Appendix D
Climate Stressor Review

AECOM

Climate Stressors Review

Long Beach Climate Action and Adaptation Plan

FINAL | August 27, 2018

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Section 1. Introduction

1.1 Background

The City of Long Beach is completing a climate vulnerability assessment to identify high level vulnerabilities, considering the City's unique geographical, social, and economic characteristics. The vulnerability assessment will inform the development of adaptation strategies that reduce vulnerability and enhance resilience. As a part of the vulnerability assessment process, this memo presents a review of the most relevant climate change stressors for the City of Long Beach based on the scientific literature. This memo is not intended to be an exhaustive literature review, but rather highlight the historic climate trends, climate projections, and potential impacts from the scientific literature that are most applicable to Long Beach in order to inform the exposure component of the vulnerability assessment.

The memo starts with a review of three primary climate change stressors (sea level rise, precipitation, and extreme heat) and two secondary climate change stressors (drought and decreased air quality.) Primary climate change stressors are first-order local conditions that are directly affected by changes in global atmospheric and oceanic temperatures. Secondary climate stressors are conditions affected by complex interactions between primary variables and other factors. The relevance of each stressor to Long Beach is described. Then, historic trends are provided so that future climate projections may be understood in comparison to past variability. Next, climate change projections are provided for mid-century and end-of-century. Lastly, the memo provides a high level overview of potential impacts these stressors could cause based on the literature. These impacts will be further assessed and specified during the vulnerability assessment process.

It should be noted that this memo represents a review of best available science at the time of writing (August 2018). As the science on climate change continues to evolve and new studies are available, this memo may require updating.

1.2 Information Sources

This memo draws on the best available data and climate science and the potential effects for Long Beach and/or the Los Angeles (L.A.) region. Where region-specific studies are not available, California and U.S. studies were reviewed. Regional and state level studies are available through the California Energy Commission's California Climate Change Center. To date, the California Climate Change Center has conducted three assessments, the latest released in July 2012, with a fourth assessment currently underway. The memo also draws on Cal-Adapt, a web-based climate data and information portal produced by the State of California's scientific and research community. The site contains historic data (1950-2013) and projections (2010-2100) from a variety of sources that have downscaled global climate models for more fine-scale resolution. National climate change studies are available through the National Climate Assessment.

1.3 Modeling Climate Change

General Circulation Models (GCM) are a tool used by climate researchers to better understand potential future changes in our global climate. GCMs incorporate the physical processes of the atmosphere, ocean, and land surface to simulate the response of the climate system to changing greenhouse gas (GHG) and sulfate aerosol emissions. These models are based on well-established physical principles and have been demonstrated to reproduce observed features of recent climate and past climate changes.

The science of climate change is continuously being revised as climate models are improved and updated with new data and observations. Such revisions improve our understanding of natural climate variability and the complexity of the global response to atmospheric greenhouse gases.

1.4 Greenhouse Gas Emission Scenarios as Climate Model Inputs

Because the level of future emissions is unknown and will be affected by population, economic development, environmental changes, technology, and policy decisions, the Intergovernmental Panel on Climate Change (IPCC), developed a range of possible future emissions that is used in climate models to provide scientific consistency in climate modeling efforts.

The IPCC's Fifth Assessment Report on Climate Change (AR5), released in 2014, adopted a new set of emissions scenarios referred to as Representative Concentration Pathways (RCP). Relative to previous GHG emission scenarios, RCPs offer an enhanced representation of climate processes, including updates in data and advances in model development. The RCPs represent the change between incoming and outgoing radiation to the atmosphere caused by differences in atmospheric composition. The four RCPs – RCP 2.6, RCP 4.5, RCP 6, and RCP 8.5 – are named after a possible range of radiative forcing in the year 2100 (+2.6, +4.5, +6.0, and +8.5 watts per square meter, respectively). Figure 1 describes each RCP scenario.

RCP8.5	RCP6	RCP4.5	RCP2.6
Describes a world characterized by rapid economic growth. CO_2-equivalent concentrations reach ~1,370 parts per million by the end of the century.	Represents a stabilization scenario. CO_2-equivalent concentrations reach ~850 ppm by the end of the century, followed by stabilization.	Represents a stabilization scenario where CO_2-equivalent concentrations reach ~650 ppm by the end of the century , followed by stabilization.	Signifies a peak and decline scenario where CO_2-equivalent concentrations peak at ~490 ppm by mid-century, followed by rapid GHG emission reduction.

Figure 1: Summary of RCP Scenarios

1.5 Downscaling of Global Circulation Models

GCMs provide estimates of climate change at a global level because the resolution—approximately 200 kilometers (km)—is typically too coarse to provide detailed regional climate projections. Therefore, model outputs are refined through additional analysis or modeling to provide finer regional detail through a process known as "downscaling." Downscaling is the term used to describe methods to generate locally relevant data from GCMs by connecting global-scale projections and regional dynamics (i.e., a 200 km GCM may be downscaled to a 25 km scale for a specific region). Downscaling GCM model output allows for more place-based projections of climate change at the state and local level; however, increased resolution does not necessarily equate to greater accuracy or reliability, as uncertainties remain in all climate projections.

Section 2. Climate Change Stressors

This section describes the relevance of each climate stressor to Long Beach, historical trends, and climate projections. The stressors analyzed include both primary climate stressors (sea level rise, temperature, and precipitation) as well as secondary climate stressors (drought and air quality). Table 1 summarizes the climate projections for Long Beach and/or the L.A. region. Where available, both mid-century and end-of-century projections are provided. More detailed discussion of each climate stressor is provided in the sections that follow.

Table 1: Summary of Climate Projections for Long Beach

	Climate Projections	
Sea Level Rise	Mid-Century • Projection 11.2 ± 3.5 inches • Range 5.0 to 23.9 inches (NRC 2012)[1]	End-of-Century • Projection 36.7 ± 9.8 inches • Range 17.4 to 65.6 inches (NRC 2012)[1]
	• Higher storm tides, more extensive inland flooding, and increased coastal erosion during storm events due to higher sea levels (CNRA 2009)	
Extreme Heat	Mid-Century • +7 to +12 extreme heat[2] days in Long Beach • Avg. temperature + 3 to +4°F in L.A. region (Sun et al. 2015)	End-of-Century • +7 to +33 extreme heat[2] days in Long Beach • Avg. temperature +3 to +8 °F in L.A. region • Avg. temperatures outside of historical (1981-2000) variability, particularly in late summer and early fall (Sun et al. 2015)
	• Heat waves will occur more frequently, be more intense, and longer-lasting (Cayan et al. 2009) More humid heat waves with less cooling at night (Gershunov and Guirguis 2012)	
Precipitation	Mid-Century • +6% to + 11% avg. annual precipitation in Long Beach (Cal-Adapt 2017)	End-of-Century • 1% to +25% avg. annual precipitation in Long Beach (Cal-Adapt 2017)
	• Near-zero change in avg. annual precipitation in L.A. region for both mid and end-of-century, but with large uncertainty. (Berg et al. 2015) • Increase in intensity of precipitation events (CEC 2012; Pagan et al. 2014) • High year-to-year variability in annual precipitation to continue under climate change (Berg et al. 2015; Pierce et al. 2011)	
Drought	• Overall regional drying trend with longer and more frequent droughts (CEC 2012; Pierce et al. 2011) • Higher temperatures leading to higher water demand (Pagan et al 2015) • Reduced snowpack and increased intensity of runoff events in watersheds that supply water to Long Beach (CEC 2012; Pagan et al 2015)	
Air Quality	• Higher temperatures will increase air pollution formation (CNRA 2014) • An increase in wildfire and energy consumption in the region could worsen air quality (CEC 2006) • Higher temperatures, precipitation change, and increasing CO_2 concentrations are expected to increase pollen and some airborne allergens (CNRA 2014; Fann et al. 2016) • Climate change may negatively impact indoor air quality through the growth and spread of pests, infectious agents, and disease vectors (Nazaroff 2013; Fann et al. 2016)	

1. NRC (2012) was considered best available sea level rise science at the initiation of this plan and is therefore referenced in the sea level rise section of this memo. Since this project was initiated, the California Ocean Protection Council (OPC) released new sea level rise guidance that is also considered and summarized in this memo.
2. Sun et al defines extreme heat at 95˚F and above.

2.1 Sea Level Rise, Coastal Flooding, and Shoreline Change

This section discusses sea level rise, which is a primary climate stressor, as well as coastal flooding and shoreline change, which are secondary climate stressors that are the result of complex interactions between sea level, wind, waves, and natural and human-altered landscapes.

The City of Long Beach is located within San Pedro Bay on the Pacific coast. The city shoreline is a combination of a 5.5 mile stretch of sandy beach along with a fortified shoreline within portions of the sheltered embayments and port. Portions of the city lie at a low elevation and have major industry along the water's edge, notably the Port of Long Beach – the second busiest seaport in the United States – as well as transportation, water, and power infrastructure, beaches, marinas, homes, and businesses. Sea level rise will elevate the mean sea level baseline, thereby elevating tides, waves, and storm surge. Even a small increase in sea levels will increase the frequency of coastal storm flooding events. The effects of tides, storm waves, and sea level rise are additive and together combine to cause increased coastal flooding, inundation, and erosion (AOP 2015). Sandy beaches, such as Junipero Beach, Belmont Shore Beach, and Peninsula Beach, will consequently become increasingly susceptible to coastal erosion as sea levels rise (NRC 2012).

2.1.1 Historical Events and Trends

Sea Level Rise

Sea levels have been rising globally since the end of the last Glacial Maximum around 18,000 years ago. Driven primarily by thermal expansion of ocean water and melting land ice, global seas have risen 400-450 feet in this time (Griggs et al 2017). Over the past century, a network of more than 1,750 tide gauges has been gathering data on ocean water levels. Several approaches have been used to analyze these data to calculate an average global sea level rise, yielding rates from about 1.2 mm/year to 1.7 mm/year (approximately 0.05 to 0.07 inches/year) for the 20th century. However, since 1990 this global rate has more than doubled and continues to increase (Griggs et al 2017). Satellite observations show accelerating rates of ice loss from both the Antarctic and Greenland ice sheets, which combined, contain enough water to raise sea levels around 200 feet (Griggs et al 2017).

