 – 2.7	2.5 – 4.3	
Low Emissions	2080 – 2100	1.0 – 1.2	0.5 – 2.0	2.0 – 2.9	3.6 – 5.3	6.3 – 9.8
High Emissions	2080 - 2100	1.4 – 2.1	0.9 – 3.1	2.7 – 4.1	4.3 – 6.6	

Note: The 'Low Emissions' scenario for the OPC 2018 guidance document represents the RCP 2.6 scenario and is not reflective of the RCP 4.0 scenario modeled throughout this report. The 'High Emissions' scenario provided above does reflect the RCP 8.5 scenario modeled throughout this report.

2017 CoSMoS 3.0

U.S. Geological Survey' (USGS') Coastal Storm Modeling System version 3.0 (CoSMoS 3.0) provides projections of coastal flood hazards and cliff erosion for the area between Point Conception and the U.S.–Mexico border. The intent is to provide region-specific, consistent information on coastal storm and sea level rise scenarios. The model uses downscaled GCMs and considers factors such as long-term coastal shoreline change, stream inputs, dynamically downscaled winds, and varying sea level rise scenarios to produce hazard projections for every 9.8 inches (0.25 meters) of sea level rise. Results map a dynamic wave run-up extent (differing from Federal Emergency Management Agency [FEMA] and Coastal Resilience maximum wave run-up) and account for various sea level rise, storm frequencies, and uncertainties. An interactive web mapping portal shows the results of the hazard data (www.ourcoastourfuture.org). For a comparison of the model results please see Appendix B.

CoSMoS 3.0 also provides data for other shoreline change or hazard models within the region. This model was evaluated for the Carpinteria vulnerability study; however, the model was not selected due to the following reasons: inaccuracies in observed flood extents compared with existing 1 percent annual chance storm mapped hazard zones, lack of explicit mapping of coastal erosion hazards, and the unavailability of hazard data in a format (closed polygon) suitable for the geospatial analysis. For details on the selection of the model for the vulnerability assessment, please see Appendix A.

2017 Coastal Ecosystem Vulnerability Assessment

The 2017 Santa Barbara Area Coastal Ecosystem Vulnerability Assessment (CEVA) is a multidisciplinary research project that investigates future changes to southern Santa Barbara County climate, beaches, watersheds, wetland habitats and beach ecosystems. This assessment builds on the State's *Fourth Climate Assessment* with a focus on ecosystem changes.

The hydrological model results provide additional insights, beyond the small increase in average annual precipitation (Myers et al 2017):

- Change in annual precipitation averaged over coastal watersheds is small.
- The number and magnitude of larger rainfall events increases.
- Annual runoff and annual peak discharge increases.
- Changes in year-to-year variability and an increase in annual peak discharges alter watershed flood frequency distributions.
- Specific discharges (e.g., 1 percent annual chance storm) are projected to increase even more than high extreme annual peak discharges.

These increases in storm intensity may indicate that there could be larger fluxes of sediment supplied to the coast followed by wildfires and longer droughts, as exemplified by the January 2018 mudslides in Montecito and Carpinteria.

Ecosystem results for Carpinteria Salt Marsh show that high salt marsh and transitional habitats are the most vulnerable to sea level rise with a threshold of impact beginning to occur with approximately 1 foot of sea level rise. A decline in these wetland habitats could affect 14 of the 16 plant species of special concern found in the Carpinteria Salt Marsh (Myers et al 2017). In addition, beaches, which provide a valuable habitat as well as recreational resources, are projected to narrow even in places where sand dunes (like Carpinteria State Beach) back the beach. With approximately 20 inches of sea level rise, about 60 percent of the dry sand beaches could be gone without additional human intervention.

2016 FEMA Revised Flood Insurance Rate Maps

FEMA FIRMs map the existing 100-Year FEMA Flood Event (e.g. 1 percent annual chance storm) and are the regulatory tool administered under local flood plain ordinances, which are used to determine flood insurance premiums, base floor elevations (BFE), and coastal construction standards. The existing maps were initially developed in the mid-1980s, based on a now outdated understanding of coastal processes.

The FEMA California Coastal Analysis and Mapping Project (CCAMP) is conducting Countywide updates to the coastal flood hazard mapping along the entire coast of California with best improved science, coastal engineering, and regional understanding. These mapping revisions include revised VE (wave velocity), AE (ponded water), and X (minimal flooding) hazard zones. The FEMA methodology specifically maps flood extents associated with the existing 1 percent annual chance storm (e.g. 1 percent wave event). The new maps will not account for future sea level rise. The Preliminary Draft revised FIRM maps were released in December 2016 for Santa Barbara County and showed some increases in coastal high velocity zones that require changes in BFEs from 11 feet to between 15 and 17 feet for the City beach areas.

2016 County of Santa Barbara Coastal Resilience Project

The Coastal Resilience model was a multi-year effort to evaluate the impacts of sea level rise and other coastal hazards along the County's coastline. The project modeled coastal hazard projections for the entire County. The climate change modeling effort, building on initial Pacific Institute studies in the State's *Second Climate Assessment*, projects the impacts of coastal erosion and coastal flooding for the entirety of Santa Barbara County, extending from Jalama Beach County Park to Rincon Point (Revell et al 2011; PWA 2009). Unlike other models, the Coastal Resilience model includes coastal confluence modeling for Carpinteria Creek. A technical methods report presents technical documentation of the methods used to map erosion and coastal flood hazards under various future climate scenarios. The climate change-exacerbated coastal hazard modeling considered different scenarios of sea level rise, waves, and existing coastal shoreline protection. The study and model outputs provide most of the hazard identification used in support of the City's vulnerability assessment.

A web mapping application operated in collaboration with The Nature Conservancy provides an interactive visualization tool allowing users to view the projected risks of different scenarios of coastal hazards—such as coastal storm flooding, erosion, tidal inundation, and fluvial flooding—at a variety of spatial and temporal scales, including modeling results for the City (https://maps.coastalresilience.org/California).

Since the Coastal Resilience model was selected by the City to best represent the extent of observed coastal hazards, additional details on the modeling methods and assumptions are described further in Chapter 5, *Vulnerability Methodology*.

2017 Rising Seas in California: An Update on Sea-Level Rise Science

In 2017, OPC commissioned a scientific update on sea level rise to reflect advances in understanding of ice sheetloss and sea level rise projections. *Rising Seas in California: An Update on Sea-Level Rise Science* is a synthesis of the state of the science around sea level rise and identifies several key findings, with the intent of providing guidance in preparing for sea level rise:

- Scientific understanding of sea level rise is advancing at a rapid pace;
- Coastal California is already experiencing early signs of sea level rise, including more extensive flooding during coastal storms and high tides;
- The rate of ice loss from Greenland and Antarctic ice sheets is increasing, which is a primary contributor to sea level rise;
- New evidence has highlighted a potential for extreme sea level rise with up to 10 feet by 2100;
- Probabilities of sea level rise scenarios are identified, and can inform planning decisions;
- Current policy decisions are shaping the coastal future; and
- Adaptation planning should start immediately without waiting for scientific certainty.

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