MORRO BAY
NATIONAL ESTUARY PROGRAM

Climate Vulnerability Assessment Report

FINAL DRAFT

Prepared by the Morro Bay National Estuary Program for submittal to the US EPA

Part of the Climate Ready Estuaries Program

October 2015

Acknowledgments

The completion of this report could not have been done without the collaborative efforts of the MBNEP staff and local experts. A special thank you goes out to those who are listed below and in the list of additional experts and collaborators. Many of them dedicated much of their time and energy towards reviewing and editing this document and providing feedback.

Expert Resource Team Members

Evan Mundahl	Author/GIS analyst	Climate Vulnerability Assessment Intern, MBNEP
Rachel Pass	Draft Editing	Comm. & Outreach Coordinator, MBNEP
Lexie Bell	Draft Oversight	Assistant Director, MBNEP
Jennifer Nix	Draft Oversight	Restoration Projects Manager, MBNEP
Adrienne Harris	Draft Oversight	Executive Director, MBNEP
Ann Kitajima	Watershed Expertise	Monitoring Program Manager, MBNEP
Karissa Willits	Watershed Expertise	Monitoring Coordinator, MBNEP
Mike Multari	Draft Oversight	City and Regional Planning Dept., Cal Poly
Clinton Francis	Bird Ecology Expertise	Biological Sciences Dept., Cal Poly
Ethan Bell	Steelhead Trout Expertise	Senior Fisheries Ecologist, Stillwater Sciences

Table of Contents

List of Figures

List of Tables

List of Acronyms

Morro Bay National Estuary Program……………………………………………………...MBNEP

California Polytechnic State University, San Luis Obispo………………………………………Cal Poly

California Men's Colony……………………………………………………………………………….CMC

United States Army Corps of Engineers……………………………………………………...…ACOE

Coastal San Luis Resource Conservation District………………………………………………CSLRCD

Morro Bay Comprehensive Conservation and Management Plan……………………………………CCMP

Morro Bay Sediment Report………………………………………………………………………….MBSR

Central Coast Regional Water Quality Control Board ……………………………………...Water Board

Total Maximum Daily Load…………………………………………………………………….TMDL

Morro Bay Water Quality Report……………………………………………………………….MBWQR

California Department of Fish and Wildlife…………………………………………………...DFW

Dissolved Oxygen……………………………………………………………………………………..DO

Cubic Feet per Second………………………………………………………………………………….cfs

National Pollutant Discharge Elimination System………………………………………………..NPDES

Stormwater Pollution Prevention Plan…………………………………………………………SWPPP

Interlocutory Stipulated Judgment……………………………………………………………………..ISJ

Intergovernmental Panel on Climate Change………………………………………………………….IPCC

Basin Characteristic Model……………………………………………………………………………BCM

Special Report Emissions Scenarios…………………………………………………………………..SRES

Representative Concentration Pathway…………………………………………………………………RCP

Geophysical Fluid Dynamics Laboratory……………………………………………………………..GFDL

Parallel Climate Model……………………………………………………………………………PCM

Model for Interdisciplinary Research on Climate………………………………………………..MIROC

Climate Water Deficit…………………………………………………………………………….CWD

University of California San Diego……………………………………………...……………UCSD

North Bay Watershed Association…………………………………………………………...NBWA

National Oceanic and Atmospheric Administration………………………………………….NOAA

Los Alamos National Laboratory……………………………………………………………..LANL

The Naval Postgraduate School………………………………………………………...……NPG

The United States Army Corps of Engineers Cold Regions Research and Engineering Lab.............CRREL

The National Center for Atmospheric Research...……………………………………………NCAR

Sea Level Rise……………………………………………………………………………………..SLR

Japan's Center for Climate Systems Research……………………………………………..CCSR

Japan's National Institute of Environmental Studies…………………………………………….NIES

Frontier Research Center for Global Change………………………………………………..FRCGC

San Luis Obispo…………………………………………………………………………...SLO

Large Woody Debris………………………………………………………………………...LWD

Best Management Practices………………………………………………………………...BMPs

The Civilian Conservation Corps……………………………………………………………CCC

Federal Emergency Management Agency…………………………………………………....FEMA

1. Executive Summary

The Morro Bay National Estuary Program (MBNEP) has prepared this document to assess and summarize potential climate change impacts to the watershed and estuary of Morro Bay, in the context of MBNEP's watershed goals. Analysis includes the use of climate change models, historic data, research, and input from experts. Through these efforts, the Estuary Program formulated a list of possible climate change impacts and associated risk levels. Results included estimates of climate change at the watershed scale and predictions of hydrologic and ecosystem shifts in response to such change. Climate change effects and their corresponding likelihoods can be found throughout section 3 and a summary of climate model outputs can be found in section 2.6.4.

All climate change models agree that the Morro Bay climate will become drier and warmer in the future. These predictions are the most certain; all other predictions rely on assumptions of the interactions these changes will have on local climate factors. That being said, the MBNEP must prepare for both a "warmer wetter" and "warmer drier" climate in the future with more intense droughts. Effects from these possible scenarios include warmer surface and water temperatures, drier conditions, more intense storms, and sea level rise. These changes pose significant risks to the MBNEP's goals and their ability to protect and enhance the local ecosystems.

Through the collaboration of experts and MBNEP staff, possible impacts from climate change on local ecosystems and hydrologic processes were hypothesized. These stressors were then sorted by their individual likelihood and the consequences of their impact. Through this analysis, effects that pose the greatest risk to the MBNEP were ones with the highest likelihood of occurring and the most severe consequences. High and moderate priority climate change effects were addressed within a list of possible mitigation efforts. However, each effort was analyzed for the feasibility of its implementation and only a select few were chosen for the future adaptation action plan.

As climate change progresses and impacts are better understood, the adaptation plan will be updated to efficiently use MBNEP resources. Monitoring and review of this document will occur every 5years to ensure that predictions and impacts are up to date with current trends and stressors.

2. Introduction

Located along the Central Coast of California, the Morro Bay watershed experiences a Mediterranean climate with dry summers and winters punctuated by sporadic storms. The watershed drains into the Morro Bay estuary, a 2,300 acre semi-enclosed body of water that is recognized as an estuary of both state and national significance. The watershed encompasses a total area of 75 square miles and is divided into two main sub-watersheds, Chorro Valley and Los Osos Valley. About 60 percent of the total land area of the watershed resides in the Chorro Valley.

Land use for the Morro Bay watershed includes mostly open space used for cattle grazing, agriculture, and a range of public uses. Some of these public uses include parks, golf courses, nature preserves, a military base, and rangeland owned by California Polytechnic State University (Cal Poly). Some developed areas in the watershed include Cuesta College and the California Men's Colony (CMC). However, the densest developed areas surround the bay in the communities of Morro Bay and Los Osos.

Over the past century, the bay has been significantly altered to accommodate human needs. In the 1940s the US Army Corps of Engineers was instructed by the US Navy to reinforce the causeway connecting the Embarcadero to Morro Rock, install revetment between Tidelands Park and Coleman road along the Embarcadero, construct the North and South Jetty Breakwaters, and dredge to deepen the main navigation channel. Post-project construction also included a stone groin within the harbor mouth to control littoral sand transportation at the North end of the sand spit. Later in the 1950s, a power plant was constructed near the harbor mouth that used water from the estuary in its cooling towers. It was decommissioned in 2013.

During the 20th century, the community of Los Osos began to expand and develop where coastal dune habitat existed along the south end of the bay. Also during this time the US Navy harbor improvements were converted to civilian uses, allowing for the communities and tourism industry to thrive in the area. In the upper watershed, mines were opened up to extract chromium and nickel, and oak savannah and scrub areas were converted into grassland. Other areas used for agricultural production were cleared and leveed around the creeks and disconnected from their floodplains. Each of these activities has contributed to accelerated erosion and sedimentation in the watershed and bay. Efforts have been made throughout the area to remedy some of these impacts, including some projects headed by the Estuary Program. Significant portions of the watershed are now preserved through conservation easements or publicly owned open space.

Figure 1: Photo of Morro Bay.

Even though the historic ecosystem and habitat processes of the Morro Bay estuary and watershed have been altered, it remains one of the least-disturbed wetland systems on the Southern and Central California Coast. It serves as a vital stopover and wintering ground for many migratory birds in the Pacific Flyway. The estuary environment encompasses the lower reaches of Chorro and Los Osos creeks, a variety of wetlands, salt and freshwater marshes, intertidal mudflats, eelgrass beds, and other subtidal habitats.

The significance of these types of habitats and the necessity of protecting them led to the enactment of the National Estuary Program amendment to the Clean Water Act in 1987. The amendment allowed for the creation and funding of estuary programs focused on water quality and the integrity of the entire estuarine system. In 1995, The Morro Bay National Estuary Program was inducted into the ranks of 27 other estuary programs within the United States and two others in California.

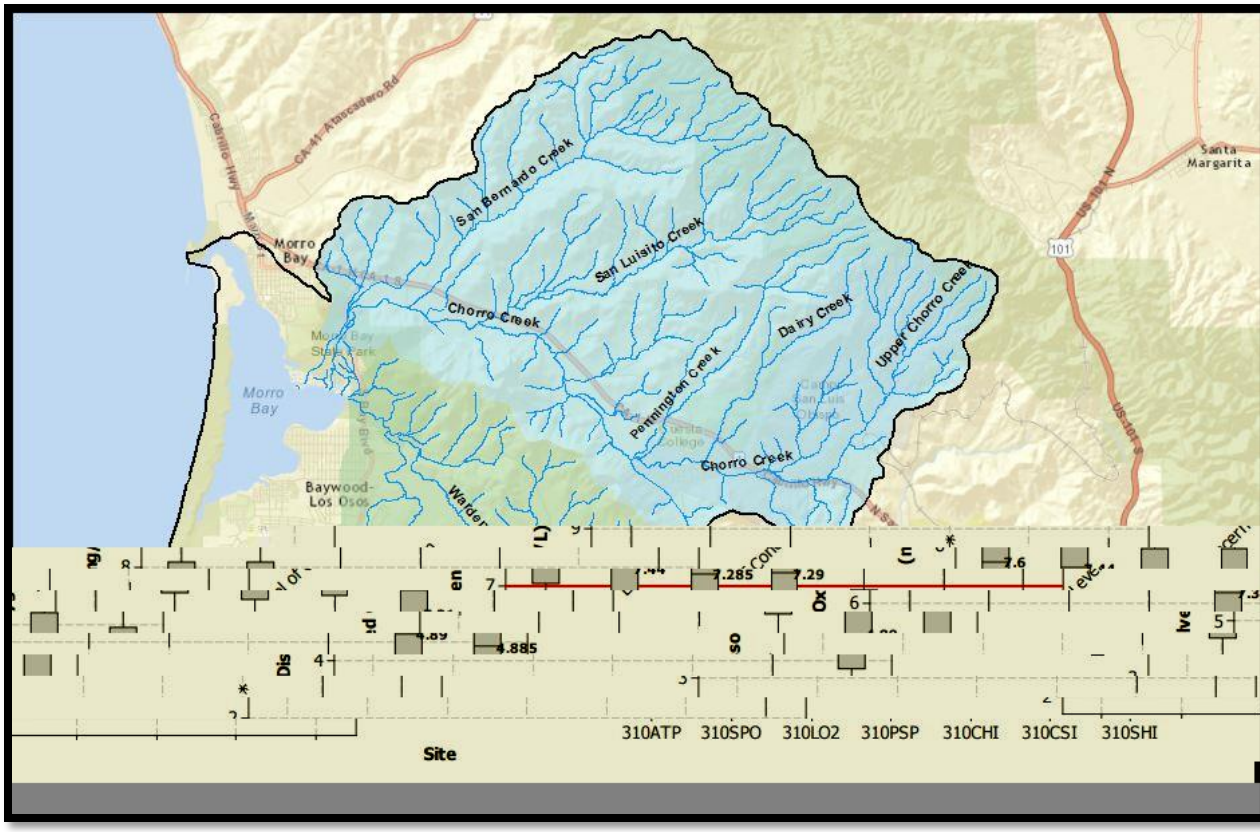

Figure 2: Map of the Morro Bay Watershed.

2.1 Project Scope

The Climate Vulnerability Assessment for the Morro Bay estuary presents an analysis of the likelihood and severity of climate change effects on the goals of the MBNEP, as well as an adaptation action plan to best prepare for such effects. The assessment is designed to inform how the MBNEP will address climate-related impacts in the future and reduce the risks they present to attaining their program goals. Impacts from climate change focus on the alteration of the many processes within the Morro Bay estuary and watershed. Analysis includes the use of climate change models, historic data, and local expertise in the prioritization of impacts and their subsequent adaptation plans.

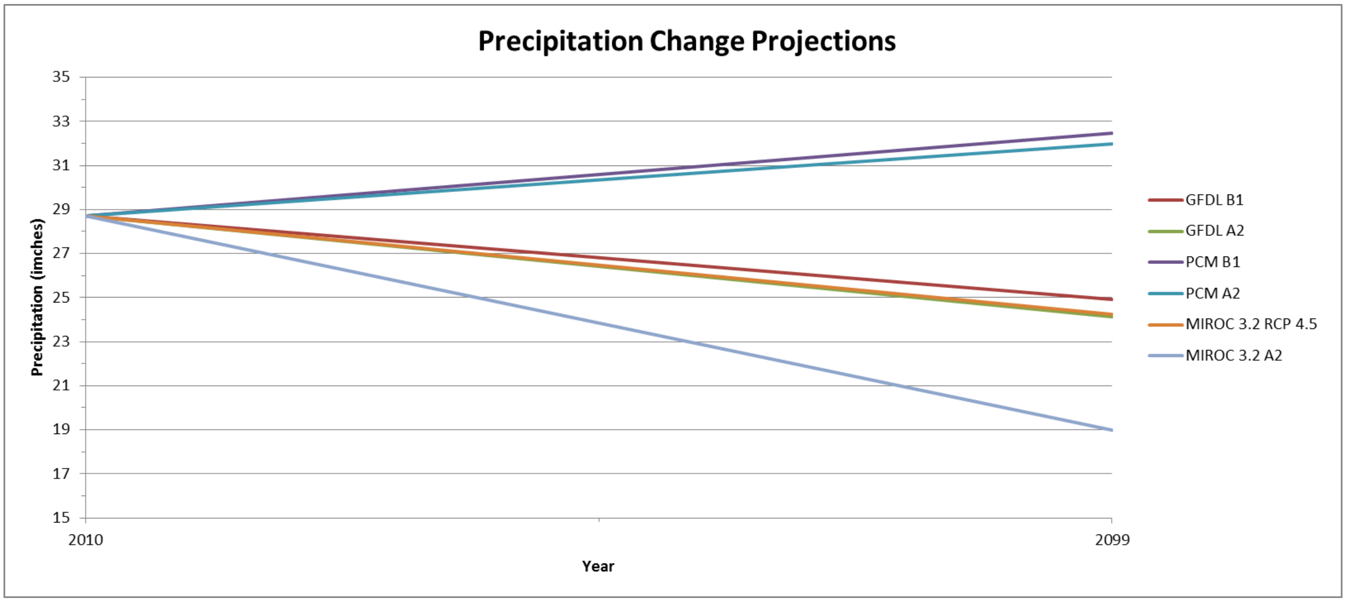

Figure 10: Model and scenario combinations with their associated precipitation change projections.