These rates reflect global mean sea level rise values, but there is tremendous regional variability due to local and regional processes such as vertical land motion, ocean and atmospheric patterns, and other effects. Analysis of approximately 90 years of tide data from 1923 to 2016 at the Los Angeles tide station (#9410660) by NOAA indicates a long-term trend of historic mean sea-level rise of approximately 0.96 mm/yr (0.04 +/-0.01 inches/year) (NOAA 2017).

Coastal Flooding

Prior to the construction of the Port of Long Beach in 1911, the City of Long Beach shoreline was composed of extensive mudflats, barrier islands, estuaries, and sand spits (Griggs et al 2005; Hapke et al 2006). The region is part of the San Pedro Littoral Cell, which is bordered by Palos Verdes to the northwest and Newport Canyon to the southeast. Historically, the Los Angeles and San Gabriel Rivers supplied the shoreline with sand and longshore transport was generally to the southeast with sand transported offshore into Newport Canyon. Palos Verdes provided some protection from winter storm waves approaching from the northwest making the area suited to development and a port.

Extensive development of the area and shoreline has significantly altered coastal processes, which is important to consider when identifying existing and future climate risks. The last of three large breakwaters was constructed in 1942, such that the majority of the Port and Long Beach shoreline is sheltered from waves. The area is still vulnerable to storms and waves, particularly when they approach the coast from a more westerly or southerly direction (as opposed to the typical northwest winter storm waves).

Waves approaching from these directions can damage the breakwaters and propagate between gaps in the breakwaters that are used for navigation. These storms can be especially damaging during El Niño conditions, which can raise coastal sea levels 10 - 30 cm (0.33 - 0.95 ft) during the winter months (NRC 2012) and when the typical winter storm track shifts to the southwest. Multiple storms damaged the breakwaters and caused flooding and damage at the shoreline during the 1982-1983 El Niño winter. The breakwaters were again damaged when a southeaster struck the coast in January 1988. Historically, the most costly storm to impact the southern California coast is the 1939 southerly tropical storm, causing today's equivalent of $34.1 million of damage and the only tropical storm in California's history to make landfall (WRCC 2008; WRH 2010). The storm caused massive flooding in the low-lying areas of Long Beach (then unprotected by the breakwaters), damaging homes, and scattering large amounts of trash and debris along the beach (WRH 2010). Recently, Hurricane Marie produced waves of up to 20 feet causing extensive flooding in southeastern Long Beach in late August 2014, and causing an estimated $20 million in damages across southern California (Zelinsky & Pasch 2015). The waves significantly damaged a section of the Middle Breakwater leading to further damage within the Port of Long Beach from wave action (CLB Staff Survey 2017). While this storm did not make direct landfall in southern California, the size, period, and extreme southern angle of the waves made the event particularly damaging.

Figure 2: Port of Long Beach Damage from Hurricane Marie in 2014

Several inland locations within Alamitos Bay are protected from large storm waves but are flooded during high tides, particularly King Tides, which are the highest tides of the year. According to City staff, locations with recurrent King Tide flooding include Bay Shore Avenue, Colorado Lagoon, the Peninsula, and Alamitos Bay (Figure 3). According to a coastal flooding study by Strauss et al (2016), there were only 32 flood days between 1955-1984 compared to 133 flood days between 1985-2014 in La Jolla, California, the nearest location to Long Beach in the study. These additional flood days are largely attributed by the authors to anthropogenic climate change.

Marine Stadium

Naples Island

Alamitos Bay

Peninsula

Figure 3: Examples of King Tide Flooding

Shoreline Change

Human development also significantly altered natural shoreline change patterns. This is important to consider as the wide sandy beaches along much of Long Beach can partially function as a buffer against future sea level rise. The channelization of the Los Angeles and San Gabriel Rivers significantly reduced the natural sediment supply to the Long Beach shoreline. Despite this, much of the sandy beach has accreted over the 20th century due to the breakwaters limiting wave-induced erosion, a system of sand retention structures including groins and jetties, and several ongoing beach nourishment and sand bypassing projects (Figure 4). Figure 2 shows historical shorelines derived from NOAA T-Sheets, historical photographs, and airborne topographic LiDAR data and illustrates the overall accretion trend. Long-term accretion rates range between +0.5 to 1.5 meters/year in much of the area resulting in a relatively wide, flat sandy beach (Hapke et al 2006). Although much of the sandy shoreline is currently accreting and will provide some protection against future sea level rise, historical shoreline trends may not be indicative of future shoreline change because the existing coastal processes, both natural and anthropogenic, may change and could be overwhelmed by more extreme future sea level rise.

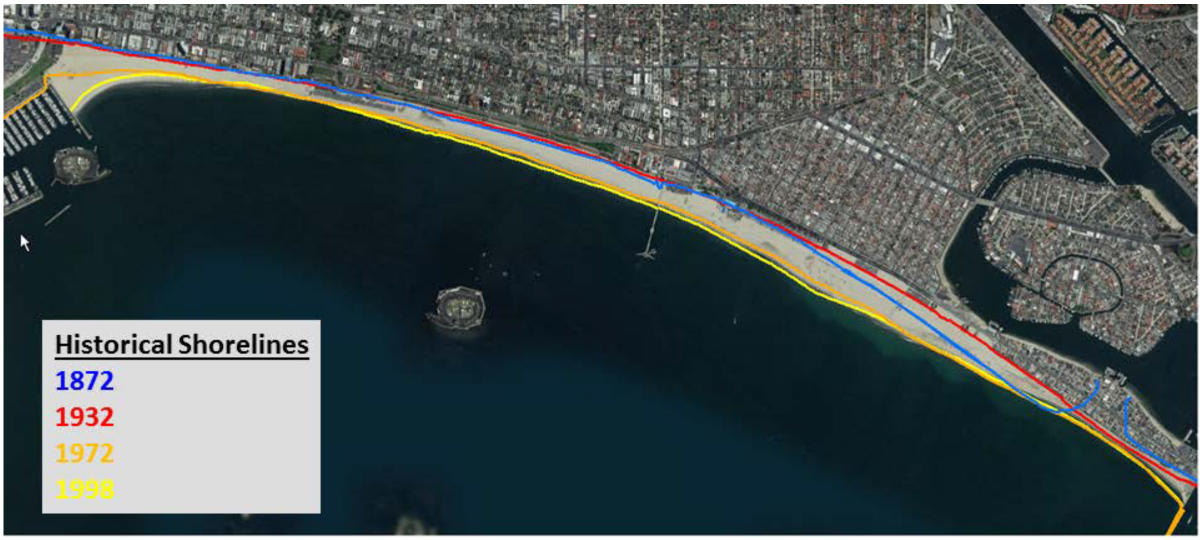

Figure 4: Historical Sandy Beach Shorelines in Long Beach
Notes: Historical high water line shorelines (1872, 1932, and 1972) are compared to a historical mean high water line (1998) and show historical accretion along the beach during the 20th century.
Source: Hapke et al (2006) – (https://pubs.usgs.gov/of/2006/1251/#data/)

The current breakwater and jetty configuration has left the southeastern tip of the Peninsula exposed to erosion, and several homes are threatened. This area is not adequately protected by the Long Beach Breakwater and waves attack the sandy beach from the south. The jetty at the San Gabriel river mouth inhibits northwest sand transport to naturally replenish this area. The City maintains a sandy beach here by bypassing sand from the accreting northwestern shoreline to the eroding southeastern shoreline (AOP 2015). In the winter and during large south swell events, an emergency sand berm is built to protect the homes from flooding.

Long Beach, once known as the "Sinking City," has a history of subsidence primarily from oil and gas extraction from the Wilmington Oil Field. A subsidence bowl, centered around the Port of Long Beach, reached a depth of 29 feet before measures were taken to arrest the subsidence. Over 20 square miles of land adjacent to the shoreline from the Port of Long Beach to Seal Beach are affected by subsidence. Constant monitoring and control is still required by Long Beach Energy Resources Department to maintain stability and will continue to be so into the future (CLB 2017). The lowered land elevation from subsidence increases the City of Long Beach's vulnerability to storm flooding, sea level rise, and coastal erosion.

2.1.2 Future Projections

Sea Level Rise

Future sea level rise is expected to vary regionally due to differences in atmospheric and oceanographic process and vertical land motion. Various methods have been used to predict both future global sea level rise and regional sea level rise at numerous locations around the world. Up until 2018, the state of California utilized the National Research Council (NRC) 2012 sea level rise projections as best available science in state policy and guidance. In 2017, a new study was released by Griggs et al (2017) with updated modeled projections along the California coastline. This study informed the development of Ocean Protection Council's (OPC) new sea level rise guidance document that was adopted in March 2018. The OPC is currently reviewing the new guidance document with stakeholders and state agencies to develop an approach to administer the new guidance. Since the Long Beach Climate Action and Adaptation Plan was initiated prior to adoption of the OPC (2018) guidance, NRC (2012) projections were adopted to inform the vulnerability assessment; however, for completeness, both studies are summarized and compared in this section.

NRC (2012) used multiple global climate models with different global emissions scenarios to develop regional future sea level rise projections for the Los Angeles area and three other locations along the west coast. The study produced a projection, reflective of an average of the models, and a range of the model projections for three future years: 2030, 2050, and 2100. Generally, regional sea levels in the Los Angeles area are projected to increase at slightly higher rates than global sea levels. Table 2 summarizes the NRC projections for the Los Angeles area while also providing a comparison with mean global sea level rise projections. The NRC projections for the years 2030, 2050, and 2100 are 6, 11, and 37 inches respectively.

Table 2: Mean Regional vs Global Sea Level Rise Projections Relative to the Year 2000

Year	Southern California		Global	
	Projection	Range	Projection	Range
2030	5.8 ± 2.0 in	4.6 – 11.8 in	5.3 ± 0.7 in	3.3 – 9.1 in
2050	11.2 ± 3.5 in	5.0 – 23.9 in	11.0 ± 1.3 in	6.9 – 19.0 in
2100	36.7 ± 9.8 in	17.4 – 65.6 in	32.6 ± 4.2 in	19.8 – 55.2 in

Source: NRC (2012)

Note: The low value of the range for each year was computed by subtracting twice the standard deviation from the mean in the projection column, and adjusting to the difference between emission scenarios A1B and B1. The high value of the range was computed by adding twice the standard deviation to the mean, adjusting to the difference between emission scenarios A1FI and A1B, and adding the dynamical imbalance contribution (NRC 2012). Please refer to IPCC (2000) for more information on the emission scenarios.

Griggs et al (2017) completed an update to California's sea level rise science that informed the OPC's 2018 guidance document. Future sea level rise projections were developed at each tide station along the California coast. Table 3 presents sea level rise projections for Los Angeles, California. The study incorporated a range of global emissions scenarios ranging from aggressive emissions reductions (RCP 2.6) to no emissions reductions (RCP 8.5) through end of century. Multiple climate models for each global emissions scenario were evaluated to generate a range of future sea level rise predictions using a probabilistic approach. The advantage to this approach is it provides more detailed projections for asset managers to make risk-based decisions for sea level rise planning and design.

Table 3: Sea Level Rise Projections at Los Angeles, CA

Year (Emissions Scenario)	Inches Above 1991-2009 Mean Sea Level (in)			
	Median (50% probability of exceedance)	Likely Range (67% percent likely range)	1-In-20 Chance (5% probability of exceedance)	1-In-200 Chance (0.5% probability of exceedance)
2030	4	2 to 6	7	8
2050	8	6 to 12	14	22
2100 (RCP 2.6)	16	8 to 25	36	65
2100 (RCP 8.5)	26	16 to 38	49	80

Source: OPC (2018)

The NRC (2012) and OPC (2018) reports show similar regional sea level rise projections for comparable global emissions scenarios. The mid-range NRC (2012) projections for 2030, 2050, and 2100 are close to the OPC median projections. The high-range NRC projections for 2030 and 2050 are also comparable to the 0.5% exceedance OPC values; however, the OPC 0.5% exceedance projections for 2100 exceed the NRC high-range projection. The high-range OPC projection is 80 inches compared with 66 inches for NRC; however, the 66-inch value falls within the range of high-end projections for OPC (65 to 80 inches).

Coastal Flooding

In the next phase of the vulnerability assessment, SLR scenarios will be selected for further identification of asset-specific vulnerabilities. For illustrative purposes only, Figure 5 shows the areas in Long Beach that may be flooded during a 100-year tide event (i.e., the expected water level including astronomical tides, storm surge, and El Niño effects, but no wave effects) with one meter (39 inches) of sea level rise. This sea level rise projection is approximately equal to the mid-range NRC and OPC projections for 2100 and has a roughly 20% chance of being met or exceeded by 2100 under a high emissions scenario (RCP 8.5) according to OPC (2018). The figure illustrates a "bathtub" type analysis, where the floodwaters are simply projected inland to where ground elevations exceed the future 100-year flood level. The projected extent of inundation indicates the portions of Long Beach most susceptible to flooding impacts under a likely end-of-century sea level rise scenario.

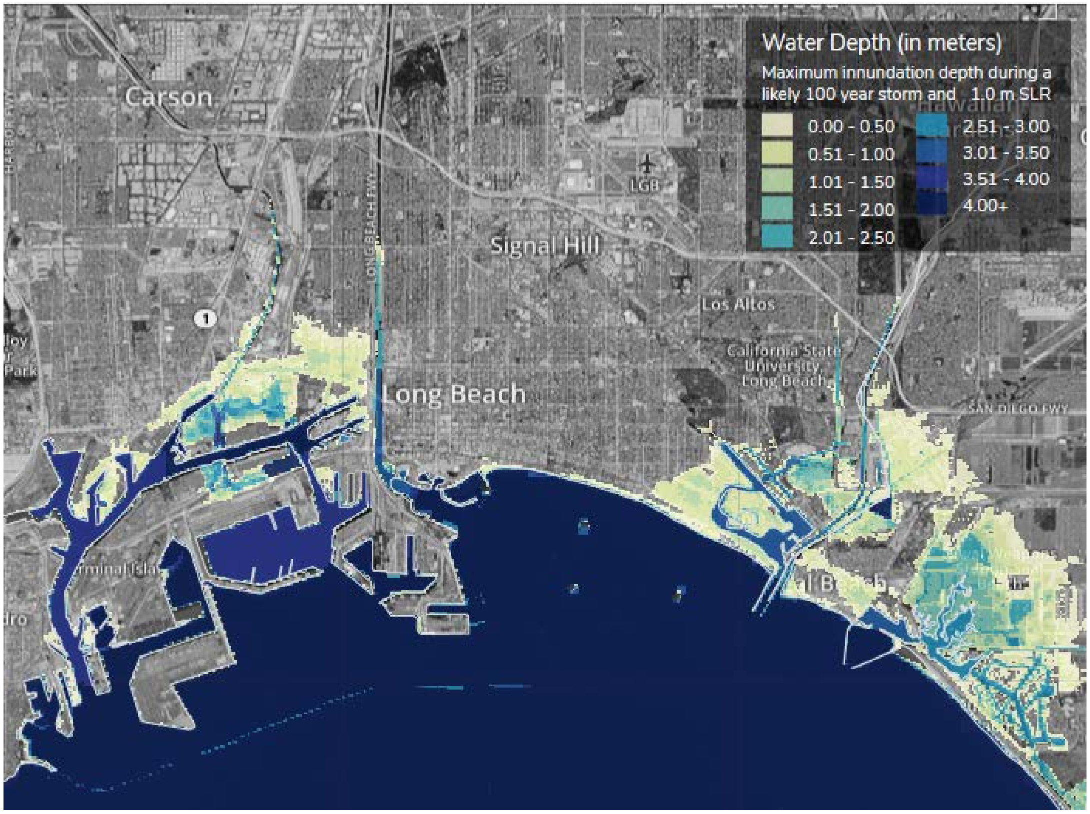

Figure 5: Projected Flooding During 100-year Tide Event with 1-meter Sea Level Rise

Source: NOAA

Rising seas and the associated increase in coastal flooding from waves, storm surge, and tides, potentially coupled with more intense coastal storms will increase the rate of coastal erosion and alter sediment transport patterns in the region (CNRA 2009). CoSMoS, a coastal storm modeling system created by the United States Geological Survey (USGS), is another source of future wave runup, sea level rise, and shoreline change modeling data. The USGS has conducted shoreline change modeling using CoSMoS for multiple future shoreline management scenarios, ranging from no beach nourishments and retreat from the shoreline to systematic beach nourishments and no retreat from the coast. As an example, Figure 6 displays the CoSMoS projected future shoreline change for multiple sea level rise scenarios assuming no future nourishments and a retreat from the shoreline. The figure illustrates that the entire beach will generally erode and that erosion will generally increase with higher amounts of sea level rise. In particular, the homes at the southeast tip of the peninsula and the facilities, parking lot, and park at Junipero Beach could be threatened under higher sea level rise scenarios.

Figure 6: Projected Shoreline Change due to Multiple Sea Level Rise Scenarios Assuming no Future Beach Nourishments
Source: USGS CoSMoS (https://www.sciencebase.gov/catalog/item/57f1d4f3e4b0bc0bebfee139)

Among scientists, there is general consensus that climate change will affect the intensity, frequency, and paths of coastal storms. However, there is yet to be a clear consensus on what the nature of these changes will be in the North Pacific Ocean (NRC 2012). “Storminess” is an overarching term used by the NRC to include physical processes such as frequency and intensity of storms, shifts in storm tracks, magnitude of storm surges, and changes in wind speed and wave height. Evidence of observed changes in storminess in the 20th century historical record as well as future modeled projections have been found by researchers, but the interpretation of these results is difficult due to natural climate variability. Further research is needed to determine the validity and relevance of these storminess projections, particularly for the southern California shoreline.

2.2 Extreme Heat

While trends in average annual temperature are an important indicator of climate change, extreme temperature events have greater impacts on communities. Although Long Beach’s climate is greatly influenced by its coastal geography, which leads to cooler temperatures compared to inland and valley locations, extreme heat is still a major threat to human health. In addition, due to normally mild temperatures, Long Beach residents may be less prepared for heat waves than other places. Furthermore, as a highly urbanized area with lots of impermeable surfaces (e.g., pavements, roofs), Long Beach is susceptible to the urban heat island effect, which makes air temperatures even hotter.

2.2.1 Historical Events and Trends

According to data from Cal Adapt, from 1950 to 2013, Long Beach experienced an average of 3.3 extreme heat days per year, but with considerable inter-annual variability, as depicted in Figure 7 (Livenh et al. 2015).