2.6.5 Morro Bay and San Luis Obispo Historic Climate Data

While these climate models have been downscaled to be more accurate on the regional and watershed scale, their predictions are still uncertain. It is important to reference historic climate data to support their predictions and to capture inter-annual variations in climate. Regional climate data was collected from the Morro Bay Fire Department and Cal Poly campus. Over the last 54 years (1960-2014) Morro Bay climate data shows an increase in average annual temperature of about 1F | with recent records continuing to increase. A more drastic observation from the data is that of the average maximum daily temperatures, which increased about 3F | or 5%. Average daily minimum temperatures also increased a little over 1F | since 1960. This supports the basis of climate change that surface temperatures, are indeed, warming over time.

Cal Poly, San Luis Obispo precipitation records are also available from 1870 to present. These records were analyzed to find trends in precipitation over the last 143 years (1870–2013). Separating the data into 25-year intervals, the most recent period (1989–2013) had the highest amount of 30-inch or greater precipitation events on record. This may suggest that future years will have more frequent large precipitation totals and more intense storm events. Years with rainfall below 12 inches, or that were in a drought, did not show any increase in frequency.

Precipitation data was also examined by month from October to May. The analysis showed an increase of about 1 inch of rain during November and February. October, December, April, and May, however, showed little or no variation from the historic average. January saw about a 0.5 inch decrease in rainfall average, and March saw an increase of about 0.2 inches. Figures 11-13 show the change in monthly average precipitation for Morro Bay and the actual precipitation data can be found in the appendix. The figures display what the average rainfall patterns looked like in 1910 and 2010. These were created by comparing the average monthly rainfall totals from 1870 to 1910 and the average totals from 1870 to 2010. This trend shows a shift in rainfall over the winter season and may account for more sporadic and intense rainfall events. The IPCC predicts that in subtropical dry regions, mean precipitation will likely decrease while extreme precipitation events over most of the mid-latitude land masses will very likely become more intense and frequent (IPCC, 2014). Historic data seems to suggest that high precipitation years are become more frequent with more intense precipitation events.

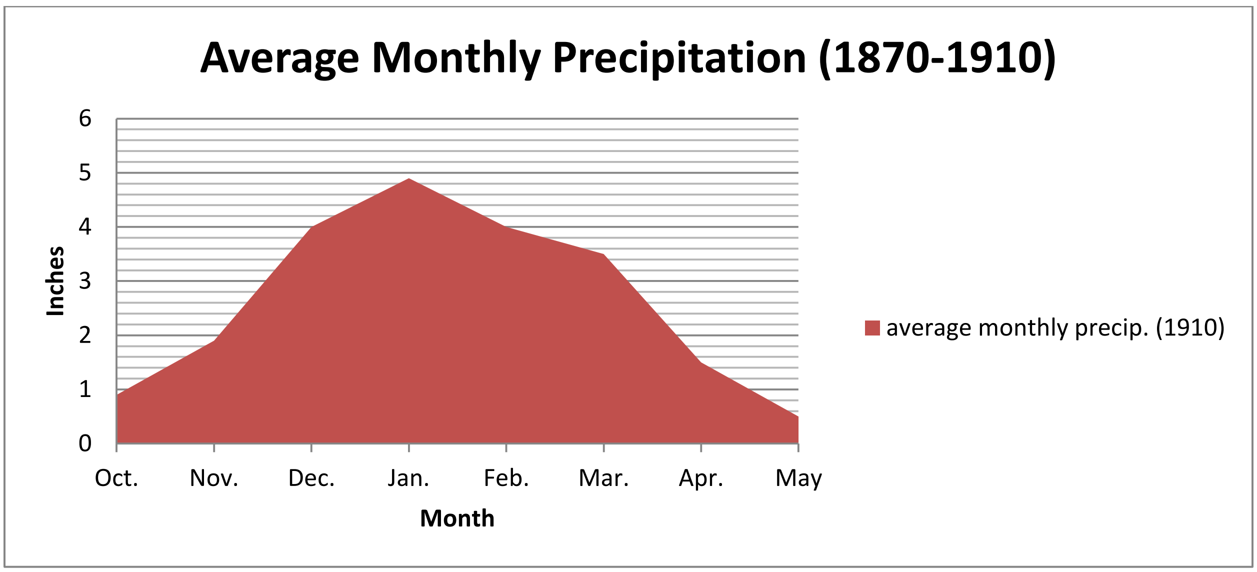

Figure 11: Average monthly precipitation for SLO in 1910.

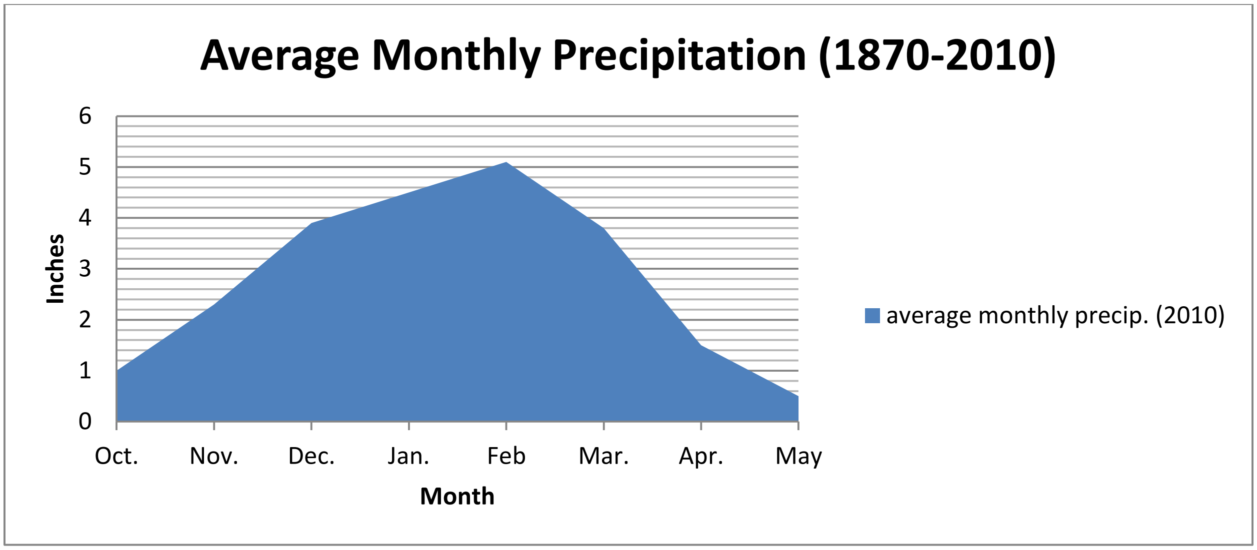

Figure 12: Average monthly precipitation for SLO in 2010.

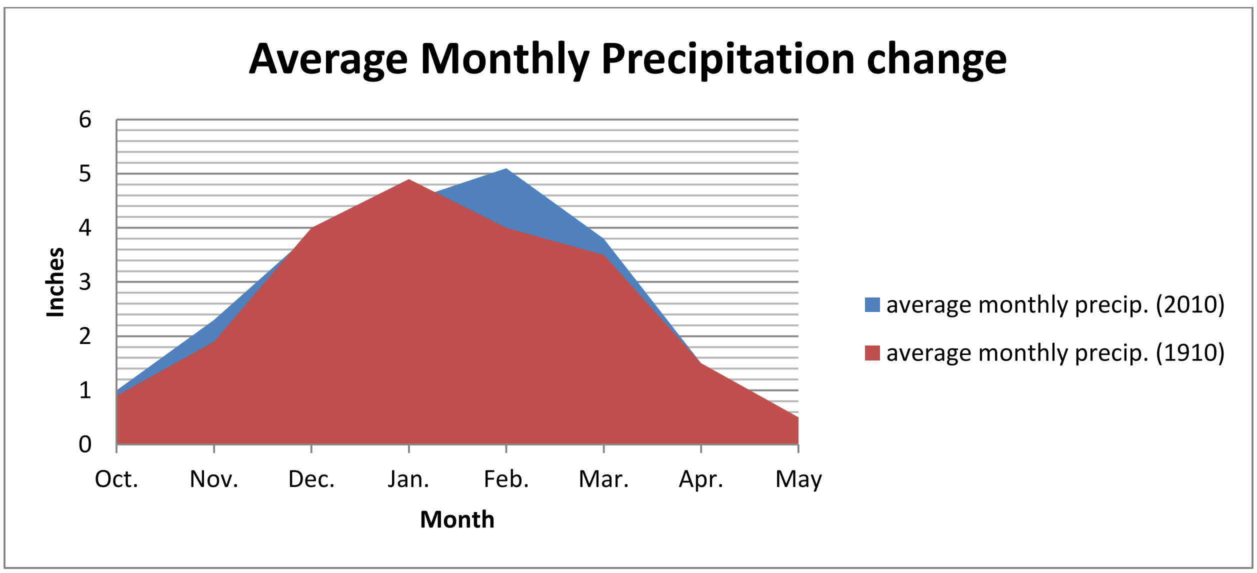

Figure 13: Average monthly precipitation for SLO in 1910 and 2010.

2.6.6 Sea Level Rise and Ocean Acidification

Increased atmospheric carbon and the subsequent warming will alter the ocean both physically and chemically. As temperatures increase and warm the ocean, it will begin to expand. This combined with the melting of land-based ice will compound to raise sea levels. The San Francisco Bay estimated that over the past 100 years sea levels had increased regionally by 0.5 feet (Micheli et al. 2010). With medium confidence, the IPCC estimates that the sea level will rise between 1.3 and 2.7 feet by 2100 (IPCC 2014).

In 2014, The NOAA Coastal Service Center produced the "Digital Coast Sea Level Rise and Coastal Flooding Impacts Viewer," which displays the areas affected by sea level rise (see http://coast.noaa.gov/digitalcoast/tools/slr). Examples of this are shown in figures 14 and 15. The mapping tool shows general areas that are vulnerable to sea level rise, but may not accurately depict the extent of the rise in water levels. Predicting inundation comes with high uncertainty due to the many variables that remain unknown.

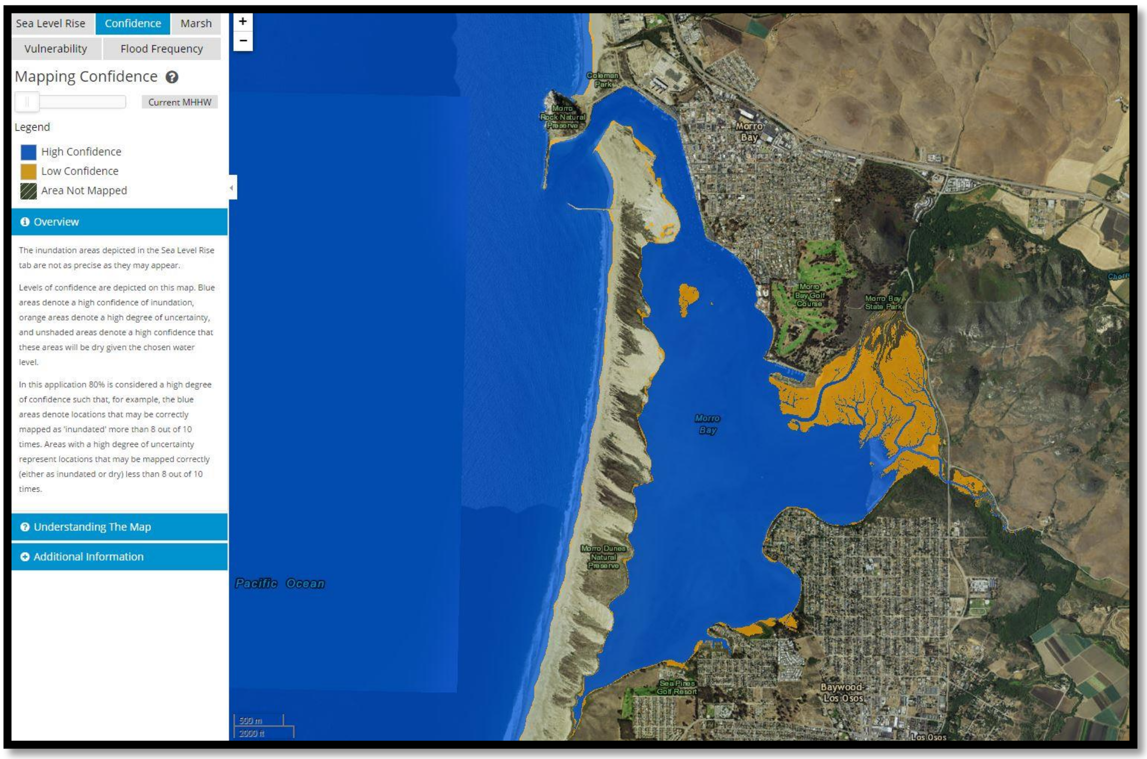

Figure 14:Current sea level produced by NOAA.

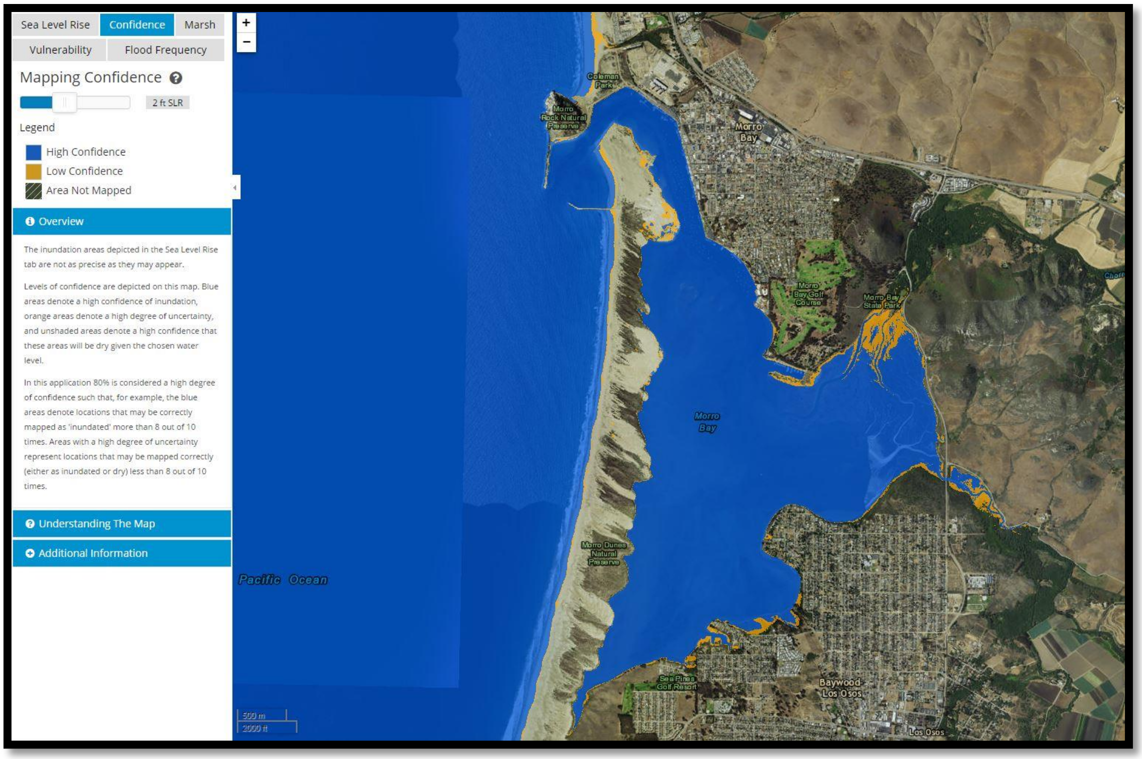

Figure 15: Two foot sea level rise prediction produced by NOAA.