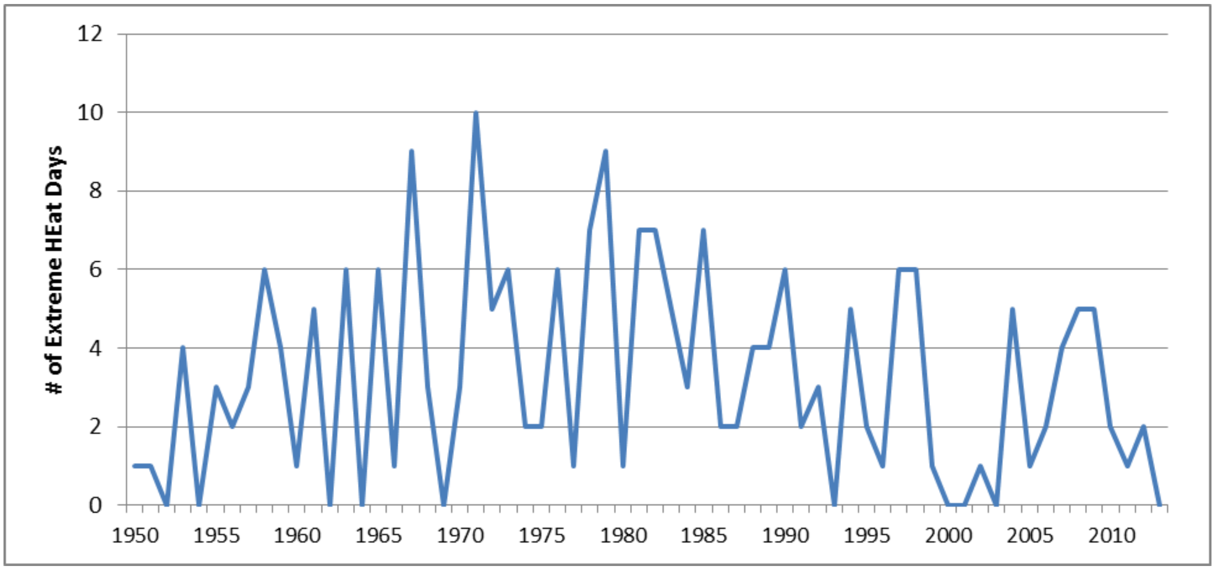

Figure 7: Number of Extreme Heat Days per Year, 1950-2013
Source: Livenh et al. 2015, via CalAdapt

Heatwaves are the tendency for multiple hot days in succession. In Long Beach, and California more broadly, heat waves have historically been dry (low humidity) and as a result, the temperature is high during the day, but cools off at night. However, since the 1980s, there has been an observed trend towards more humid, more intense, and longer lasting heat waves in California. Due to the increased humidity, heat waves have become more accentuated at night, meaning nighttime temperatures do not cool off (Gurshunov et al. 2009). Figure 8 below shows heat wave activity in California since 1950. The red line is based on maximum (daytime) temperature and the blue line is based on minimum (nighttime) temperatures. High nighttime temperatures limit the ability of people to cool down and recover, adding to the risk of illness and fatalities (CDPH 2012).

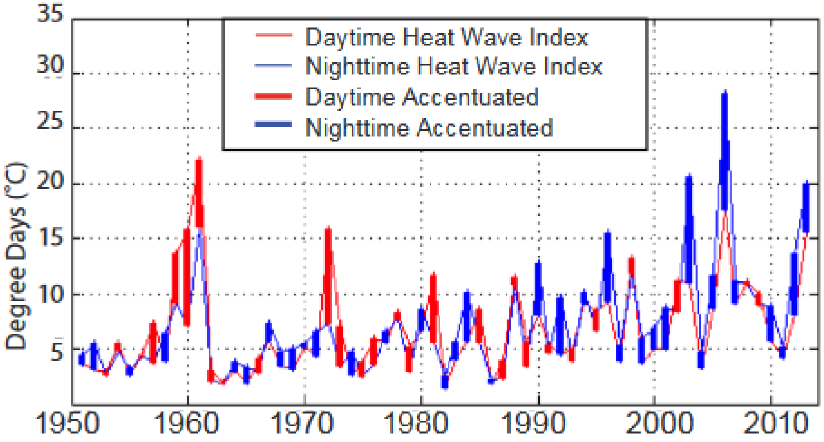

Figure 8: Daytime and Nighttime Accentuated Heat Waves
Source: California-Nevada Climate Application Program, 2015. “California Heat Waves”

In 2006, California experienced a heat wave that was particularly intense and long-lasting. Los Angeles County recorded its highest ever temperature at 119°F and high temperatures lasted for almost two weeks. Humidity levels in California were also unusually high during that event (Gurshunov et al. 2009). Approximately 163 deaths in Los Angeles County were attributed to the heat wave (Ostro et al. 2009). The increase in power demand also led to outages that affected more than 1 million households in Southern California (Barboza 2010b).

In July 2015, high temperatures may have been a factor in equipment failures that caused two powers outages in downtown Long Beach that left thousands of residents and businesses without power for days. The power outage stranded people without medical devices, refrigeration, air conditioning or elevator service during a period of high temperatures. This was particularly challenging for seniors living in high-rise apartments (KPCC 2015).

The urban heat island effect also contributes to extreme heat conditions in Long Beach. The urban heat island refers to the phenomenon that urban areas are often warmer than nearby rural areas due to the abundance of impervious and dark colored surfaces that absorb sunlight and release it back into the environment as heat. A study that modeled how urbanization in Los Angeles and San Diego Metropolitan areas contributes to warming found that averaged over the region during the month of July, urbanization increases the daytime (2pm) near-surface air temperature by 1.3°C (2.3°F) and nighttime air temperature by 3.1 °C (5.6 °F) (Vahmani et al. 2016). Urbanization results in even greater surface temperature warming at night with an increase of 6.1 °C (11.0 °F). The nighttime warming of air and surface temperatures are due to man-made materials, such as concrete, that absorb energy during the day and release it at night.

The most intense urban heat island effects are often seen in neighborhoods where dense land use and impervious, paved surfaces predominate and trees and vegetation are less common. Access to the cooling effects of urban greening and open space is often most limited for low-income urban communities (CDPH 2012). A Tree Canopy study conducted by Loyola Marymount University found a statistically significant relationship between high surface temperatures and minimal tree canopy in coastal Los Angeles County. As illustrated in Figure 7, higher surface temperatures tend to be found in Central, West, and North Long Beach, which are also areas with less tree canopy (LMU 2015). The amount of green space varies greatly across different parts of Long Beach. East and Southeast (coastal) Long Beach has significantly more green space per person while North and West parts of Long Beach have significantly less (CLB 2013). Green space not only influences temperatures, but also air quality, which is discussed in the next section.

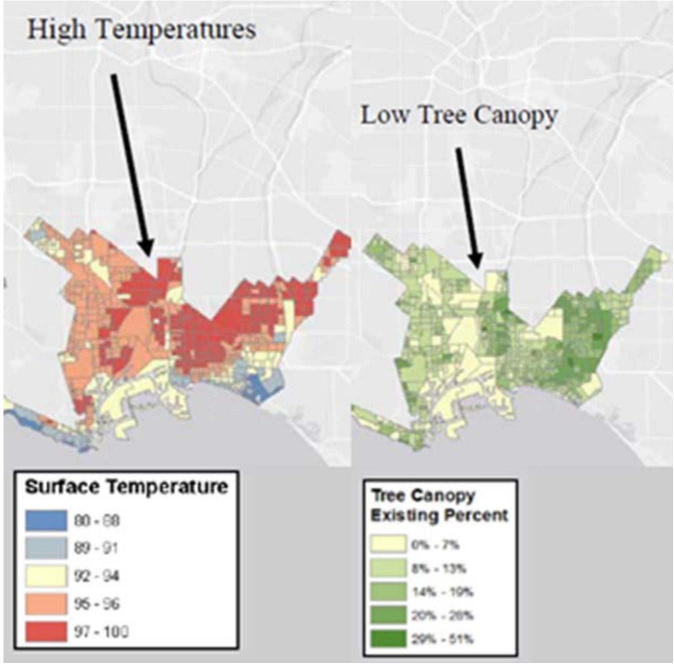

Figure 9: Surface Temperature and Tree Canopy in Coastal Los Angeles County
Source: Loyola Marymount University Tree Canopy Study

2.2.2 Future projections

The number of extreme heat days (over 95 °F) in Long Beach per year is projected to increase from an average of four in the baseline period (1980-2000) to 11-16 days by mid-century and 11-37 by end-of century, depending on the emissions scenario (Sun et al. 2015). Projections for extreme heat days (over 95.8 °F) from Cal Adapt, which draw from Pierce et al. 2015, are slightly lower: six-eight extreme heat days by mid-century; nine-20 extreme heat days by end-of-century in Long Beach, depending on the emissions scenario. As demonstrated in Figure 10, as a coastal city, Long Beach will not experience an increase in extreme heat days as severe as inland and valley locations in the region. Despite this, it is important to note that Long Beach might be more vulnerable to extreme heat than other coastal cities in the Los Angeles area. Coastal cities in this region are typically cooled by onshore winds, which blow from west to east. The Long Beach shoreline generally faces southward and Palos Verdes to the west can block some of the cooling onshore winds. Figure 10 illustrates that Long Beach is significantly warmer than Santa Monica, which is a coastal city with a more typical westward-facing shoreline.