The Federal Emergency Management Agency (FEMA) has also provided flood maps showing areas vulnerable to flooding. This is important when analyzing the effects of sea level rise during large flood events, like the 100 year storm. Figure 16 below shows the extent of flooding from the 100 and 500 year storm events. The combination of sea level rise and flooding events could pose many risks to the MBNEP in the future.

Figure 16: FEMA map showing areas vulnerable to flooding. Blue areas are water levels during the 100 year flood event and orange areas are levels during the 500 year flood event.

As carbon concentrates in the atmosphere, it will increase diffusion pressure into the ocean water and create more carbonic acid, which will reduce the pH over time making the oceans more acidic. Predictions for ocean pH change are not well understood, but are not expected to be significant in Morro Bay. However, impacts in the Pacific Northwest may indirectly affect Morro Bay's shellfish economy.

2.6.7 Climate Change Conclusions

More concentrated and higher precipitation years are predicted to produce more frequent large intensity storms that can alter the hydrology and ecology of the Morro Bay watershed. Increased temperatures and drier conditions will also modify the biological and ecological processes that impact the communities that rely on them. This is shown in the models as increased Climate Water Deficit, leading to increased stress on plants and wildlife. As temperatures increase with carbon emissions, the oceans will continue to warm and acidify, decreasing the pH and causing the sea levels to rise through thermal expansion. These impacts are discussed in further detail in section 3.

3. Climate Change Stressors and Likelihood Analysis

Stressors from climate change are analyzed and discussed for their impacts on the MBNEP's goals. Each stressor is broken up into subcategories for each of the priority issues. In each subcategory, discussions about the severity and likelihood of each impact are analyzed. Discussions are followed by a table identifying the likelihood of each impact. Impact analysis was deliberated by multiple local experts in Morro Bay to accurately identify their effects on the Estuary Program's goals.

3.1 Increasing Storminess

The most recent global climate models suggest a wide range of precipitation outcomes for Morro Bay. Variations in precipitation projections can be attributed to differences in algorithms used to estimate the influence the ocean will have on coastal climates in the future. However, all of these models do indicate that the frequency of large storm events will increase. Furthermore, historic precipitation data from San Luis Obispo and Morro Bay suggest that the frequency of very high rain years is increasing. In the recent 25-year period ending in 2014, there were four years with above 30 inches of rain and two years with above 40 inches—more than any other previous 25-year period since 1885. This suggests that large storm events are becoming more frequent, especially when analyzing the 25-year moving average. This average did not deviate much from the annual precipitation average until recently, when it has begun to deviate as much as four inches. Increased variability of the 25-year average around the annual average will create a much more dynamic and unpredictable climate in the future, resulting in more pronounced dry and wet years.

More frequent large storm events and rain years will have many implications for the Morro Bay watershed. Low-lying areas that are within the flood prone elevation of streams will be in immediate danger. These areas will be more frequently inundated during intense rainfall events. High precipitation and intense storms also carry more pollutants and sediments into streams that eventually make their way into the estuary. While more precipitation may increase groundwater recharge, too much rainfall at once may cause more runoff and erosion. These impacts may be detrimental to the water quality and ecosystem services that the watershed and estuary provide to the community

All models predict drier soil conditions, which have higher infiltration rates. This may increase the amount of recharge and runoff buffer capacity of soils for the first few storms, but in high-precipitation years, these effects would not last long, as soils would saturate quickly. Analyzing the watershed soils using NRCS data shows that the majority of soils had high to moderate runoff potential and low infiltration. This may be because the dominant soil types are clayey and loamy claypan with some fine loam. Soils with high clay contents and clayplans have low permeability and high water-holding capacity. All climate projections show increased drought stress (CWD) on soils between 4–21.4%. While drier soils do have higher infiltration rates, the effects will most likely be minor in the Morro Bay watershed, due to the soil compositions.

3.1.1 Accelerated Sedimentation

Larger storms will likely increase erosion and, thereby, sedimentation to streams. Sedimentation increase could have substantial impacts on the ecology of the watershed and estuary.

- Much of this sediment will be deposited into the estuary, raising the base elevation and altering the ability for mudflats, salt marshes, and freshwater/brackish wetlands to receive the tidal and stream flows they need to remain productive. Many areas will also become shallower causing eelgrass (*Zostera marina*) habitat to migrate to deeper areas.
- High precipitation events also contribute to larger and higher-velocity peak flows; these powerful stream flows can erode away the stream banks and carry more sediment (NRCS, 2009).
- Upland tributaries have flashy peak flows that may increase in intensity with storminess. This can cause increased head-cutting of gullies and rills across the landscape that can contribute large spikes of sediment and erode hillsides. This problem exists now and will persist in the future, but with greater intensity.
- Increased sedimentation can fill in viable habitat for South–Central California steelhead trout (*Oncorhynchus mykiss*), an important indicator species for overall watershed health. Steelhead spawn in the gravel of riffles and spend much of their time in pools where they can conserve energy (Moyle at al., 2008). Sedimentation can fill in these habitat features.
- Timing of storms will be important to sediment inputs as well. Runoff occurs when soils are saturated from recent rainfall events, reducing their infiltration rate. When the next storm comes, the ability of the soil to take in water is exceeded by the precipitation rate, causing water to concentrate in overland flow (runoff). If there are multiple consecutive storms, runoff can be expected and can compound with stream bank failure. It is uncertain, however, if rainfall will be more concentrated or episodic in the future climate.
- Turbidity will increase in conjunction with sedimentation from more frequent large storms. This can cloud stream and estuary waters and limit light penetration. Very high levels can degrade habitat quality and negatively affect eelgrass beds.

3.1.2 Bacteria/Nutrient/Toxics

- More frequent high-precipitation events may lead to more pollutants during wet years. The increase in stormwater could result in higher loads of non-point source pollution, including cattle and pet waste, excess fertilizer, pesticides, and many others. Oyster farms have automatic closures when rainfall exceeds 0.3–0.4 inches in a 24 hour period to avoid bacterial harm (George Trevelyan, 2015). As a result of increasing storminess, these closures may increase in frequency with more storms exceeding this threshold.
- Increased bacteria levels may increase DO demand. Large influxes of bacteria from storms into the streams and estuary can consume DO and reduce the amount available to aquatic species (EPA, 2012).
- Septic systems have long been associated with water quality issues for Los Osos and the estuary. However, construction of a new wastewater treatment plant is underway. This should reduce the possibility of septic tank failure during large storm events.
- Currently, two new wastewater treatment plants are being constructed within the Morro Bay watershed. The Morro Bay and Cayucos joint treatment plant is in the process of moving upslope and inland to the Rancho Colina site, and is projected to be finished by 2021. The new site is at an elevation much higher than the 100-year flood levels. The new location and upgraded technology should reduce the possibility of overflow from large storms. The Los Osos plant is scheduled to finish in 2016 and will also be outfitted with updated technology with no discharge into surface waters. It, instead, will be injecting the water into the aquifers to combat salt water intrusion or will be used for irrigation. Both plants should have reduced risk of flooding.

  Pump stations for the wastewater treatment plants may be vulnerable to frequent large storms. Their electric motors may fail if water reaches them, causing untreated sewage water to seep out. These pump stations are well-engineered for this risk, but more pressure from storms may occur in the future.
- No manure storage or detention basins are located in the watershed, so there is no risk of pollution from this source.

3.1.3 Hydrologic Change

- High velocity peak flows may cause steelhead trout to seek refugia. During these strong flows, steelhead and aquatic species are unable to swim against the current and seek refuge in pools or off-channel habitats where they can conserve energy.

- Large peak flows from storms can increase sediment loads, which fill in stream habitats and accelerate downcutting. This can lead to high entrenchment ratios and further channelizing of the stream. Higher entrenchment can disconnect streams from their floodplains, causing them to focus their stream energy into narrow channels and significantly increase their sediment loads. This also reduces the amount of water that can permeate through the streambed and eventually into the groundwater tables below, thus, reducing groundwater recharge.

3.1.4 Environmentally Balanced Uses

- Higher precipitation years may increase groundwater recharge. However, more intense storms will most likely contribute more runoff. Given that the soils in the watershed have low infiltration rates and moderate to high runoff potential, recharge during these intense rainfall events may decrease.
- Frequencies for such large flood events, such as the 100- and 50-year storms, will become more frequent in the future climate. More frequent floods may endanger low-lying agriculture, recreation, and infrastructure in the area. The FEMA produced flood map shows mostly agricultural areas being endanger of flooding.
- Landslide risk may increase as larger storms may oversaturate soils.

3.1.5 Ecosystem Restoration/Conservation

- Stream beds will be more frequently scoured of their habitat complexity and become degraded. This is a natural process, but if frequencies increase and compound with human alterations, streams may not be able to reach equilibrium.
- Plant species within the flood-prone areas of the watershed will be more susceptible to inundation, which may cause a shift in habitat and species composition. Breaching of stream banks will be more frequent and flood adjacent flat areas. This may lead to the creation of wetlands and shift vegetation to a more hydrophytic community. This may also increase viable habitats for wetland species, such as California red-legged frog (*Rana draytonii*), and allow for water to pool and increase groundwater recharge.

Table 3: Impacts from increased storminess and their likelihood.

	Climate change impact likelihood			
	Likely	**Possible**	**Not likely**	**Comments**
Increased storminess	Sedimentation increase			High rain intensity is a major contributing factor to sediment inputs in streams
	More frequent floods			Flood events will become more frequent with large and intense storms
	Aggradation of estuary			Erosion from strong storms leads to deposition in estuary
	More intense and frequent pollution flushes			Pollution peaks from rainfall events will become more intense and frequent due to increases in precipitation which carry more pollutants from agriculture and urban areas through the stream system
	More frequent oyster farm closures from bacteria pollution			The 0.3–0.4 inch threshold will be exceeded more frequently
	Landscape runoff (overland flow) increase			The number of events with landscape runoff will increase in frequency due to more intense storm events
	Altered flood-prone area habitat			More frequent floods may increase wetland habitat and favor hydrophytic species

Table 3 continued…

	Climate change impact likelihood			
	Likely	**Possible**	**Not likely**	**Comments**
Increasing storminess	Increased stormwater runoff			More rain means more runoff from compacted areas
		Increased groundwater recharge		High precipitation years will be more frequent
		More frequent landslides		Higher hillside saturation may lead to landslides
		High stream velocities disrupt steelhead		High peaks flows from large storms can force steelhead to seek refugia to conserve energy

3.2 Warmer Annual Temperatures

Climate models all agree that surface temperatures will increase between 0.54 F |and 1.26 F |over the next 20 years, and will continue to increase through the end of the century (IPCC, 2014). Models are also certain that there will be more frequent hot and fewer cold temperature extremes on daily and seasonal timescales, as global mean surface temperature increases. Another high-certainty prediction is that heat waves will become more intense and will occur with a higher frequency and longer duration (IPCC, 2014)(National Climate Assessment, 2014). Higher annual temperatures will lead to warmer/longer summers and warmer winters. This will affect temperature-sensitive ecosystem interactions and may increase stream and estuary temperatures. Warmer waters will have important impacts on the Morro Bay watershed and estuary. Effects of these warmer waters will be more pronounced during summers than winters.

3.2.1 Accelerated Sedimentation

- Surrounding soils and vegetation will dry out faster and earlier in the season in the projected future. Drier conditions may effectively lengthen the fire season, increase fuel loading (intensity), and frequency of fires throughout the watershed. Wildfires remove ground cover and can lead to increased soil erosion. A study looking at historic fire data in the western United States estimated a 650% increase in fire frequency from 1970 to 2003 attributed mainly to climate change (National Climate Assessment, 2014). More frequent wildfires expose soils to erosion and landslides, which can release large amount of sediment into streams (National Climate Assessment, 2014). Possible impacts to other native plant communities could be from grassland fires spreading to coastal scrub and maritime chaparral, which cover 11% and 9% of the watershed respectively (Sims, 2010). These communities will become drier as well, making them more susceptible to fire. The scrub and chaparral plant communities are not well-adapted to frequent wildfire, and may shift into coastal grasslands if fires become too frequent. The fire return interval for maritime chaparral is anywhere from 40 to 70 years and 10 to 20 years for coastal scrub (NPS, 2007). While these plant communities respond well to fire and contain species that require fires to germinate new seeds, too frequent fires will reduce their population's ability to rebound. One native species in particular that may benefit from increased fire frequency is the Indian knob mountainbalm (*Eriodictyon altissimum*), which has suffered from suppressed wildfire (Sims, 2010). Timing of fire will also be important because spring burns favor native grasses, while fall burns favor non-native species (NPS, 2007). In 1994, fires along Highway 41 in the Morro Bay watershed followed by heavy rains led to significant increases in sediment to the estuary. Fuels management has been present throughout the watershed through grazing and agricultural practices, which is reflected by the infrequency of fires in the area.

3.2.2 Bacteria/Nutrients/Toxics

- Longer growing seasons and warmer temperatures may require urban landscapes and agriculture to take up more water and increase pesticide and fertilizer use (National Climate Assessment, 2014). This would be most impactful if farms began to double or triple crop to maximize their production potential.
- Warmer waters facilitate the growth and abundance of bacteria (National Climate Assessment, 2014). More favorable water temperatures for bacteria may allow them to persist longer and consume more DO. However, bacteria require a vector to deposit them into the water. Commonly, bacteria are carried by precipitation from storm events into streams and, eventually, the estuary. Due to the inability for bacteria to independently transport itself, concentrations will likely not increase, but may persist longer in warmer water.