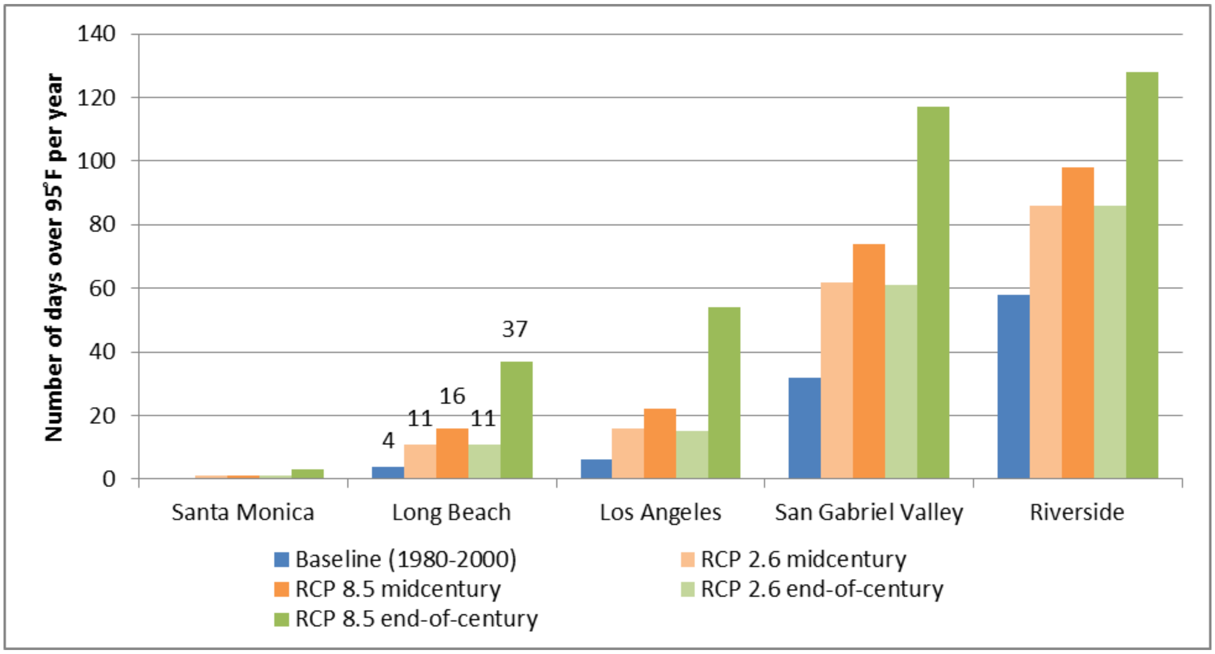

Figure 10: Average Number of Extreme Heat Days in Long Beach and around the LA Region
Source: Sun et al. 2015

Heat waves will not only occur more frequently, but will also be more intense and long-lasting due to climate change (Cayan et al. 2009). The occurrence of heat waves having durations of five days or longer will become more frequent (20 times more frequent in some simulations) by end-of century (Cayan et al. 2009). Relative to baseline local conditions, heat waves are expected to become more extreme along the coast relative to other parts of the state (Gershunov and Guirguis 2012). This has health implications as people living near the coast may be less prepared and acclimatized to extreme heat than others.

Towards end-of-century, extreme heat days will be particularly frequent and intense in late summer and into fall (Sun et al 2015; Pierce et al. 2015). The extended duration of when extreme heat events could occur has a variety of planning implications, including cooling energy demand and emergency response readiness.

2.3 Precipitation

Changing precipitation patterns in response to climate change is a primary climate stressor. Long Beach lies within a semi-arid region consistent with a Mediterranean climatic pattern of dry summers and wet winters (CEC 2012). Precipitation patterns, including quantity, frequency, and distribution, affect both water supply and flooding from runoff during storm events.

Precipitation can generate flooding in two distinct ways. *Riverine flooding* occurs during extreme, regional rainfall events as rivers, creeks, and channels discharge excess water from an entire watershed. The Los Angeles and San Gabriel rivers drain much of the Los Angeles Basin and discharge into San Pedro Bay. This type of flooding could impact the City of Long Beach if high flows overtop and/or comprise the levees bordering these rivers. Precipitation can also generate localized *urban flooding* during high rainfall events if the City's local stormwater collection system is overwhelmed and cannot drain the excess stormwater. This type of flooding tends to be localized near storm drains and other stormwater collection system components.

Sea level rise can exacerbate localized, precipitation based flooding in a number of ways. The stormwater system in Long Beach is designed to convey stormwater away from developed areas into adjacent water bodies such as Alamitos Bay and San Pedro Bay. The vulnerability of the system to sea level rise and storm events depends on the system's current storage and flow capacity, the elevation and location of the outfalls, and whether they are gravity drained or pumped. In general, stormwater pumping systems rely on uninterrupted power and many of the components are sensitive to water and salt exposure. The capacity to collect, convey, and discharge flows to the bay will be reduced by higher sea levels. Outfalls that are below future high tide or increased storm water levels may need to be elevated, have check valves installed to prevent backflow, or be pumped rather than gravity drained. Reduced discharge capacity and/or failures of pump stations could cause flooding of adjacent properties and disrupt access to homes, jobs, and recreation areas, leading to potentially significant consequences.

Without action, SLR poses the following threats to the stormwater system and adjacent areas:

- **Urban flooding.** The majority of the Long Beach stormwater system is gravity driven. Excess stormwater flows from higher elevations, including Belmont Heights, until reaching the bay. As low-lying stormwater outfalls become partially or completely inundated by rising water levels, drainage of stormwater can be impeded, resulting in inland urban flooding during storms. Difficulties draining stormwater can cause road closures, impede access to facilities, and damage private and public property.
- **Saltwater intrusion into the stormwater system.** During large tide and storm events, saltwater may enter the stormwater system through open outfalls, leaky tide gates, overflow weirs, and through catch basins located in areas where coastal waters have overtopped the shoreline. Backflow of high tides into the stormwater system may cause surface flooding in low-lying areas that sit at elevations below the hydraulic grade line, even if shoreline protection systems are high enough to prevent overland coastal flooding. Saltwater may also cause premature corrosion of pipes and equipment in the system.
- **Elevated groundwater levels.** As sea levels rise, so will groundwater levels. SLR causes saline water to intrude into underground reservoirs, raising the historical groundwater elevation ranges beyond what the Long Beach utilities were planned and built to accommodate.

2.3.1 Historical Events and Trends

Average annual precipitation recorded near Long Beach between 1950 and 2013 was 12.3 inches (Pierce et al. 2014). Seasonal averages ranged from 0.02 inches in July to 3.0 inches in February. Between 1970 and 2000, the Long Beach Airport experienced an average of 36 days per year with measurable precipitation (NCDC 2004). Increased variability in annual precipitation is already becoming apparent with both the driest and wettest years on record having occurred in the last decade in the Los Angeles region (DWR 2008).

Storm frequency and intensity in Southern California have increased, consistent with statewide and national trends. Between 1948 and 2011, the frequency of extreme downpours increased by 35 percent in California south of the San Francisco Bay (Madsen and Wilson 2012). Consequently, an intense storm that formerly occurred in the region only once per year now occurs every nine months on average. During the same period, Southern California experienced a seven-percent increase in the amount of precipitation per storm. Increases in extreme precipitation events are likely caused by warmer storms and atmospheric rivers over the Pacific carrying large amounts of moisture to the California coast through winter storms (CEC 2012).

Historic flood events include major storms in March 1938, February 1941, and January 1956, which resulted in flooding along the San Gabriel River (LHMP 2004). There has not been recent flooding along the San Gabriel

River due to channelization and flood control projects. In 1968, a high intensity rainfall coincided with high tide, causing flooding in Belmont Shore, Pacific Coast Highway near Pacific Avenue and the intersection of Orange and Wardlow Road (LHMP 2004).

A storm in January 2010, which was an El Niño year, overwhelmed the drainage system and caused flooding of residential neighborhoods and streets near Wilson High School, flooding of the 710 freeway, and the CSULB Student Union building (Barboza 2010). City staff report that flooding issues often relate to storm drain maintenance (for example, keeping storm drains clear of debris). According to a staff survey, the West Industrial Area suffered property losses due to flooding prior to installing a new storm drain system in 2012 (CLB Staff Survey 2017).

Most recently, the winter storms of 2017 caused street flooding, park flooding, beach closures, water quality issues, downed trees, and closure of the Main Library auditorium. Individuals experiencing homelessness were highly exposed to health hazards during this time (CLB Staff Survey 2017).

2.3.2 Future Projections

There is considerable uncertainty regarding the effects of climate change on precipitation and there is no general consensus among future precipitation models for Long Beach. Research conducted for California's Third Climate Change Assessment projects a considerably drier climate in southern California by the mid-to-late century (CEC 2012) as a result of decreased precipitation, earlier snowmelt, and increased temperatures. A study that examined downscaled outputs of 16 GCMs predict that the total amount of precipitation along the Southern California coast will decline by an average of nine percent by mid-century (2060-2069) compared to a 1985-1994 baseline (Pierce et al 2011). Berg et al (2015) reports a near-zero change in average annual precipitation in the L.A. area for both mid-century and end-of-century projections. Pagan et al (2015) reports a large variation in total annual precipitation projections depending on the model. Cal-Adapt, which provides an average of several climate model calculations, projects a six to 11 percent increase in precipitation by mid-century and a one to 25 percent increase in precipitation by end-of-century for Long Beach (Cal-Adapt 2017). This range spans low (RCP 4.5) to high (RCP 8.5) emissions scenarios.

Regardless of average annual precipitation estimates increasing or decreasing, precipitation events are projected to increase in intensity, decrease in frequency, and be concentrated during the winter months (Pagan et al 2015). The total number of days with rainfall per year is expected to decline by 13 percent on Southern California's coast by the 2060s (Pierce et al 2011), therefore concentrating the annual precipitation into fewer rainfall events leading to greater runoff and other such impacts.

2.4 Drought

Drought is a secondary climate stressor that is driven by both climate conditions and social and economic stressors. This discussion focuses on the climate-related stressors of precipitation and temperature patterns. Drought is particularly relevant as the City of Long Beach lies within a semi-arid climatic region that is already heavily dependent on imported water to meet local demand (Pagan et al 2015). As of 2015, 39 percent of the water supply is from imported sources, 54 percent from groundwater, which is also partially dependent on imported sources for recharge, and 7 percent is recycled (Pagan el al 2015). Regionally, the City of Long Beach is largely dependent on water imports from the Colorado River and Sierra Nevada watersheds for both reservoir storage and groundwater recharge; therefore, drought in the City of Long Beach is closely tied to drought and precipitation patterns in these watersheds (Pagan et al 2015).

2.4.1 Historical Data and Trends

A study of historic drought using tree ring data going back 1,200 years concluded that three-year droughts are not unusual in California and can occur with as little as a single year between events. Over the last 1,200 years, it was estimated that there were 37 occurrences of three-year droughts and 66 dry periods lasting between three and nine years (where a dry period is defined as being below the years' 800 – 2014 mean precipitation levels). Although periodic drought is normal for Southern California, 2014 was estimated to be the worst single drought year of the last 1,200 years in California (Griffin et al 2014). The recent 2011-2015 drought led the Metropolitan Water District of Southern California (MWDSC) to enter into shortage conditions and enact the Water Supply Allocation Plan, which more closely manages supply and demand (Pagan et al 2015).