- Increased water temperatures may also create more toxic pollutants (National Climate Assessment, 2014). Increased water temperatures may provide a catalyst for pollutants to become more reactive and form more toxic elements (Nature, 2010).
- Warmer water temperatures may also facilitate the survivability of new pathogens and diseases in the estuary. These can negatively affect eelgrass by allowing pathogens, such as *Labrinthula macrocystis,* to have greater abundance, survival, and transmission. *Labrinthula* has been targeted as a contributor to eelgrass population declines in much of the United States and Morro Bay (Bjork et al., 2008). Southern sea otters (*Enhyfra lutris nereis*) are vulnerable to parasites, bacteria, and diseases as well (Sims, 2010). New pathogens may also endanger steelhead and human populations. During the past year, Oregon and northern California have had record high stream temperatures from lack of snowpack, warmer annual temperatures, and warmer El Niño conditions. This has led to an increase in salmonid mortality from diseases and thermal pollution. Biologists along the Deschutes River in Oregon found that mortality of sockeye was associated with a warm-water disease that infects the gills. Many northern California rivers, such as the American, Merced, and Klamath have been forced to close fishing season to save their fisheries (KGW, 2015). Overall, warmer water temperatures combine with other factors and create an inhospitable environment for many aquatic species. Communities in Mexico and northern Europe have had increased levels of *vibrio* strains in their warmer ocean waters that have led to seafood and recreational deaths from sickness (Nation Climate Assessment 2014). *Vibrio* currently persists in ocean waters that exceed 68°F, which may occur in the future of Morro Bay. As ocean water warms, suitable habitats for pathogens and diseases will move north into previously uninhabitable areas. These changes may also negatively impact the oyster farming industry in the bay. Warmer waters may also allow for parasites and bacteria to have greater survival and transmission.
- Warmer waters may also facilitate algal blooms that can consume DO, shade out eelgrass (*Zostera marina*), and can be toxic to California sea lions (*Zalophus californianus*). Toxic blue algae prefer warm water that allows them to float and absorb sunlight more easily, further increasing water temperatures and shading out the estuary (EPA, 2015). Shallow areas will be more vulnerable due to lack of depth available to buffer temperature changes. This may affect the salt marshes, mudflat habitats, and much of the back bay. However, streams within the watershed will also be very vulnerable. Chorro Creek and Los Osos Creek, and many of their tributaries, are 303 (d) listed by the Clean Water Act for nutrient impairment, a primary factor in algae growth. Chorro Creek also has a high natural source of heavy metals, which is another substrate that algae need to grow. The combination of pollution and warmer

temperatures may facilitate larger and more frequent algae blooms that consume DO and reduce water quality. This is already a problem, as Chorro Creek is 303 (d) listed for low DO levels and the bay has frequently been observed to have algal blooms and low DO in the southern portion of the bay.

3.2.3 Hydrologic Change

- Warmer annual temperatures are projected to decrease the amount of fog days and reduce the moisture provided to the area. In 2010, a study of coastal fog in the eastern Pacific, using long-term airport data, found that the occurrence of summertime fog has declined by 33% over the last 100 years (Johnstone and Dawson, 2010). Projections from this data are uncertain, however, and should only be used as possible discussion of effects. There are many other variables that drive coastal fog that are still not well understood. If coastal fog was to decrease in frequency, it would result in a significant loss of moisture for the area.
- Wetlands and off-channel habitats may dry out earlier in the year from decreased flows.
- Warmer waters can hold less DO (IPCC, 2014). Steelhead trout begin to see impairment when DO drops below 11 mg/L (Karter, 2008).
- Warmer temperatures may stratify the water column in the bay creating a semi-permanent thermocline that can reduce the mixing of DO and nutrients. This may be offset, however, by more intense winds that can cause turbulent mixing.

3.2.4 Environmentally Balanced Uses

- Water supplies will be increasingly stressed by plants, agriculture, and urban demand due to increased heat stress (National Climate Assessment 2014).
- Warm waters can cause oysters to spawn in Morro Bay, which can lead to poor meat quality (George Trevelyan, 2015).
- Temperature criteria for California Men's Colony wastewater treatment plant outflow may need to be reconsidered due to warmer receiving water. In order to minimize effects downstream, it may be necessary to reduce the temperature of discharged effluent.

3.2.5 Ecosystem Restoration/Conservation

- Invasive insects may invade the warmer climate and further reduce fitness of native plant and animal species (McMichael and Bouma 2000, WCS 2008). Insects may migrate from the south or come in through boater traffic.

- Warmer stream temperatures during summer and fall may reduce juvenile rearing habitat quality in the freshwater environment. This may result in decreasing population trends over time.
- Warmer temperatures may favor invasive species over native species. Plant species better adapted to a drier subtropical climate may invade and native plants may migrate north.
- Habitats may become drier and decrease the diversity of plant life that can tolerate the warmer/drier conditions.
- Aquatic and terrestrial species that rely on wetlands and off-channel habitats in the watershed and estuary may need to adapt to possible earlier dry-outs or loss of habitat. Some special species of concern include California red-legged frog (*Rana aurora draytonii*) and southwestern pond turtle (*Actinemys marmorata pallida*) (Sims, 2010).
- Bird migrations may shift in timing or alter their flight patterns in response to climate change. With warmer temperatures, some avian species have begun to migrate earlier in fall and leave earlier in winter, while other birds that were previously sedentary now migrate (Carey, 2009). Species that used to migrate may stay for the winter or may mis-time the food supply along their migration corridor. Migratory bird species that mis-time their food supply may have the strongest decline in populations (Both et al., 2006). While some species may be able to breed and arrive earlier in the season, these processes may be unable to adapt at the rate of climate change (Both et al., 2006).

  These effects on Morro Bay are something to be aware of and have been monitored by the Morro Coast Audubon Society. The National Audubon Society's Climate Change report cited that out of the 588 North American bird species, 314 were listed as climate endangered or threatened (Audubon 2014). The listing as endangered or threatened is differentiated by the area of suitable habitat impacted. Climate endangered species are affected where they currently exist and climate threatened species are impacted where they may exist in the future. The suitable climate maps produced for each bird species individually show significant increases in habitat ranges for most species examined; however, these areas may not provide the necessary forage, nesting areas, and protection from predators (Alfano, 2014). It is uncertain if these impacts will negatively affect Morro Bay. While some bird species may no longer migrate to Morro Bay, other species may begin to in the future. Bird migrations have many complex interactions with the estuary and loss of specialized grazers may impact some habitats that rely on them to keep the trophic levels balanced. However, new specialized species may migrate in and fill the niches that may open up in response. Regardless of these changes, bird species will need to adapt to the changing climate.

Recent observations of adaptations to climate change have been linked to developmental plasticity and behavioral flexibility. These adaptations may not suffice long term, However, as changes will become more drastic than the normal inter-annual variability of food supply and other habitat resources. This may lead to a decline in species that are no longer able to breed in time to match the food supply of the area.

- Increased stream temperatures may negatively affect steelhead and the overall aquatic community. When water temperatures warm, aquatic species have increased metabolic rates that may surpass their food supply and lead to population die offs. South-Central California Coast steelhead trout may not survive in areas with temperatures above 78.8 F |, or an average temperature above 70.7 F | (Moyle et al., 2008). Their optimal mean stream temperature range is 42.8 F | and 50 F |, with mean temperatures exceeding 55.4 F | considered poor habitat (NMFS, 2007). Climate change may cause more sections of the Morro Bay watershed to become unsuitable or poor habitat for steelhead. Climate change conditions may also favor invasive spices, like Sacramento Pikeminnow (*Ptychocheilus grandis*), and crayfish (*Cambrus spp.*) that can compete with native steelhead and tidewater gobies. These invasive species have already been identified in the watershed and may receive a competitive advantage over native species if temperatures warm.
- Warmer water temperatures were attributed to the almost complete extinction of eelgrass in the Chesapeake Bay during a record high summer in 2005 where temperatures exceeded their thresholds for survival (National Climate Assessment, 2014). Eelgrass declines may also cause a decline in Brant geese (*Branta bernicla*) and many other bird and aquatic species that rely on the habitat (Sims, 2010). Loss of eelgrass would destabilize the trophic levels of the estuary and could cause a dramatic shift in species biodiversity and abundance.
- Jellyfish may also invade the bay. In recent history, jellyfish populations have increased from loss of predators and increased food source. However, research on jellyfish has observed a natural 20-year cycle of jellyfish blooms not connected to climate change (Poppick, 2013). Recent examples of jellyfish-filled nets and clogging of infrastructure have piqued public concerns about climate change, but research suggests this is normal behavior. Jellyfish blooms do not present a danger to the Morro Bay ecosystem.

Table 4: Impacts from warmer temperatures and their likelihood.

	Climate change impact likelihood			
	Likely	**Possible**	**Not likely**	**Comments**
Warmer temperatures	Increased urban and agricultural water use			More temperature/moisture stress on plants
	Increased algal blooms and decomposition rates			Warmer waters facilitate algae growth and decomposition
	Increased temperature/moist-ure stress on plants			Warmer/drier climate conditions
	Less DO from warmer water temperatures			Warmer water can hold less oxygen and increases DO consumption
	Bird migration shifts and population declines			Some birds may alter migration cycles or mistime food supplies resulting in lower survival rates
	Less suitable habitat for steelhead			Warmer temperatures may decrease the amount of viable habitat for steelhead
	More algal blooms			Sea otters, steelhead and other aquatic species are sensitive to algal blooms
	Increased water budget stress			More water use to combat drier conditions from all stakeholders

Table 4 continued…

	Climate change impact likelihood			
	Likely	**Possible**	**Not likely**	**Comments**
Warmer temperatures	Eelgrass declines			Warmer waters in the Chesapeake bay are linked to an almost complete extinction of eelgrass in 2010
	Favorable conditions for bacteria			Warmer temperatures allow bacteria to survive longer
	Warmer streams during summer and fall			Warmer streams may reduce rearing habitat quality for steelhead
		Increased use of herbicides/pesticides		Longer growing season may lead to more herbicide/pesticide use
		Introduction of new pathogens/diseases		Warmer waters may allow for new pathogens/diseases to be introduced
		Toxicity of pollutants may increase		Warmer waters may facilitate reactions that produce more toxic forms of pollutants
		Decreased coastal fog		Recent observations show a decrease in coastal fog
		Oyster infections		Warm water bacteria can infect embryos

Table 4 continued…

	Climate change impact likelihood			
	Likely	**Possible**	**Not likely**	**Comments**
Warmer temperatures		Aquatic habitats may dry out earlier		Lower summer flows and increased temperatures may dry out wet habitats earlier in the year
		Favors invasive species		Species better adapted to warmer/drier conditions will be better adapted to climate change
		Invasive insects		Invasive insects may migrate to the warmer climate
			New CMC discharge requirements	Warmer stream temperatures downstream of their effluent may require them to release cooler water
			Semi-permanent thermocline	More intense winds may mitigate thermoclines by mixing bay water
			Invasive species altering fire regime	invasive species have already compromised many communities
			Jellyfish invasion	Studies suggest population booms are natural

3.3 Increasing drought

Drought is defined as "a prolonged period of abnormally low rainfall; a shortage of water resulting from this (Webster)." For this analysis, abnormally low rainfall is considered below the annual average and a prolonged period is over two years. In general, for the southwest region of the United States, there is high confidence that droughts will intensify during the dry season from lack of soil moisture (Southwest Climate Alliance, 2013). This, combined with evidence that heat waves will become longer, more intense, and more frequent, will further compound these effects (National Climate Assessment, 2014)(IPCC, 2014). The regional patterns of drought for Morro Bay and San Luis Obispo show a much more variable rainfall patterns through the years. Current trends seem to be moving towards a less stable precipitation regime with more deviation from the average from year to year. Historical data suggests that wet years will have much greater spikes in precipitation than before and dry years will be more intense and frequent. However, some of these effects may be mitigated by the coastal climate of Morro Bay (Micheli at al., 2010).

The main impact from more intense droughts from climate change is the exacerbation of warmer temperature effects discussed in section 3.2 above.

3.3.1 Accelerated Sedimentation

- More intense droughts may further increase fire risk in the watershed. Loss of ground cover can leave soils vulnerable to sedimentation. This was a major impact after the 1994 highway 41 fire in Morro Bay. Increases in fire risk may not be significant, however, because droughts and wildfire are already part of the ecosystem. Too frequent fires may have greater consequence, but grazing operations may mitigate fuel loads and manage fire prevention.

3.3.2 Bacteria/Nutrients/Toxics

- Drier and hotter droughts will increase water temperatures, which favor bacterial growth, algal blooms, decomposition, and lower DO levels in the estuary and watershed (EPA, 2012).

3.3.3 Hydrologic Change

- Groundwater levels may decline and more saltwater intrusion may occur. This has recently become a problem during the current drought for Los Osos. The drinking water has become increasingly salty from the decreasing aquifer levels (Wilson, 2015). This may also become a threat to Morro Bay's water source as state water is becoming more tightly managed.

- Lower water tables will result in lower base flows year-round and less water available for wetland and off-channel habitats.

3.3.4 Environmentally Balanced Uses

- More frequent droughts may increase water stress in soils and plants. All models predict increased drought stress, regardless of wetter or drier climate, via the Climate Water Deficit estimate. Warmer temperatures year-round will exacerbate the stressors of drought. Plants will be subject to increased evapotranspiration rates, forcing them to increase water uptake to compensate. This may further stress agricultural crops and urban landscapes that will also need to be irrigated more in response (National Climate Assessment, 2014). More water uptake will further decrease available water for riparian and wetland areas.

3.3.5 Ecosystem Restoration/Conservation

- Invasive plant species may also continue to thrive during hotter and drier droughts. Much of the watershed and bay are already influenced by invasive species, but climate change may make eradicating them much more difficult as they may become more resilient than native species.
- Many aquatic and terrestrial species rely on wetlands and off-channel habitats in the watershed and estuary, and will need to adapt to earlier dry-outs or loss of habitat. Most native flora and fauna are adapted to drought conditions given the area's historic climate, but with drier conditions and more intense heat, these adaptations may be compromised.
- Steelhead trout migrations may be further impacted by low flows. Recent history suggests that steelhead are already under stress from low flow conditions and climate change impacts will likely exacerbate them.
- As previously stated, warmer water temperatures were attributed to the almost complete extinction of eelgrass in the Chesapeake Bay during a record high summer in 2005, in which temperatures exceeded their thresholds for survival (National Climate Assessment, 2014). More intense droughts exacerbate these warm water effects.

Table 5:Impacts from increased drought and their likelihood.

	Climate change impact likelihood			
	Likely	**Possible**	**Not likely**	**Comments**
Increased Drought	Decreased DO levels			Warmer water holds less DO and facilitates algal blooms and decomposition
	Loss or early dry-out of wetland habitats			Drier conditions and lower water tables will supply less water and more will be lost to evaporation.
	Increased moisture/temperature stress on plants			Drier conditions overall
	Stressed water budget			Drier conditions leading to increased water use
	Saltwater intrusion			Lower groundwater levels will increase saltwater intrusion
	Thermal pollution			Low drought flows and warmer conditions will increase water temperatures
	Favors invasive plant species			More intense droughts may favor invasive plant species that are more drought tolerant

Table 5 continued…

	Climate change impact likelihood			
	Likely	**Possible**	**Not likely**	**Comments**
Increased Drought	Loss of specialized wetland species			Early dry out and loss of wetland habitats may cause a loss in specialized species that rely on them for habitat
	Decline in eelgrass			Warmer waters linked to decline in Chesapeake bay
		Increased fire season length and frequency		Longer and more intense droughts may increase fire risk

3.4 Sea Level Rise

Using the NOAA Coastal Service Center's "Digital Coast Sea Level Rise and Coastal Flooding Impacts Viewer," the areas most vulnerable to sea level rise were identified. These include the mud flats, South Bay Boulevard, Los Osos Creek and Chorro Creek, the Los Osos Creek Bridge, and Sweet Springs Nature Preserve. Water levels are predicted to inundate the mud flats in the estuary and abut South Bay Boulevard. Water may move past the Los Osos Creek Bridge and pool upstream of the current estuary. In Los Osos, the Sweet Springs Nature Preserve is predicted to be inundated as well.

3.4.1 Accelerated Sedimentation:

- Sea level rise may inundate areas in the Back Bay and throughout the estuary that have been aggrading over time. This may mitigate some of the negative effects of sedimentation in the estuary by raising the water levels to compensate.
- Higher sea levels may increase or migrate areas of salt marsh and mudflats. These areas provide good habitat for many unique native species. If the aggradation of the estuary exceeds the increase in water level than the back bay may be converted to salt marsh and mudflat.

- Increased water levels in the estuary may cause a shift in suitable habitat for eelgrass as some of their current habitat extent becomes deeper.
- Sea level rise may reduce the retention time of sediments and water in the back bay. In recent history, this part of the estuary has been aggrading and retention times have increased from the reduction in water depth. With higher water levels, tidal influence and wind on this area of the estuary may help mitigate aggradation and flush out water and sediments more frequently.
- Increases in coastal erosion may occur in some areas. Fortunately, the sandspit may mitigate much of the sea level rise and its effects on the coast and communities. However, it may also lose some of its buffering capacity from storm surges and tidal influence. The net effect is uncertain, as the sandspit may also build up due to littoral sand transport.

3.4.2 Bacteria/Nutrients/Toxics

- Large storm surges may have a stronger ability to flush in-bay pollutants.

3.4.3 Hydrologic Change

- Ocean water moving further upstream in the estuary may increase salt water intrusion into the groundwater table and alter the salinity gradient (National Climate Assessment, 2014). This will have important implications for Los Osos, which relies on groundwater for its water supply, and Morro Bay, which is allotted state water but may need to find other sources in the future.

3.4.4 Environmentally Balanced Uses

- Some infrastructure, such as South Bay Boulevard, parts of Los Osos, and Coleman Road, may need to be closed during large storm surges or king tides. These areas may be increasingly more vulnerable to tidal influences.
- Another major concern is the combination of storm surges with flooding events. Looking at areas vulnerable to flood and sea level rise, it is possible that the combination could endanger infrastructure near the confluence of Los Osos and Chorro Creek with the estuary. Los Osos is currently vulnerable to flooding in some areas regardless of climate change. Sea level rise effects and flooding events may not significantly increase the risk of flooding in Los Osos.

3.4.5 Ecosystem Restoration/Conservation

- Many unique habitats in the estuary may be subject to changes in salinity. This may cause vegetation communities to migrate, if possible. Estuary habitats support an abundance of unique flora and fauna that will need to adapt to the changes in salinity over time and those that cannot may be lost.

Table 6: Impacts from sea level rise and their likelihood.

Sea Level Rise	Climate change impact likelihood			
	Likely	**Possible**	**Not likely**	**Comments**
	Increased salt water intrusion			Ocean water and influence will move further inland
	Change in wetland inundation frequency and salinity			Salt marsh, brackish/freshwater wetlands, and mudflats will become more frequently inundated and influenced by salinity
	Shift/increase in suitable eelgrass habitat			Some areas may be inundated allowing for eelgrass to populate while others may become too deep
	Reduced water/sediment retention times			The back bay will have deeper water, which may improve circulation
	May mitigate aggradation of the back bay			As the base elevation of the back bay increases, sea level rise may offset the elevation gain or create salt marsh and mudflats in the future

Table 6 continued…

	Climate change impact likelihood			
	Likely	**Possible**	**Not likely**	**Comments**
Sea Level Rise	Increased infrastructure risk			Many low-lying areas near the bay will be more vulnerable to king tides/storm surges
	Salt marshes may move inland			Higher water may inundate historic wetlands and migrate them inland
		Loss of specialized wetland species intolerant of salinity change		Species unable to migrate to new habitats and intolerant of salinity change may be lost

3.5 Ocean Acidification

Ocean pH is projected to acidify by 0.3 to 0.4 from an average of 8.0, by 2100. The decrease may lower the saturation levels of calcite and aragonite in the ocean (Raven et al., 2005). These compounds are key substrates needed to form the calcium carbonate shells of invertebrate species. Decreasing calcium carbonate substrates will lead to less of it available for shellfish and less to be contributed to the nutrient cycles of the ocean. These effects may be offset, however, by increasing water temperatures that raise the saturation level for aragonite and calcite (Raven et al., 2005).

Ocean acidification has been affecting oyster farms in the Pacific Northwest for the past decade. Oysters rely on aragonite to form their initial shells and in acidic waters it becomes less available and can cause mass die-offs of young oysters. In the Pacific Northwest, hatcheries are unable to pump ocean water or have had to add sodium carbonate to raise the pH (National Climate Assessment, 2014). This has led to seed shortages throughout oyster farms in the United States. Morro Bay hosts two oyster farms that rely on these hatcheries to buy their seed. The Pacific oysters (*Crassostrea gigas)* are not native to Morro Bay and are unable to produce viable seed in the bay. This is why the Morro Bay oyster farms are so reliant on the Pacific Northwest hatcheries. While problems with acquiring seed have caused trouble for oyster farms in the bay, they have not had any adverse growth affects from low pH levels on their product.

3.5.1 Bacteria/Nutrients/Toxics

- Lower pH may result in increased toxicity of pollutants and more free metals. However, pH change will not be significant enough to catalyze such reactions. These effects are seen when pH drops below 6.5, which is not projected for Morro Bay (CADDIS, 2012).

3.5.2 Environmentally Balanced Uses

- Oyster hatcheries in the Pacific Northwest may no longer be able to produce viable seed. This would force closures of oyster farms that rely on their hatcheries, including farms in Morro Bay.
- More acidic waters may corrode infrastructure in the bay and estuary more rapidly. Corrosion rates of pipes, boats, pilings and many other metal fixtures that are inundated by sea water may increase. This effect has been found to be insignificant, however, since the decrease in pH is not enough to increase corrosion rates significantly (Raven et al., 2005).

3.5.3 Ecosystem Restoration/Conservation:

- More acidic ocean water may increase the amount of ionic compounds and favor the dissolution of aragonite and calcite. This would negatively impact estuary species that need calcium carbonate to develop (Raven et al., 2005).
- Steelhead trout have an optimal pH level between 7.0 and 8.0, but can survive anywhere from 5.8 to 9.6 (Moyle, 2002). Ocean acidification projections do not go below this range in Morro Bay. The worst case scenario for ocean pH is 7.8.

Table 7: Impacts from ocean acidification and their likelihood.

Ocean Acidification	Climate change impact likelihood			
	Likely	**Possible**	**Not likely**	**Comments**
	pH-sensitive species loss of fitness			Aquatic species sensitive to pH may lose some fitness
		Decrease in available substrates for $CaCO_3$ users		Oysters and other shellfish in danger
		Seed shortage or loss of PNW hatcheries		Current seed shortage and production problems
			Corrosion of infrastructure	Corrosion may increase but not enough to garner significance
			Increased pollutant toxicity	Decrease in pH is not significant enough

3.6 Possible Offsetting Impacts

- High precipitation years may increase groundwater recharge and raise the water table. This may mitigate the effects of decreasing summer low flows and possibly drought. Local precipitation data shows a trend towards more frequent high rainfall years (above 30 inches) allowing for more subsurface storage. This may extend groundwater supplies into subsequent years.
- Sea level rise may improve habitat in the back bay by providing more water and allowing for more tidal influence to help with flushing of sediments and pollutants, and increasing DO. Recently, aggradation of the estuary has caused waters and sediments to stagnate in the back bay as water becomes shallower. Sea level rise may counteract these impacts by deepening water which can decrease temperatures, reduce resistance to mixing, and inundate areas that are aggrading.
- Acidification of the ocean may lower the amount of calcium carbonate that the estuary can hold. This can impact oysters and other shellfish and plankton that rely on calcium carbonate to produce their shells. This impact may be offset, however, by warmer water temperatures that can increase the amount of calcium carbonate the estuary can hold. This may reduce acidification impacts to below levels of significance.

3.7. Possible Compounding Impacts

- As the sea level rises, it may begin to reduce the land area of the sandspit and therefore reduce its buffering capacity of storms and storm surges. Less sandspit area may lead to more breaching during storms and king tides, lessening its ability to protect the bay from storm impacts. It is uncertain, however, if the sandspit will build up in response or shift further inland.
- Higher sea levels and more powerful storms may combine to create large flood events from storm surges and peak flows. This may endanger many of the low lying areas around the bay. Areas of high concern are Coleman Road, South Bay Boulevard, and parts of Los Osos. These areas are most susceptible to sea level rise which may be compounded by storm surges. Large peak flows may exacerbate these effects in the estuary, increasing susceptibility to flooding.

4. Significance (Severity) vs. Probability (Likelihood)

Individual climate change risks were separated into their stressors and sorted by the likelihood and consequence of their impacts. Likelihood and consequence were discussed are discussed in section 3. By organizing each impact in the following tables, they can be prioritized in the future adaptation plan. Impacts are color-categorized by their significance: green is low priority, yellow is moderate priority, and red is high priority. Also, impacts that may have a positive effect are noted by a plus sign.

4.1 Increasing Storminess

Table 8: Likelihood v. Consequence table for increasing storminess.

Likelihood of occurrence				
	High	**1. More frequent and intense peak flows disrupting steelhead**	**1. Sedimentation increase** **2. Increased landscape and stormwater runoff** **3. More frequent floods** **4. More frequent oyster closures**	**1. Increased frequency and intensity of pollution-flushing events** **2. Erosion and aggradation of estuary**
	Medium	**1. More frequent landslides** **2. More groundwater recharge (+)**	**1. Altered flood-prone area habitat**	
	Low			**1. More frequent flooding**
		Low	**Medium**	**High**
	Consequence of impacts			

4.2 Warmer Temperatures

Table 9: Likelihood v. Consequence table for warmer temperatures.

Likelihood of occurrence	**High**		**1. Increased biological activity (decomposition./metabolism/ bacteria/etc.)** **2. Drier habitats** **3. Alteration of bird migration pattern and population declines**	**1. Increased agricultural/urban water use** **2. More frequent algal blooms** **3.Temperature stress on plants** **4. Lower DO levels**
	Medium		**1. Increased use of pesticide/herbicide** **2. Favorable conditions for invasive plants and insect** **3. Thermal pollution of streams and estuary s**	**1. Favorable conditions for new pathogens/diseases and bacteria** **2. Oyster infections** **3. Eelgrass population declines**
	Low	**1. Jellyfish invasion**	**1. Semi-permanent thermocline**	**1. More frequent fire** **2. CMC lower temp. discharge requirements** **3.Less coastal fog** **4. More toxic pollutants**
		Low	**Medium**	**High**
			Consequence of impacts	

4.3 Increasing Drought

Table 10: Likelihood v. Consequence table for increasing drought.

Likelihood of occurrence	**High**			**1. Decreased DO levels** **2. Early dry-out of wetlands** **3. Increased drought stress** **4. Thermal pollution** **5. More frequent algal blooms** **6. More salt water intrusion**
	Medium		**1. Favorable conditions for invasive plants and insects**	**1. Eelgrass population declines** **2. Loss of specialized wetland species**
	Low			**1. More frequent fires**
		Low	**Medium**	**High**
	Consequence of impacts			

4.4 Sea Level Rise

Table 11: Likelihood v. Consequence table for sea level rise.

Likelihood of occurrence				
	High		**1. Wetlands becoming more salty or inundated** **2. Salt marsh/mudflat migration inland**	**1. Increased salt water intrusion**
	Medium	**1. Reduced retention times in the back bay (+)** **2. Mitigate warmer bay waters (+)** **3. Mitigate aggradation of estuary (+)**	**1. Shift in eelgrass habitat** **2. Loss of specialized wetland species intolerant to salinity change** **3.Increased infrastructure risk**	
	Low			
		Low	**Medium**	**High**
	Consequence of impacts			

4.5 Ocean Acidification

Table 12: Likelihood v. Consequence table for ocean acidification.

Likelihood of occurrence	**High**	**1. Loss of pH-sensitive species fitness**		
	Medium		**1. Seed shortage or loss of PNW hatcheries**	
	Low	**1. Corrosion of infrastructure** **2. Increased toxicity of poll**	**1. Decrease in available aragonite/ calcium carbonate**	
		Low	**Medium**	**High**
		Consequence of impacts		

4.6 Discussion

By sorting impacts into color categories via the probability vs. significance tables, climate change effects were prioritized by level of concern. Out of 54 impacts, 27 were listed in red boxes of high priority, 17 were listed in yellow boxes of medium priority, and 10 were listed in green boxes of low priority.

5. High Significance – High Likelihood Effects (Red Box)

Discussion on the impacts and likelihood of each stressor can be found in Section 3 above.

Increasing storminess

1. Increased frequency and intensity of pollution flushing events

2. Sedimentation increase

3. Increased erosion and aggradation of the estuary

4. Increased landscape and stormwater runoff

5. Increased frequency of flood events

6. Increased frequency of oyster closures

Warmer temperatures

1. Increased agricultural and urban water use

2. More frequent algal blooms

3. Increased temperature stress on plants

4. Lower DO levels

5. Drier habitat conditions

6. Alteration of bird migrations and population declines

7. Increased biological activity (decomposition./metabolism/bacteria/etc.)

8. Favorable conditions for new pathogens/diseases and bacteria

9. Oyster infections from warm water bacteria

10. Eelgrass population declines

Increasing drought

1. Decreased DO levels

2. Early dry-out of habitats

3. Increased drought stress on plants and animals

4. Thermal pollution of streams and the estuary

5. More frequent algal blooms

6. Eelgrass population declines

7. Increased salt water intrusion into local aquifers

8. Loss of specialized wetland species

Sea level rise

1. Increased salt water intrusion into local aquifers

2. Salt marsh/mudflat migration inland

3. Change in wetland inundation frequency and salinity

6. Future Mitigation/Adaptation Planning

Risks are broken down by their priority zone (red/yellow/green) and the approach to be taken. Discussion and information on each of the climate change stressors can be found in section 3. Identification of priority issues can be found in Section 4.

Approach definitions

Mitigate: Risks that have a potential action that can lower the risk level and create a win-win situation. Actions may include planting riparian shade plants or restoring floodplain connectivity.

Transfer: Another organization may be working towards reducing a certain risk already and the Estuary Program may participate in the effort, but will not be the lead.

Accept: The Estuary Program accepts that climate change may bring on some impacts but no actions are identified at this time. Impacts will continue to be monitored and reviewed.

Avoid: An impact is identified as increasing with climate change, but focusing resources on reduction is not feasible.

6.1 Possible Transfer Organizations

Organizations with overlapping interests and resources that may be able to collaborate on climate change mitigations are listed in the below table. These organizations and agencies may be able to share resources and take responsibility of some mitigation efforts.

Table 13: List of partners and organizations.