2.4.2 Future Projections

Climate change, through its impacts on precipitation and temperature, is predicted to increase the severity and length of future droughts (CEC 2012). By the end of the century, all climatic models included in the California Climate Change Center's Third Assessment predict regional drying, primarily from decreased precipitation and compounded by warming (CEC 2012).

Both annual precipitation quantity and distribution affect aridity and drought. When total annual precipitation is concentrated into fewer events, reservoirs exceed their capacity and the ground becomes saturated, limiting groundwater recharge. Consequently, less water is retained within the watershed and more is lost to stormwater runoff than would be when annual precipitation is more evenly distributed throughout the year. Although average annual precipitation has for now remained relatively stable in the region, climate models project moderate annual precipitation increases as well as increased seasonal variability and intensity of precipitation events by the 2060s (Pierce et al 2011).

Temperature is the second significant driver of drought as higher temperatures increase snow melt, soil evaporation, and evapotranspiration, leading to drier soils and vegetation. Average annual temperatures in the Los Angeles region are projected to increase 3–4°F in the L.A. region by mid-century (Sun et al 2015).

As mentioned above, changes in climate in the Sierra Nevada and Colorado River Basin may have significant implications for water supply in Long Beach. One study predicts increased frequency of critically dry years in the Sierra Nevada watershed (CEC 2012). However, projections of climate change suggest that even if total precipitation does not change significantly, predicted warming will both reduce the amount of snowpack in these regions and increase the intensity and frequency of runoff and precipitation events (Pagan et al 2015). Intense precipitation events in these watersheds produce quantities of water in a short time frame that exceed the storage capacity of the reservoirs while reduced snowpack decreases the availability of the gradually released meltwaters throughout the drier summer months. In other words, the water from these critical supply areas is predicted to become less available to the City of Long Beach by mid-century (Pagan et al 2015). Even if precipitation does not decline overall in the region, the models still show drying based on the impacts of warming alone, including increased soil evaporation in the summer months and earlier snow melt in the Sierra Nevada, a major municipal water source (CEC 2012). Additionally, water rights allocations for the Colorado River Basin were based on a time period of unusually wet years. The State of California only holds surplus rights and the majority of this water goes to agriculture (MWDSC 2010). Reservoir levels along the Colorado River are expected to diminish up to 30% by 2050 (Barnett et al 2004) and as populations in Southern California expand, the municipalities will experience increased demand for a decreasing water supply.

2.5 Air Quality

Air quality is driven by emissions and climate factors. Emissions can come from vehicles, industries, power plants, and wildfires. Climatic factors that influence air quality include temperature, precipitation and wind. Other factors that contribute to poor air quality in Long Beach, and the region overall, include topography, intense traffic, and the urban heat island effect (AOP 2015). Air quality is especially relevant as a secondary climate stressor in Long Beach as there are several sources that impact local air quality, including the 710 and 405 freeways, refineries, the Port of Long Beach, and major industrial sources (AOP 2015) and thousands of people whose health may be impacted by poor air quality. People who are especially sensitive to poor air quality include the young, elderly, those who have existing respiratory conditions, and those who work outside.

2.5.1 Historical Events and Trends

Ozone and particulate matter (PM) are two air pollutants that pose a significant threat to human health. Ground level ozone, often called smog, forms when volatile organic compounds (VOCs) and nitrogen oxides (NOx) react in sunlight. These pollutants come from vehicles, industries, power plants, and products like paints and solvents. PM is a mixture of solids and liquid droplets floating in the air. They can be emitted directly from vehicles, power plants, industries, and wildfires, but most particles form in the atmosphere as a result of complex reaction of chemicals. Fine particles (PM 2.5) are particularly harmful to human health as they can penetrate deep into the lungs and even into the bloodstream.

Data reported in the AOP (2015) study show a recent downward trend in air pollution in the region. In the Los Angeles-Long Beach-Santa Ana region, there has been a downward trend in ozone pollution since early 2000s, but there were still 67 days when ozone levels were unhealthy for sensitive groups in 2014 (AOP 2015). The South Coast Basin is designated an extreme non-attainment zone for the federal ozone standard. The EPA recognizes that California has unique challenges in addressing ozone pollution because of its topography, wildfires, and transportation and freight movement. As a result, the South Coast Air Basin is not required to meet 2008 federal standards until 2032 (EPA 2015).

Days that violate air quality standards in Los Angeles County tend to occur in the summer months when temperatures are higher (CLB 2013). This is because heat can increase the formation of air pollution, such as ozone. In addition, high temperatures are also associated with weak winds and atmospheric stagnation which can cause air pollution to build up. Due to wind patterns and topography, Long Beach does not experience as much ozone pollution as other parts of the region, particularly compared to inland areas (AOP 2015). From 2014 to 2016, Long Beach had only 1 day in violation of the federal 2015 standard for 8 hour-concentration of ozone (CARB 2017).

There has also been a downward trend in PM pollution since 2000 in the Los Angeles-Long Beach-Santa Ana region, but there were still 16 days in 2014 when PM2.5 reached unhealthy levels for sensitive groups (AOP 2015). During the past decade, Central Long Beach experienced a 35% decrease in PM2.5; however, the annual average is still above the California clean air standard (Meijgaard 2012). Table 4 below shows the number of days above federal PM2.5 standards for three monitoring stations in Long Beach.

Table 4: Number of Days Where PM2.5 Exceeds Federal Standards

Monitoring Station	Site Number	Address	2014	2015	2016
North Long Beach	70072	3648 N. Long Beach Blvd	2	3	0
Long Beach-Route 710 Near Road	70032	5895 Long Beach Blvd	0	7	0
South Long Beach	70110	1305 E. Pacific Coast HWY	2	4	0

Source: California Air Resources Board, 2017

Air toxics are pollutants that cause cancer or other serious health effects. Diesel PM accounts for 68.2% of the carcinogenic risk from exposure to air toxics in the Southern California air basin (SCAQMD 2015). Diesel PM is emitted from diesel engines including trucks, buses, cars, ships, and locomotive engines and is concentrated near ports, rail yards, and freeways. Exposure to diesel PM has been shown to have numerous adverse health effects, including cardiovascular and pulmonary disease and lung cancer (EPA 2016). As illustrated in Figure 11, the areas of the Los Angeles Basin that are exposed to the most risk to air toxics are those near the Ports of Los Angeles and Long Beach (SCAQMD 2015). According to the AOP (2015) study, 86 out of 116 census tracts in the City of Long Beach have diesel PM emissions in the top 10% of census tracts in California.

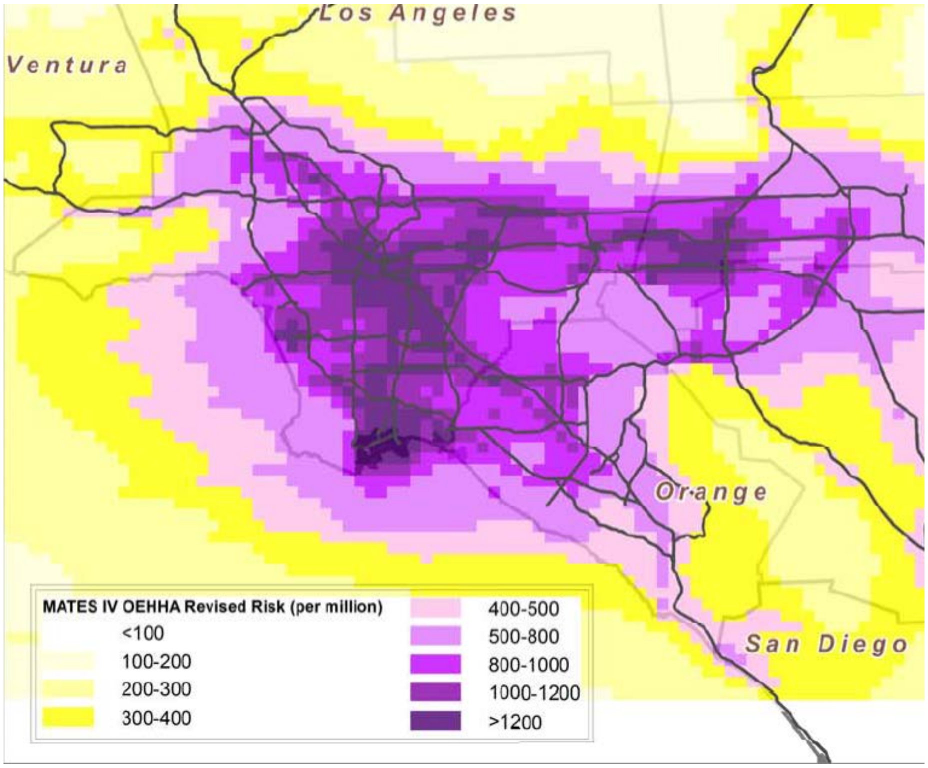

Figure9: Modeled Air Toxics Risk (MATES IV)
Source: South Coast Air Quality Management District

2.5.2 Future Projections

Higher temperatures are expected to increase the frequency, duration, and intensity of conditions conducive to air pollution formation (CNRA 2014). Specifically, studies have shown that ozone concentrations increase when maximum daytime temperatures increase (Kleeman et al. 2010). Since climate models project higher temperatures in the future for Long Beach, a “climate penalty” exists for ground level ozone, which means that greater emissions controls will be needed to meet a given air quality standard. If air pollution emissions levels remain at 1990-2004 levels, California could experience an additional 6-30 days per year with ozone concentrations above state air quality standards by 2050, due to the effects of a warmer climate (Kleeman et al. 2010). Aggressive emissions reductions have been mandated to bring the region into attainment of federal air quality standards and these policies will continue to reduce emissions, such that emissions will not remain at historic levels (SCAQMD 2016). However, higher temperatures could make meeting federal air quality standards more challenging. An increase in wildfire frequency or severity and energy consumption in the region could also contribute to the “climate penalty” for air quality (CEC 2006).