Partners/organizations	**Common Goal/objective/work area**
Morro Coast Audubon Society	Bird populations, habitat protection
Black Brant Group	Brant populations/eelgrass restoration
City of Morro Bay	Estuary and bay tourism, infrastructure development (i.e., expansions along waterfront that may impact eelgrass, boat haul-out facility, etc.), stormwater management, wastewater management
California State Parks	Mudflats and watershed health, habitat protection, monitoring of sensitive species, identification and removal of invasives
Watershed Stewards Partnership	Watershed health

Table 13 continued…

Partners/organizations	Common Goal/objective/work area
Cal Poly	Education/eelgrass/water quality
Natural Resource Conservation Service	Conservation of ecosystems, development of implementation projects
California Department of Fish and Wildlife	Steelhead/other sensitive species/CCER
Cal Trans	Highways, development/protection of infrastructure
United States Forest Service	Manage upper-watershed land
Nation Oceanic and Atmospheric Administration	Coastal grants
ECOSLO	Volunteers for ecosystem health/trail repair
State Coastal Conservancy	Conservation of coastal habitats
Land Conservancy of San Luis Obispo County	Conservation of ecologically important land, restoration work
Los Osos Community Services District	Local community service coordination, public education, stormwater management, water quantity/basin management
Small Wilderness Area Preservation	Elfin forest management, public education
San Luis Obispo County	Planning for the area, stormwater management, water management, wastewater management
Central Coast Regional Water Quality Control Board	Water quality, stormwater management, project funding
U.S. Environmental Protection Agency	Funding, policy guidance, regulatory guidance
State Water Resources Control Board	Funding
California Conservation Corps	Restoration projects
Central Coast Salmon Enhancement	Habitat acquisition and management, education
Trout Unlimited	Restoration efforts
San Luis Obispo Botanical Garden	Education and outreach
Cuesta College	Education and outreach
San Luis Obispo County Office of Education	Education and outreach
California Men's Colony	Wastewater treatment plant impacts to Chorro Creek
Morro Bay Natural History Museum	Education and outreach
Camp San Luis Obispo National Guard Base	Stormwater management

6.2 Increasing Storminess

Table 14: List of approaches to increasing storminess impacts.

Risk	**Red/Yellow/or Green Severity Level**	**Approach (mitigate/transfer/accept/avoid)**
1. Sedimentation increase	Red	Mitigate/transfer
2. More frequent floods	Yellow	Mitigate
3. Aggradation of estuary	Red	Mitigate
4. More intense and frequent pollution flushes	Red	Mitigate
5. More frequent oyster closures from bacteria pollution	Red	Mitigate
6. Landscape runoff increase	Red	Mitigate/accept
7. Increased stormwater runoff	Red	Mitigate
8. Altered flood prone area habitat	Yellow	Accept
9. Increased groundwater recharge	Green	Accept
10. More frequent landslides	Green	Accept
11. High stream velocities disrupting steelhead	Yellow	Mitigate

6.3 Warmer Temperatures

Table 15: List of approaches to warmer temperature impacts.

Risk	Red/Yellow/or Green Severity Level	Approach (Mitigate/Transfer/Accept/Avoid)
1. Increased decomposition rate	Red	Mitigate
2. Drier habitats	Red	Mitigate
3. Increased urban/AG water use	Red	Transfer
4. Algal blooms	Red	Accept
5. Temperature stress on plants	Red	Accept
6. Lower DO levels	Red	Mitigate
7. Thermal pollution	Yellow	Mitigate
8. Favorable conditions for new pathogen/diseases/bacteria	Red	Transfer
9. Less coastal fog	Yellow	Accept
10. Formation of more toxic pollutants	Yellow	Mitigate
11. Oyster infections	Red	Accept
12. Favorable for invasive insects	Yellow	Accept
13. Bird and fish migration shifts	Yellow	Accept
14. Increased use of pesticides/herbicides	Yellow	Transfer
15. Favorable for invasive plant species	Yellow	Mitigate/transfer
16. CMC temperature discharge requirements	Yellow	Accept/transfer
17. Jellyfish invasion	Green	Accept
18. More frequent fire	Yellow	Mitigate/transfer
19. Semi-permanent thermocline	Green	Accept
20. Eelgrass declines	Red	Mitigate

6.4 Increasing Droughts

Table 16: List of approaches to increasing drought impacts.

Risk	**Red/Yellow/or Green Severity Level**	**Approach (Mitigate/Transfer/Accept/Avoid)**
1. Loss of specialized wetland species	Red	Mitigate
2. Decreased DO	Red	Mitigate
3. Increased drought stress	Red	Accept
4. Thermal pollution	Red	Mitigate
5. Early dry out of habitats	Red	Mitigate
6. Algal blooms	Red	Mitigate
7. Eelgrass declines	Red	Mitigate
8. Salt water intrusion	Red	Mitigate
9. More frequent fires	Yellow	Mitigate/transfer
10. Favorable for invasive species	Yellow	Mitigate/transfer

6.5 Sea level Rise

Table 17: List of approaches to sea level rise impacts.

Risk	**Red/Yellow/or Green Severity Level**	**Approach (Mitigate/Transfer/Accept/Avoid)**
Increased salt water intrusion	Red	Mitigate
Wetlands becoming more salty/inundated	Red	Mitigate
Shift/increase in suitable eelgrass habitat	Yellow	Mitigate
Reduced water/sediment retention times	Green	Accept
Mitigate aggradation of Back Bay	Green	Accept
Mitigate increases in temperature	Green	Accept
Increased infrastructure risk	Yellow	Accept
Salt marshes/mudflats migrate inland	Red	Mitigate
Loss of specialized wetland species intolerant of salinity change	Yellow	Mitigate/accept

6.6 Ocean Acidification

Table 18: List of approaches to ocean acidification impacts.

Risk	**Red/Yellow/or Green Severity Level**	**Approach (Mitigate/Transfer/Accept/Avoid)**
pH-sensitive species loss of fitness	Yellow	Accept
Seed shortage or loss of PNW hatcheries	Yellow	Accept
Decrease in available substrates for CaCO3 users	Green	Accept
Increased pollutant toxicity	Green	Accept
Corrosion of infrastructure	Green	Accept

6.7 Possible Mitigations/Adaptations

Possible adaptation actions are listed in the table below. These actions are judged on whether they can effectively reduce the likelihood and impacts of climate change risks.

Table 19: List of potential adaptation actions.

Risk	Potential adaptation action	Could this action reduce likelihood (by itself or in combination with others)?	Could this action reduce impacts (by itself or in combination with others)?
1. Sedimentation	Levee removal projects	Yes	Yes
	Large woody debris installation	Yes	Yes
	Floodplain restoration	Yes	Yes
	Transfer some mitigations to CA DFW/State Parks	Yes	Yes
2. More frequent floods	Widen stream buffers	No	Yes
3. Warmer water temps.	Plant evergreen resilient shade trees in upland tributaries	Yes	Yes
	Lower CMC discharge temps	Yes	Yes
4. Drier habitats	Plant species that maintain soil moisture	Yes	Yes
5. Algal blooms	Riparian fencing and off-creek water	Yes	Yes
	Stream shading (decrease temps)	Yes	Yes
	Stormwater management	Yes	Yes
6. Drought stress	Plant drought-tolerant plants	No	Yes
	Rainwater harvesting	Yes	Yes
	Water conservation	Yes	Yes
	Create swales	No	Yes

Table 19 continued…

Risk	Potential adaptation action	Could this action reduce likelihood (by itself or in combination with others)?	Could this action reduce impacts (by itself or in combination with others)?
7. Salt water intrusion	Los Osos recycled water	Yes	Yes
	Rain water harvesting	Yes	Yes
	Water conservation	Yes	Yes
8. Fires	Reduce fuel loads/fire management with Cal Fire	Yes	Yes
	Reduce invasive species	No	Yes
9. Invasive species	Removal projects	Yes	Yes
	Prescribed grazing/fires	Yes	Yes
10. Sea Level Rise	Support local planning efforts that protect buffer and migration areas from development and encourage climate smart growth	No	Yes
	Facilitate plant migration	No	Yes

6.8 Selecting Adaptation Actions

The criteria for assessing actions are a combination of multiple considerations including feasibility and effectiveness, cost and cost-effectiveness, ancillary costs and benefits, equity and fairness, and robustness. These terms are explained below.

Risk reduction potential: This was presented in section 6.7 above. This table reaffirms that the adaptation action listed will reduce the risk of climate change impacts.

Feasibility and effectiveness: Is this action a proven strategy and has it been proven to be successful? Is it politically feasible? Is implementation timely enough to reduce impacts before they occur? Would the local community and stakeholders support this action? Is there permission or authority to implement this action?

Cost and cost-effectiveness: Is the cost minor (M), similar to municipal public works (S), very expensive (VE), or not possible (NP)? Is this a reasonable cost for risk reduction? Is there a long-term maintenance cost? Will future costs be avoided?

Ancillary costs and benefits: Is the action maladaptive? Are there any co-benefits to other areas? Is the action sustainable? Beneficial to other areas (B) or maladaptive (M).

Equity and fairness: Does it align with the Estuary Program’s goals? Does the action disproportionately affect parts of the community? Yes the action is equal and fair (Y), or no, the action disproportionately affects others (N).

Robustness: Will this action do well under the multiple possible future climate scenarios? Is the action flexible enough to be changed in the future if conditions vary from those predicted? How much is being invested into his action? Is it a no-regrets action?

Table 20: Adaptation action assessment table.

Adaptation Actions	Risk Reduction Potential	Feasibility and effectiveness	Cost and cost-effectiveness	Ancillary costs and benefits	Equity and fairness	Robustness	Appropriate to proceed with this action?
1. Levee removal projects	Yes	High	VE	B	Y	Robust and adaptive	No
2. LWD installation	Yes	High	VE	B	Y	Robust but maladaptive	No
3. Floodplain restoration	Yes	High	S	B	Y	Robust and adaptive	Yes
4. Transfer some mitigations to CA DFW/State Parks	Yes	Moderate	M	M	Y	Unknown	No
5. Create swales	Yes	High	S	B	Y	Robust and adaptive	Yes
6. Widen stream buffers	Yes	High	M	B	Y	Robust and adaptive	Yes
7. Plant evergreen, resilient, shade trees in upland tributaries	Yes	High	S	B	Y	Robust and adaptive	Yes
8. Lower CMC discharge temps	Yes	Low	VE	B	Y	Robust but maladaptive	No
9. Plant species that maintain soil moisture	Yes	High	S	B	Y	Robust and adaptive	Yes

Table 20 continued…

Adaptation Actions	Risk Reduction Potential	Feasibility and effectiveness	Cost and cost-effectiveness	Ancillary costs and benefits	Equity and fairness	Robustness	Appropriate to proceed with this action?
10. Riparian fencing and off creek water	Yes	High	M	B	Y	Robust and adaptive	Yes
11. Stream shading	Yes	High	S	B	Y	Robust and adaptive	Yes
12. Stormwater management	Yes	High	S	B	Y	Robust and adaptive	Yes
13. Plant drought tolerant plants	Yes	High	S	B	Y	Robust and adaptive	Yes
14. Los Osos recycled water	Yes	High	M	B	Y	Robust and adaptive	Yes
15. Water Conservation	Yes	High	M	B	Y	Robust and adaptive	Yes
16. Reduce fuel loads/ work with Cal Fire	Yes	Moderate	M	B	Y	Robust and adaptive	No
18. Invasive species removal projects	Yes	Moderate	S	B	Y	Robust and adaptive	Yes
19. Prescribed grazing/fires	Yes	Moderate	M	B	Y	Robust and adaptive	Yes

Table 20 continued…

Adaptation Actions	Risk Reduction Potential	Feasibility and effectiveness	Cost and cost-effectiveness	Ancillary costs and benefits	Equity and fairness	Robustness	Appropriate to proceed with this action?
20. Support local planning efforts that protect buffer and migration areas from development and encourage climate smart growth	Yes	High	S	B	Y	Robust and adaptive	Yes
21. Facilitate plant migration	Yes	Moderate	S	B	Y	Robust but maladaptive	No
22. Rain water harvesting	Yes	High	S	B	Y	Robust and adaptive	Yes

6.9 Summary of Adaptation Actions and Program Goals

Out of the 22 potential adaptation actions formulated by the MBNEP, 15 were chosen. These actions were seen as the most feasible and beneficial to the Estuary Program and provided the best reduction of climate change risks. Actions were also chosen for their adaptability to the range of future climate projections and the ecosystem improvements they provide regardless of climate change.

6.9.1 Proposed Adaptation Actions

- Floodplain restoration

Floodplain restoration provides benefits to water quality, ecosystem restoration, and water conservation. Better connection of streams to their floodplains can reduce sedimentation, enhance groundwater recharge, and create and improve habitats in the area. Regardless of future climate change, this action will reduce risk to the Estuary Program's goals. Some of these risks include drier conditions and more frequent intense storms. The MBNEP has been involved in many past floodplain restoration projects and plans to continue to be involved in these projects in the future.

  - Create swales

Floodplain restoration may include the creation of swales. Swales allow for increased groundwater recharge, and filtration of pollutants. They provide important habitat for many plant and animal species. These areas may also reduce the risk of flooding and provide refuge during intense droughts.

  - Widen stream buffers

Projects may also encompass the planting of riparian species to widen stream buffers. By allowing high stream flows to spread across more of the adjacent landscape and provide moisture to plants and soils, the stream buffer areas will expand. This allows for more habitat shade and refuge from future heat extremes and droughts.

- Plant evergreen, resilient shade trees in upland tributaries

As the climate changes, so will the vegetation that can tolerate it. Planting of drought-tolerant species that provide perennial shade will be necessary around stream sections that are open to sun exposure. As the climate warms and becomes drier, increased shade plants will protect waterbodies in the Morro Bay watershed from thermal pollution and evaporation. These efforts will mostly focus on upland tributaries that have little shade.

- Plant species that maintain soil moisture and are drought tolerant

  Species chosen for planting should be adept at maintaining soil moisture and be drought tolerant. As conditions become drier, plants that exhibit these characteristics will have a competitive advantage over other species and will be able to survive into the future. This will require adapting plantings to these types of species so that efforts are not wasted on plants that will not be able to survive the future climate conditions.

- Stream shading

  Improving stream shading through planting efforts will buffer streams from increasing surface temperatures. Increases in water temperatures can have many detrimental impacts to freshwater ecology in the Morro Bay watershed.

- Riparian fencing

The MBNEP has been, and continues to be, involved in riparian fencing installation. In the future, large and intense rainfall events may carry pollutants and erode landscapes that serve as rangeland and agriculture. Installing riparian fencing may help mitigate these effects to levels below significance. Keeping livestock and row crops that can compact soils or leave them vulnerable to erosion further from the stream corridor will reduce their influence on ecosystem processes that are vulnerable.

- Stormwater management

More frequent and intense storms will increase inputs of stormwater and pollution into the estuary and watershed. Currently, San Luis Obispo County, the City of Morro Bay, and the CCC have stormwater management plans. In the future, MBNEP may become more involved in implementation and monitoring of stormwater BMPs. Reduction in stormwater pollutants will reduce the risk of algal blooms and impacts on sensitive species.

- Water Conservation

While the Morro Bay climate naturally experiences periodic droughts, the future is projected to become drier and warmer across all scenarios. This will lead to more intense droughts and increase the need for water conservation. Depletion of groundwater will also contribute to more salt water intrusion that may be compounded by sea level rise. Current projects have been undertaken by the MBNEP and surrounding communities to improve the conservation of water.

- Los Osos Recycled water

By 2016, The Los Osos wastewater treatment plant is expected to be completed. The effluent water produced by the treatment plant is planned for reuse and injection into the aquifers below. The Los Osos aquifers are already experiencing pollution from salt water intrusion and septic tank pollutants. By eliminating the majority of septic systems and injecting water into the groundwater table, these effects may be mitigated.

- Rainwater harvesting

MBNEP, Cal Poly, NOAA, and CCC collaborated to install a rainwater harvesting plant on Pennington Creek. The installation served as a source of water for livestock operation in the area to reduce the uptake of ground and stream water. The success of this project will likely influence the proposal for more harvesting plants in the future. By reducing uptake from rangeland and agriculture, stream may have higher and longer lasting flows while also enhancing groundwater recharge. Providing off-creek water will also keep livestock away from the riparian corridors and reduce their impacts on nearby streams.

- Invasive plant species removal projects

The Morro Bay watershed has multiple areas that have been impacted by invasive plant species. Invasive plants can alter ecosystem processes and limit biodiversity. Biodiversity allows plant communities to better respond to natural disasters, such as climate change. Some ecosystem processes may also be altered, such as fire regime, erodibility of soils, and habitat composition.

The MBNEP produced an Invasive Species Management Plan in 2010 that provided guidelines for early detection, prevention, rapid response, control and management, and education and outreach. This program has been effective in preventing new species from colonizing within the estuary and watershed. Pressures from invasive species will only increase in the future as climate continues to become more favorable for these plants. Continued focus and engagement from partners on prevention and projects that remove invasive species will remain necessary in the future.

- Prescribed grazing/fires

Invasive species removal has proven to be extraordinarily difficult. Some methods that may be applied are prescribed grazing and fire. Many invasive species are more flammable than natives and can increase fire frequency, especially with the predicted drier climate. To reduce fire risk, controlled grazing or burning of fuels may be necessary. Management of these methods can also reduce invasive species reproduction and favor native species in the area. The implementation of such projects could provide a great benefit to ecosystem functioning in the estuary and watershed and better prepare them for climate change.

- Support local planning efforts that protect buffer and migration areas from development and encourage climate smart growth

As sea levels rise, they are projected to inundate the mud flats, Los Osos and Chorro Creek, and Sweet Springs Nature Preserve. Conservation of the areas around projected sea levels will be necessary to facilitate the migration of vital estuary habitats. Avoiding development in these areas may better prepare the area for climate change and protect the many functions of the estuary.

Other climate-smart planning may include conservation of high biodiversity areas, climate refuge, and protection of migration corridors. Areas of high conservation priority may include north-facing slopes, riparian corridors, and other open space.
Some of these efforts have been explored in other planning efforts, such as the UCSB Bren School of Environmental Science and Management report mentioned in section 2.5.

6.9.2 Other Agencies Adaptation Actions

- The Los Osos Community Service District has been drafting a septic system reuse report. The document will provide guidelines for stormwater and gray water reuse using the decommissioned septic systems on Los Osos residence properties. This may help provide more efficient water use and groundwater recharge to the area, while also reducing stormwater pollution.
- The Coastal RCD has also begun a Climate Ready Rangeland project in the Morro Bay watershed to prepare for climate change. This project involves the implementation of multiple water conservation and soil building methods, and improving grassland ecosystem health. Implementation will demonstrate climate ready management of rangelands for the many other cattle ranchers in the area with a full report expected in 2017.

6.9.3 Monitoring and Review

The Climate Vulnerability Assessment will be monitored and reviewed every 5 years. This matches the frequency of the MBNEP Comprehensive Conservation Management Plan (CCMP). Updates to this report will be necessary, as climate change effects on Morro Bay become more certain in the future and restoration projects are completed.

7. Appendix

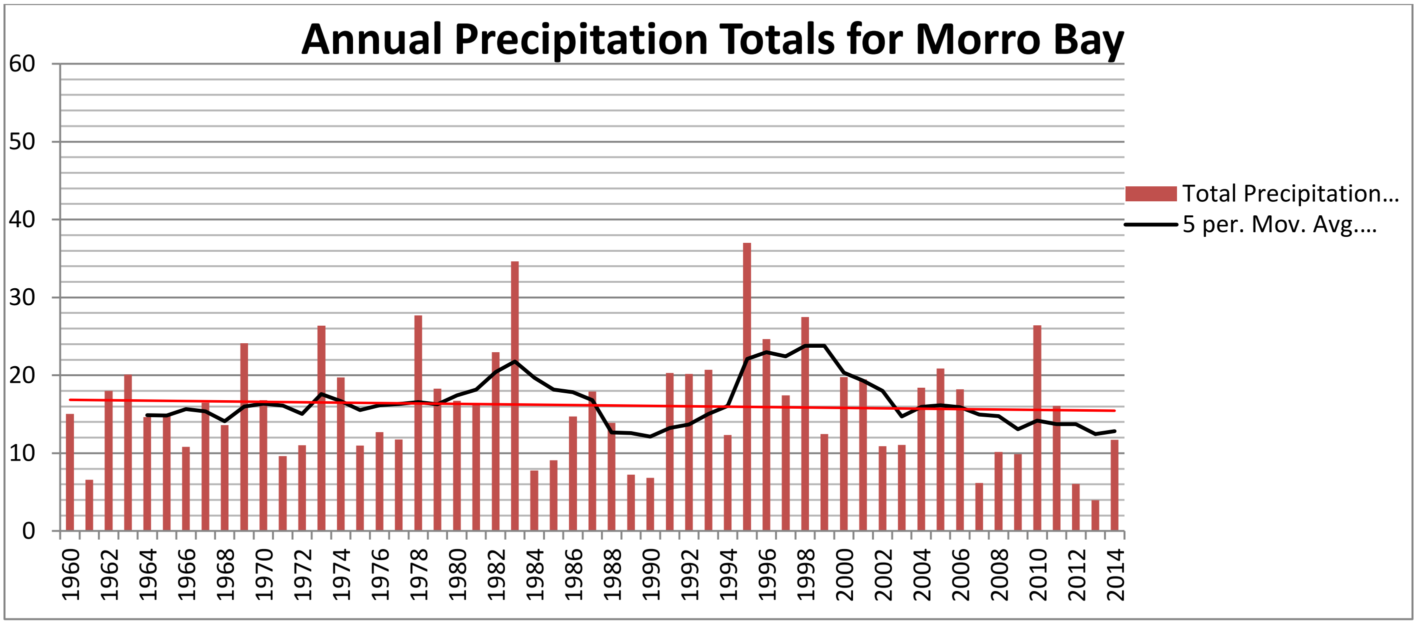

Figure 17: Morro Bay precipitation data starting in 1960, including the 5-year and annual-average trend lines. Data is from the Morro Bay Fire Department.

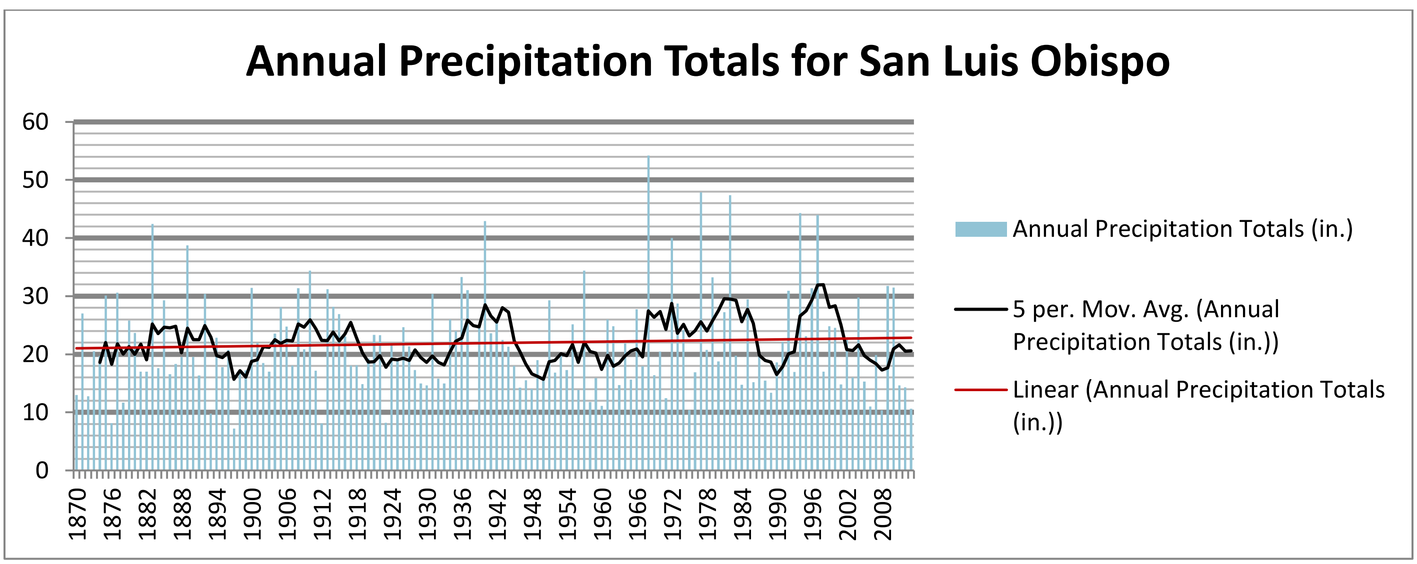

Figure 18: San Luis Obispo precipitation data downloaded from the Cal Poly Irrigation Training and Research Center (ITRC). Precipitation gauge is located on the Cal Poly campus.

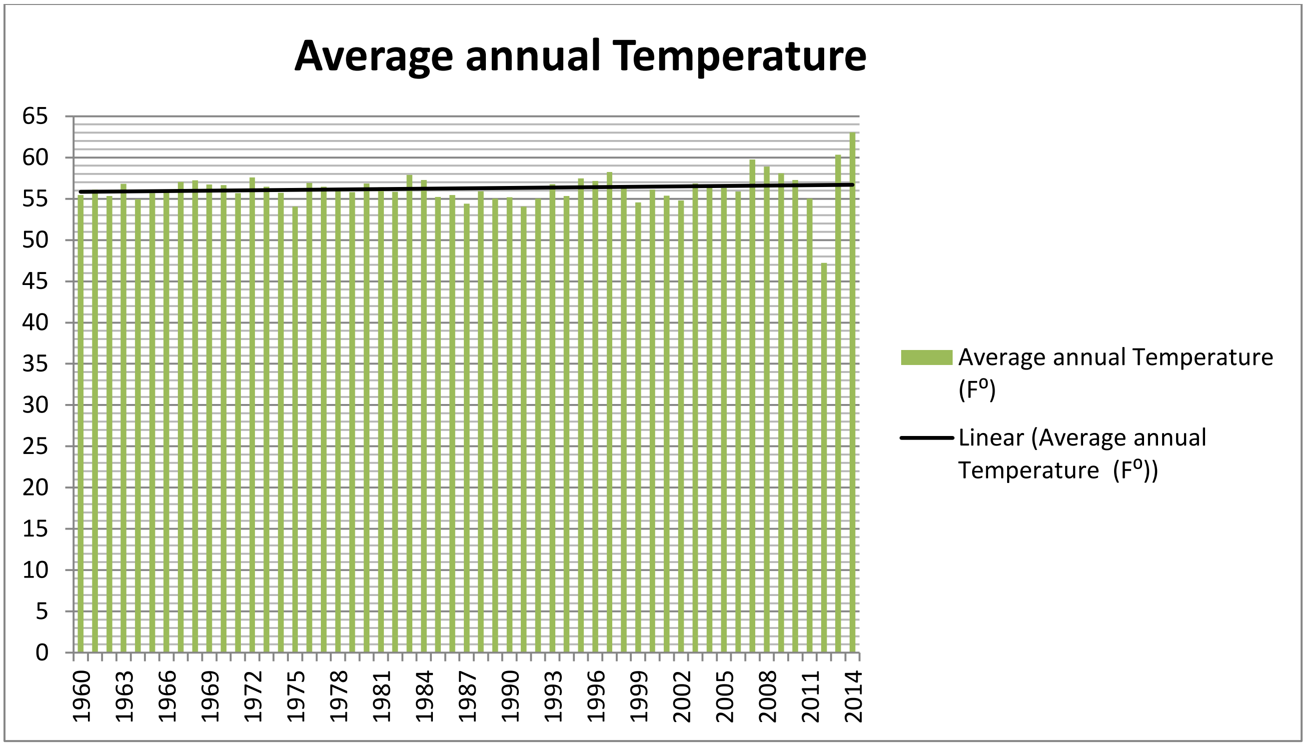

Figure 19: Morro Bay annual temperature data starting in 1960, including the annual average trend line. Data is from the Morro Bay Fire Department.

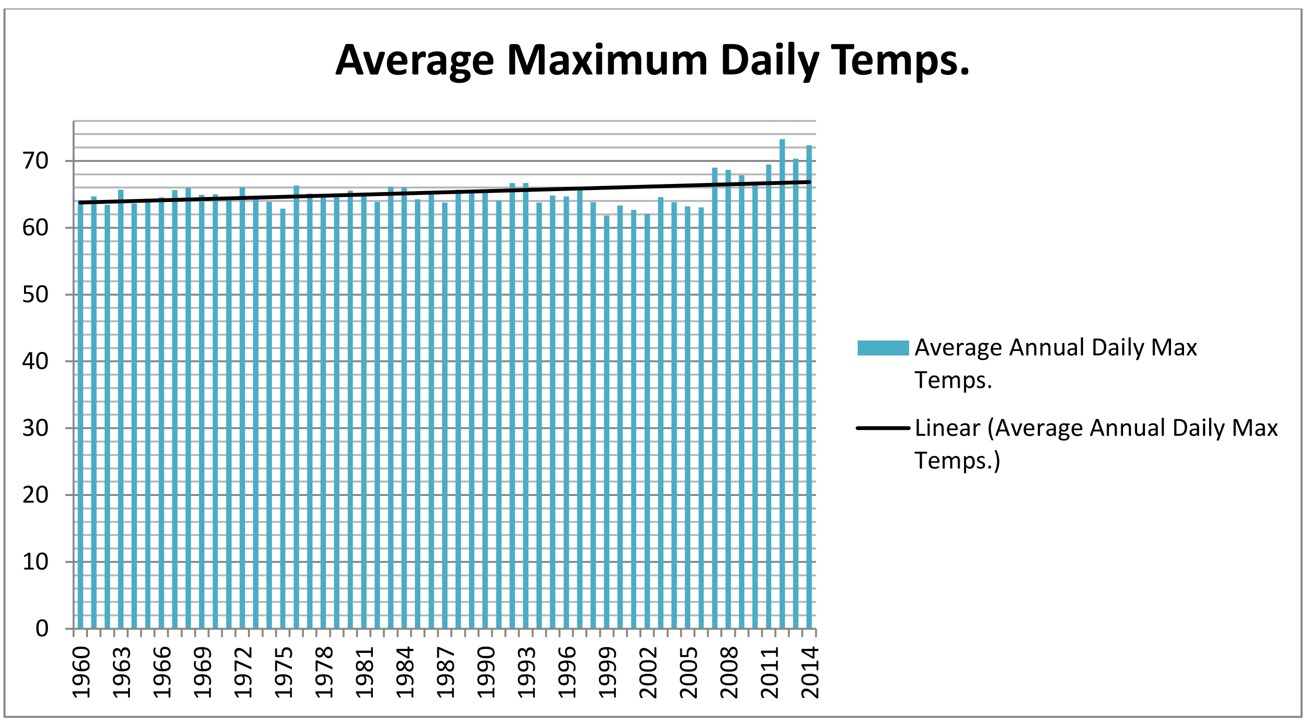

Figure 20: Morro Bay annual temperature data starting in 1960, including the annual average trend line for maximum daily temperature. Data is from the Morro Bay Fire Department.