In addition to air pollution emissions, air quality can be affected by pollen, which contains allergens. Models indicate that pollen will likely increase in many parts of the U.S., there may be shifts in the timing of allergen production, and there may be increases in allergen content or potency (CNRA 2014). Allergens can cause or aggravate health problems, including asthma and other debilitating respiratory diseases (CNRA 2014).

Climate change may also negatively impact indoor air quality. Outdoor air quality may worsen and enter buildings, emissions from indoor sources may be exacerbated by heat, there may be more exposure to mold, bacteria, and other contaminants due to flood events, and increased air conditioning use can lead to poor indoor air quality if not well maintained (Nazaroff 2013; Fann et al. 2016).

Section 3. Summary of Potential Local Impacts by Sector

Climate impacts are the result of interactions between climate stressors and physical assets (such as roads) and populations (such as the elderly). Table 5 provides an overview of major categories of potential climate change impacts for Long Beach, based on existing studies and an understanding of the types of assets and populations that exist in Long Beach. Where Long Beach-specific studies are not available, regional or state-wide studies are referenced. These are not the results of the Long Beach CAAP vulnerability assessment, but rather the vulnerability assessment will seek to build upon this summary of existing research to identify key local impacts with greater specificity based on an inventory of critical assets, an assessment of exposure to climate stressors, and asset and population sensitivities.

Table 5: Potential Local Climate Change Impacts by Sector

Sector	Potential Local Climate Change Impacts
Public Health	• Increased risk of heat-related illnesses and death. Particularly vulnerable populations include: children, the elderly, people with respiratory diseases, those who work outdoors, and poor, urban residents (CDPH 2012; CNRA 2014) • Asthma and other cardiovascular and respiratory diseases may increase due to poor air quality and increased allergens (CNRA 2014; CDPH 2012) Asthma hospitalizations rates are highest in West and North Long Beach and lowest in East Long Beach (CLB DHHS 2013). • Communities in west-central and northern Long Beach are disproportionately more vulnerable to risk associated with pollution and climate change (AOP 2015; CalEPA 2017) • Flooding events may contribute to injury, death, displacement, mental health burden (CDPH 2012) • Sewage overflow could result in water and food-borne illness (CDPH 2012) • Disrupted food and water supply could cause hunger and malnutrition, particularly in low-income, children, and elderly population (CDPH 2012) • Changes in temperature and precipitation may lead to changes in the spread of vector-borne diseases and increase the number of disease carrying vectors (e.g. standing water and mosquitos) (CNRA 2014). The City is currently monitoring and treating approx.35 sites for insects (CLB DHHS 2013). • Damage to transportation infrastructure could inhibit or delay emergency response
Coastal Resources	• Deterioration of marine ecosystem health due to pollution from sewer discharges and increased stormwater runoff (CNRA 2014) • Beach inundation and erosion will increase from SLR and storm surge (AOP 2015; CNRA 2014) • Inundation and loss of access to marinas from SLR and storm surge (CDBW 2010) • Portions of breakwaters could be compromised and overtopped during storms with SLR, leading to transmission of waves into harbor and damage to infrastructure (AOP 2015; POLB 2016) • Damage to THUMS Oil Islands during coastal storms possible, especially with SLR (AOP 2015)

Sector	Potential Local Climate Change Impacts
	• Marine ecosystems and marine economic sectors may be disrupted by ocean acidification (CNRA 2014)
Transportation	• Damage to coastal roads, railways, bridges due to SLR, storm surge, and erosion (CDOT 2013; CNRA 2014) • Damage to Port infrastructure and disruption of operations due to SLR and storm surge (POLB 2016) • Airport runways may be damaged, operations disrupted due to flooding and extreme heat (CDOT 2013). • Damage to roads, highways, and rail from extreme heat (CDOT 2013; CNRA 2014)
Energy	• Increased peak electricity demand due to extreme heat (CNRA 2014) • Reduced electricity supply due to reduced hydropower output and reduced transmission line and power plant efficiency (CNRA 2014) • Damage to coastal energy infrastructure from SLR and storm surge (CEC 2012) • Increased risk of power outages due to increased extreme heat and wildfires (CNRA 2014)
Water Supply	• Reduced imported water supply due to reduced snowpack and drier conditions in the Sierra and Colorado watersheds (CNRA 2014; Pagan et al. 2015) • Increased risks to groundwater aquifers due to SLR and increased salinity intrusion (CNRA 2014) • Increased water demand due to higher temperatures (Pagan et al. 2015) • Increase in intense precipitation events may reduce groundwater recharge (Pagan et al. 2015) • Damage to potable water infrastructure possible in a flood event (CDPH 2012)
Stormwater/ Wastewater Infrastructure	• SLR + storm event may overwhelm stormwater infrastructure causing flooding (Heberger et al. 2009) • Damage to wastewater infrastructure and sewage backup and overflow in flooding event (CDPH 2012)
Housing & Neighborhoods	• Higher temperatures exacerbated by urban heat island in neighborhoods without greening (CDPH 2012), which include Central, West and North Long Beach (green space per 1,000 varies by zip code from 0.26 to 19.21) (CLB DHHS 2013) • Disruptions to the transportation system could impact neighborhood connectivity including access to jobs, goods, services, and healthcare. • Southeastern neighborhoods are vulnerable to flooding due to SLR and storm surge (AOP 2015) • Communities in west-central and northern Long Beach are disproportionately more vulnerable to risk associated with pollution and climate change (AOP 2015) • Increased risk of displacement and loss of home due to a flood event related to SLR, storm surge, or precipitation based flooding (CDPH 2012) • Permanent property loss possible due to SLR where inundation and erosion occurs (CNRA 2014) •
Biodiversity/ Habitat	• Increase in nonnative invasive species (CNRA 2014) • Increase in mismatches of timing of migration, breeding, pollination, and other ecological processes and interactions (Kadir et al. 2013) • Increases in tropical pathogens, parasites, and diseases due to higher temperatures (CNRA 2014) • Loss of wetland habitat due to SLR (CNRA 2014). The Los Cerritos wetlands are particularly vulnerable given surrounding urban development (Cope 2015).

Section 4. Conclusions and Next Steps

This review has summarized the most relevant literature on the historical climate events, trends, and future projections for primary and secondary climate stressors in Long Beach. This information is intended to inform decisions on the projections that the City uses in the exposure analysis in the next phase of the vulnerability assessment. Sea level rise, extreme heat, and precipitation are the primary climate stressors considered in this memo. Long Beach is projected to experience 11.2 ± 3.5 inches of sea level rise by mid-century and 36.7 ± 9.8 inches by end-of-century (NRC 2012). Higher sea level rise is possible: up to 24 inches by mid-century and up to 66 inches by end-of-century (NRC 2012).The City's risk tolerance, consistency with other studies, and critical asset lifespans should be taken into account in the selection of sea level rise projections for the exposure analysis. For extreme heat, projections show that the number of extreme heat days in Long Beach will increase from historical levels of approximately four days per year to 11-16 days by mid-century and 11-37 days by end-of century (Sun et al. 2015). There is less agreement in climate models on precipitation projections. Some studies show a drying trend in Southern California (Berg et al. 2015) while others show an increase in annual average precipitation for Long Beach (Pagan et al. 2015). Most models show that there will likely be fewer rainy days per year, but precipitation events will become more intense (CEC 2012; Pagan et al. 2015).

Drought and air quality are the secondary climate stressors considered in this review. Droughts are likely to be more frequent in the future (CEC 2012; Pierce et al. 2011). In addition, higher temperatures will lead to drier soils and vegetation and higher water demand (Pagan et al 2015). The mountains that supply water to Long Beach are projected to have reduced snowpack and increased intensity of runoff (CEC 2012; Pagan et al 2015). Air quality will be affected by a changing climate, particularly higher temperatures and increased wildfire which result in a "climate penalty," making it more challenging to meet air quality standards compared to current climate conditions.

The impacts summary table demonstrates the range of potential impacts for Long Beach based on existing studies. The vulnerability assessment will seek to provide more detail on these impacts, in particular for critical assets, which will be identified in the subsequent asset inventory phase.

References

AOP 2015. City of Long Beach Climate Resiliency Assessment Report. Prepared by the Aquarium of the Pacific (AOP), for the City of Long Beach, California: 88p.

Barboza, Tony. 2010a. “Long Beach waterlogged after recent storms.” Los Angeles Times. Accessed 14 June 2017. http://articles.latimes.com/2010/jan/22/local/la-me-long-beach-rains22-2010jan22

Barboza, Tony. 2010b. “L.A. county’s emergency system weathers the heat.” Los Angeles Times. Accessed 14 June 2017. http://articles.latimes.com/2010/sep/29/local/la-me-0929-heat-resources-20100929

Barnett, T., Malone, R., Pennell, W., Stammer, D., Semtner, B., & Washington, W. 2004. The effects of climate change on water resources in the west: Introduction and overview. Climatic Change, 62(1-3), 1-11. doi:10.1023/B:CLIM.0000013695.21726.b8

Berg, Neil, Alex Hall, Fengpeng Sun, Scott Capps, Daniel Walton, Baird Langenbrunner, and David Neelin. 2015. "Twenty-First-Century Precipitation Changes over the Los Angeles Region*." Journal of Climate J. Climate 28.2: 401-21. Web.

California Energy Commission (CEC). 2006. “Our Changing Climate: Assessing the Risks to California.” A Summary Report from the California Climate Change Center.

California Department of Boating and Waterways (CDBW). 2010. “Assessing the Economic Impacts of Climate Change Events to Marine Industries in Long Beach.”

California Department of Public Health (CDPH). 2012. Climate Action for Health: Integrating Public

Health into Climate Action Planning. California Department of Public Health (CDPH) Report, 58p. Available online at: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.464.9833&rep=rep1&type=pdf.

California Department of Transportation (CDOT). 2013. Addressing Climate Change Adaptation in Regional Transportation Plans: A Guide for California MPOs and RTPAs. Prepared by Cambridge Systematics with ESA PWA, W & S Solutions.

California Department of Water Resources (DWR). 2008. Managing an Uncertain Future: Climate Change Adaptation Strategies for California’s Water. Sacramento.

California Energy Commission (CEC). 2006. “Our Changing Climate: Assessing the Risks to California.” A Summary Report from the California Climate Change Center.

California Energy Commission (CEC). 2012. Our Changing Climate: Vulnerability & Adaptation to the Increasing Risks from Climate Change in California. A Summary Report on the Third Assessment from the California Climate Change Center. CEC-500-2012-007.

California Environmental Protection Agency (CalEPA) and Office of Environmental Health Hazard Assessment (OEHAA). 2017. CalEnviroscreen 3.0. Update to the California Environmental Health Screening Tool. Available at: https://oehha.ca.gov/calenviroscreen/report/calenviroscreen-30

California Health Report 2016. Breathing Air into Asthma Prevention in Long Beach. Available at: https://www.calhealthreport.org/2016/03/07/breathing-air-into-asthma-prevention-in-long-beach/

California Natural Resources Agency (CNRA). 2014. “Safeguarding California: Reducing Climate Risks. An Update to the 2009 California Climate Adaptation Strategy.” Available at http://resources.ca.gov/climate/ safeguarding/.

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 2008 Climate Change Scenarios Assessment. March 2009. CEC-500-2009-014D.

City of Long Beach (CLB) 2004. City of Long Beach Natural Hazards Mitigation Plan. October 19, 2004.

City of Long Beach Department of Health and Human Services (CLB) 2013. Community Health Assessment. Available at: http://www.longbeach.gov/health/media-library/documents/planning-and-research/reports/community-health-assessment/community-health-assessment/

City of Long Beach (CLB) 2017. Press Release. Residents Urged to Protect from Mosquitos.

City of Long Beach (CLB) 2017. "Subsidence" Long Beach Gas & Oil Department. Available at: http://www.longbeach.gov/lbgo/about-us/oil/subsidence/

Cope, Jeff 2015. Coastal Squeeze of Vegetation Zones in the Los Cerritos Wetlands. Master’s thesis collection, Department of Geography, Long Beach California State University.

EPA, 2015. “Working to Reduce Ozone in California.” Factsheet. Available at: https://ozoneairqualitystandards.epa.gov/OAR_OAQPS/OzoneSliderApp/WorkingtoReduceOzoneinCalifornia.pdf

Fann, N., T. Brennan, P. Dolwick, J.L. Gamble, V. Ilacqua, L. Kolb, C.G. Nolte, T.L. Spero, and L. Ziska, 2016: Ch. 3: Air Quality Impacts. The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment. U.S. Global Change Research Program, Washington, DC, 69–98. http://dx.doi.org/10.7930/J0GQ6VP6

Griffin, D., and K. J. Anchukaitis. 2014. How unusual is the 2012–2014 California drought? Geophysical Research Letters., 41, 9017–9023, doi:10.1002/2014GL062433.

Griggs, G, Patcsh, K., and L. Savoy. 2005. Living with the Changing California Coast. University of California Press, 58p.

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

Gurshunov, A., D. Cayan, S. Iacobellis, 2009. The Great 2006 Heat Wave over California and Nevada: Signal of an Increasing Trend. Journal of Climate.

Gershunov, Alexander and Guirguis, Kristen. 2012. “California heat waves in the present and future.” Geophysical Research Letters, Vol 39 L19710, 2012.

Hapke, C., Reid, D., Richmond, B., Ruggiero, P., and J. List. 2006. National Assessment of Shoreline Change Part 3: Historical Shoreline Change and Associated Coastal Land Loss Along Sandy Beaches and Shorelines of the California Coast. USGS Open File Report 2006-1219, 79 p.

Heberger, M., H. Cooley, P Herrera, P. Glick, E Moore. The Impacts of Sea-Level Rise on the California Coast. A Paper from the California Climate Change Center.

IPCC (Intergovernmental Panel on Climate Change), 2000, Emission Scenarios, N. Nakicenovic and R. Swart, eds., Cambridge University Press, Cambridge, UK, 570 pp.

Kadir, T., L. Mazur, C. Milanes. and K. Randles. 2013. Indicators of Climate Change in California. State of California. Available at http://oehha.ca.gov/multimedia/epic/pdf/climatechangeindicatorsreport2013.pdf.

Kleeman, M. J., S. Chen, and R. A. Harley. 2010. Climate Change Impact on Air Quality in

California. Report to the California Air Resources Board. Sacramento, California.

KPCC 2015. “SoCal Edison says mismanagement led to Long Beach outages.”

Livenh, Ben, T. Bohn, D. Pierce, F. Munoz-Arriola, B. Nijssen, R. Vose, D. Cayan, L. Brekke. “A spatially comprehensive hydrometerological data set for Mexico and the U.S., and Southern Canada 1950-2013. Accessed via Cal-Adapt.

Loyola Marymount University (LMU) 2015. Tree Canopy Assessment: Los Angeles Coastal Zone. Available at: http://cures.lmu.edu/wp-content/uploads/2015/12/Tree-Canopy-Report-Los-Angeles.pdf

Madsen, Travis, and N. Wilson. 2012. Environment America Research & Policy Center, Frontier Group. When It Rains, It Pours: Global Warming and the Increase in Extreme Precipitation from 1948 to 2011.

Meijgaard, Jerosen, J. Fielding, R. Shimkhada, P. Vadillo. Air Pollution and Community Health in Central Long Beach. Available at: http://www.health-forecasting.org/images/pdf/LB_Brief_2012_1005.pdf

Metropolitan Water District of Southern California (MWDSC). 2010. Metropolitan Water District of Southern California’s Regional Urban Water Management Plan.

National Oceanic and Atmospheric Administration (NOAA). 2017. Mean Sea Level Trend, 9410660 Los Angeles, California. Center for Operational Oceanographic Products and Services. https://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?stnid=9410660

National Research Council (NRC). 2012. Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future. Prepared by the Committee on Sea Level Rise in California, Oregon, and Washington and the National Research Council Board on Earth Sciences and Resources and Ocean Studies Board Division on Earth and Life Studies.

Nazaroff, William. 2013. Exploring the consequences of climate change for indoor air quality. Environmental Research Letters. 8 (2013) 015022.

Ocean Protection Council. 2018. State of California Sea-Level Rise Guidance 2018 Update.

Ostro, Bart, L. Roth, R. Green, R. Basu. 2009. “Estimate the Mortality Effect of the July 2006 California Heat Wave.” A report from the California Climate Change Center. Available at: http://www.energy.ca.gov/2009publications/CEC-500-2009-036/CEC-500-2009-036-D.PDF

Pagan, B., J. Pal, C. Gao, J. Reichenberger, D. Kendall, M. Ashfaq, D. Rastogi, S. Kao, B. Naz, J. Schubel. 2015. “City of Long Beach Climate Resiliency Assessment Report Appendix A. Drought Report.

Pierce, David., T. Das, D. Cayan, E. Maurer, N. Miller, Y.Bao, M. Kanamitsu, K. Yoshimura, M. Snyder, L. Sloan, G. Franco, M. Tyree. “Probabilistic estimates of future changes in California temperature and precipitation using statistical dynamical downscaling.” Climate Dynamics.

Pierce, David., D. Cayan, B. Thrasher. 2014. Statistical Downscaling Using localized Constructed Analogs (LOCA). American Meteorological Society.

Port of Long Beach. 2016. Port of Long Beach Climate Adaptation and Coastal Resiliency Plan.

Samenow, Jason. “Los Angeles has worst heat wave in 25 years.” Washington Post. https://www.washingtonpost.com/news/capital-weather-gang/wp/2015/10/12/los-angeles-has-worst-heat-wave-in-25-years/?utm_term=.183025e642ad

South Coast Air Quality Management District (SCAQMD) 2016. Final 2016 Air Quality Management Plan. Available online at: http://www.aqmd.gov/docs/default-source/clean-air-plans/air-quality-management-plans/2016-air-quality-management-plan/final-2016-aqmp/final2016aqmp.pdf?sfvrsn=15

Staff Survey 2017. City of Long Beach Climate Action and Adaptation Plan Department Questionnaire.

Strauss, B. H., Kopp, R. E., Sweet, W. V. and Bittermann, K. Unnatural Coastal Floods: Sea Level Rise and the Human Fingerprint on U.S. Floods Since 1950. Climate Central Research Report, pp. 1-16.

Sun F., Walton DB., Hall A. 2015. A Hybrid Dynamical – Statistical Downscaling Technique, Part II: End-of Century Warning Projections Predict a New Climate State in the Los Angeles Region. Journal of Climate, 28(12): 4618-4636.

United States Geological Survey (USGS). 2000. Sea Level and Climate. USGS Fact Sheet 002-00. January.

Vahmani, P., F. Sun, A. Hall, G. Ban-Weiss. “Investigating the climate impacts of urbanization and the potential for cool roofs to counter future climate change in Southern California. *Environmental Research Letters.*

WRCC. 2008. California’s Top 15 Weather Events of the 1900’s. Western Regional Climate Center (WRCC) website, posted September 2008 (accessed 12/16/2015). Available online at: http://www.wrcc.dri.edu/extreme-events/california/.

WRH. 2010. A History of Significant Weather Events in Southern California, Organized by Weather Type. NOAA’s Western Region Headquarters (WRH) website, updated February 2010 (accessed 12/16/2015): 199p. Available online at: www.wrh.noaa.gov/sgx/document/weatherhistory.pdf.

Zelinsky DA, Pasch RJ. 2015. Hurricane Marie (EP 132014) 22-28 August 2014, National Hurricane Center Tropical Cyclone Report. NOAA and National Weather Service (NWS) Report # EP132014

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