San Luis Obispo monthly precipitation data was downloaded from the Cal Poly Irrigation Training and Research Center (ITRC). Precipitation gauge is located on the Cal Poly campus.

The monthly rainfall data below shows increases in November and February precipitation, a small decrease in January, and no change for December, April, May, or October. A slight increase is shown for March as well.

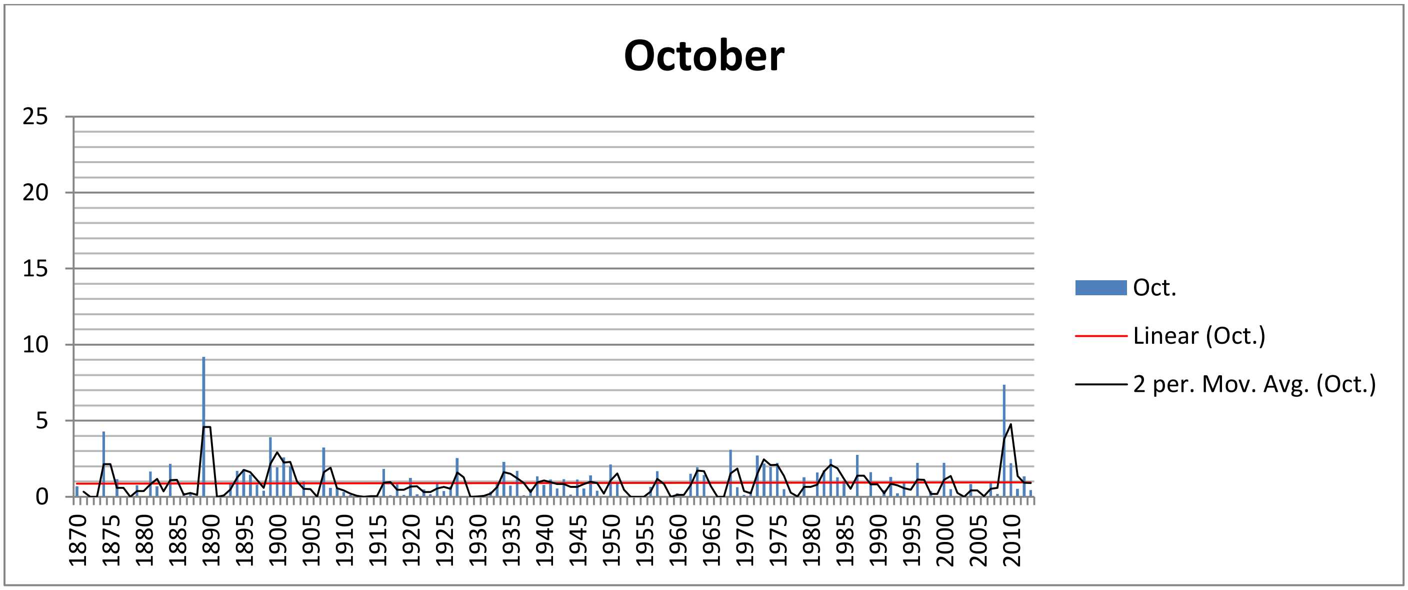

Figure 21: San Luis Obispo monthly precipitation data was downloaded from the Cal Poly Irrigation Training and Research Center (ITRC). Precipitation gauge is located on the Cal Poly campus.

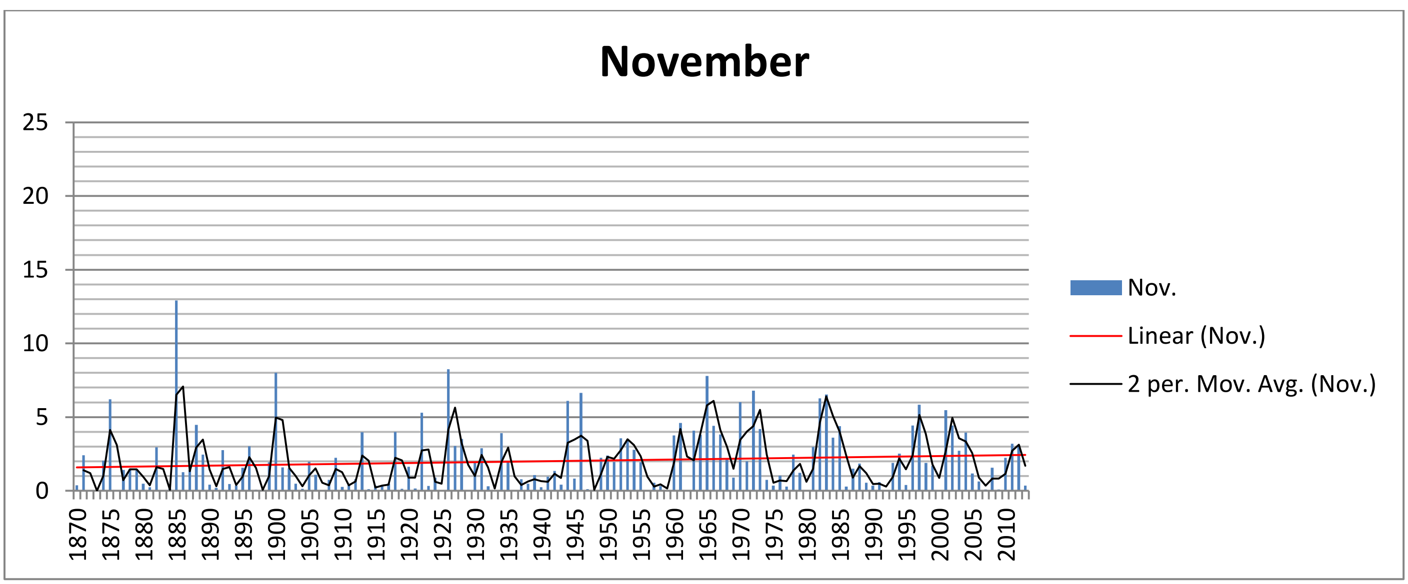

Figure 22: San Luis Obispo monthly precipitation data was downloaded from the Cal Poly Irrigation Training and Research Center (ITRC). Precipitation gauge is located on the Cal Poly campus.

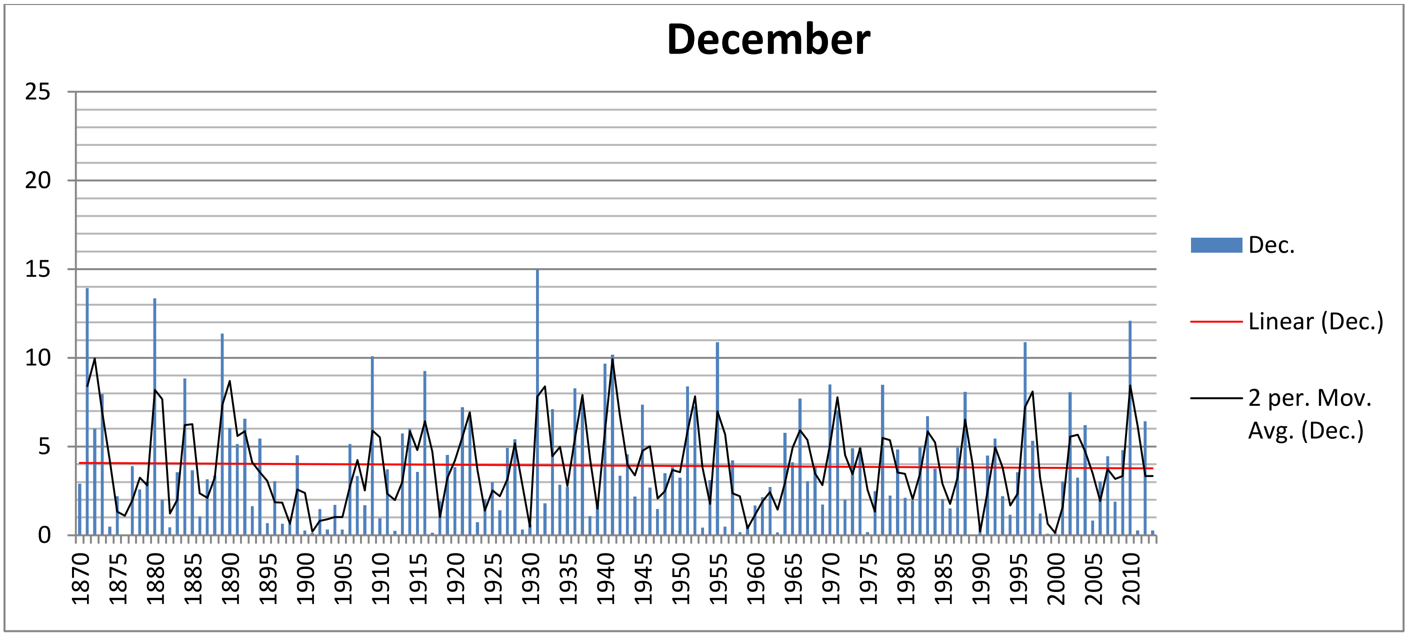

Figure 23: San Luis Obispo monthly precipitation data was downloaded from the Cal Poly Irrigation Training and Research Center (ITRC). Precipitation gauge is located on the Cal Poly campus.

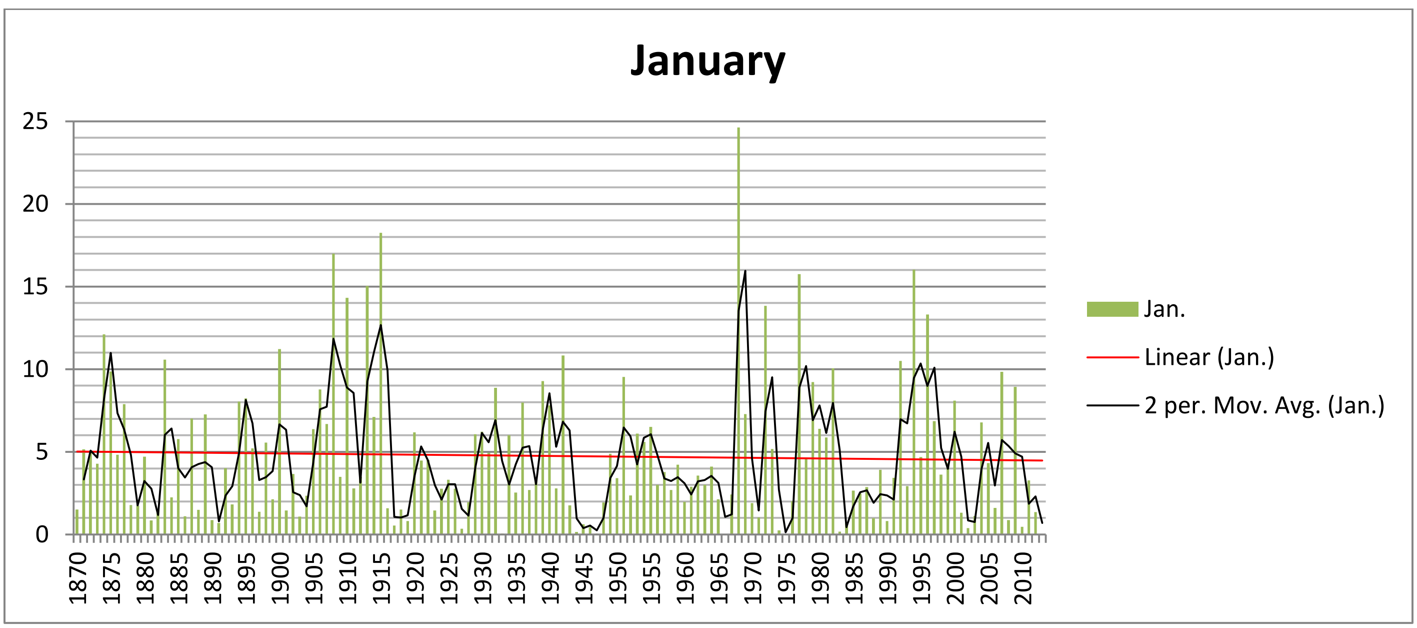

Figure 24: San Luis Obispo monthly precipitation data was downloaded from the Cal Poly Irrigation Training and Research Center (ITRC). Precipitation gauge is located on the Cal Poly campus.

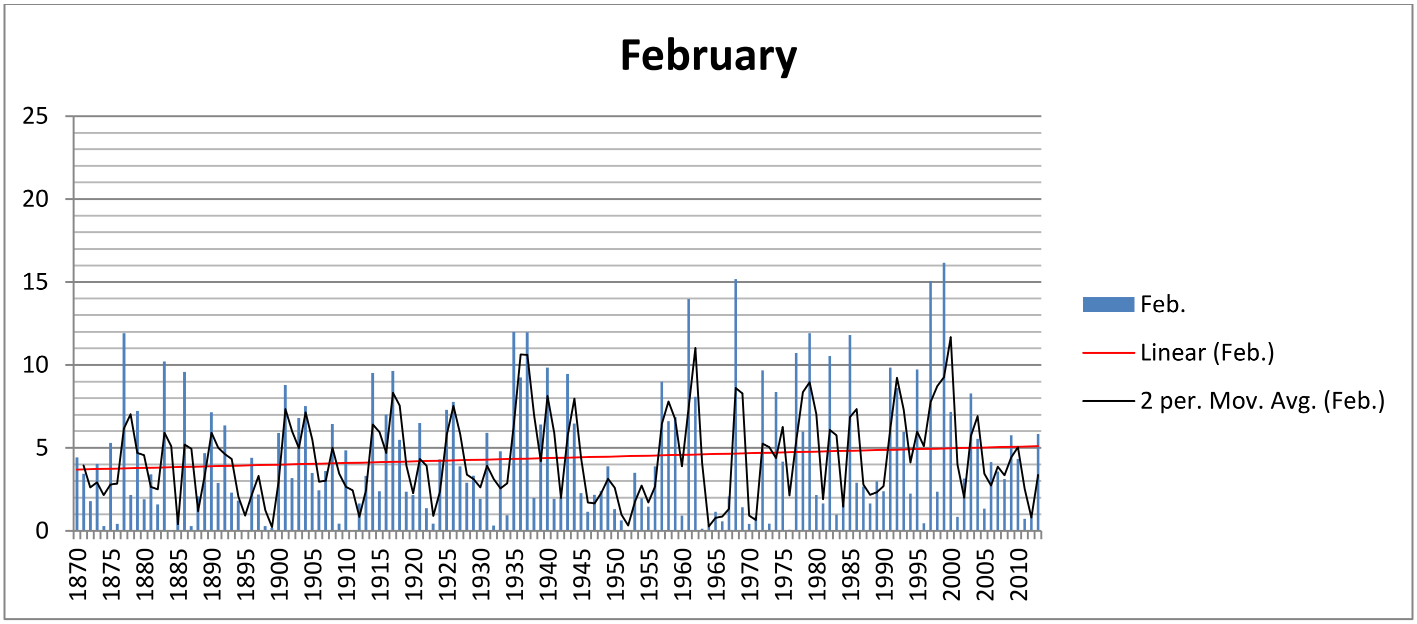

Figure 25: San Luis Obispo monthly precipitation data was downloaded from the Cal Poly Irrigation Training and Research Center (ITRC). Precipitation gauge is located on the Cal Poly campus.

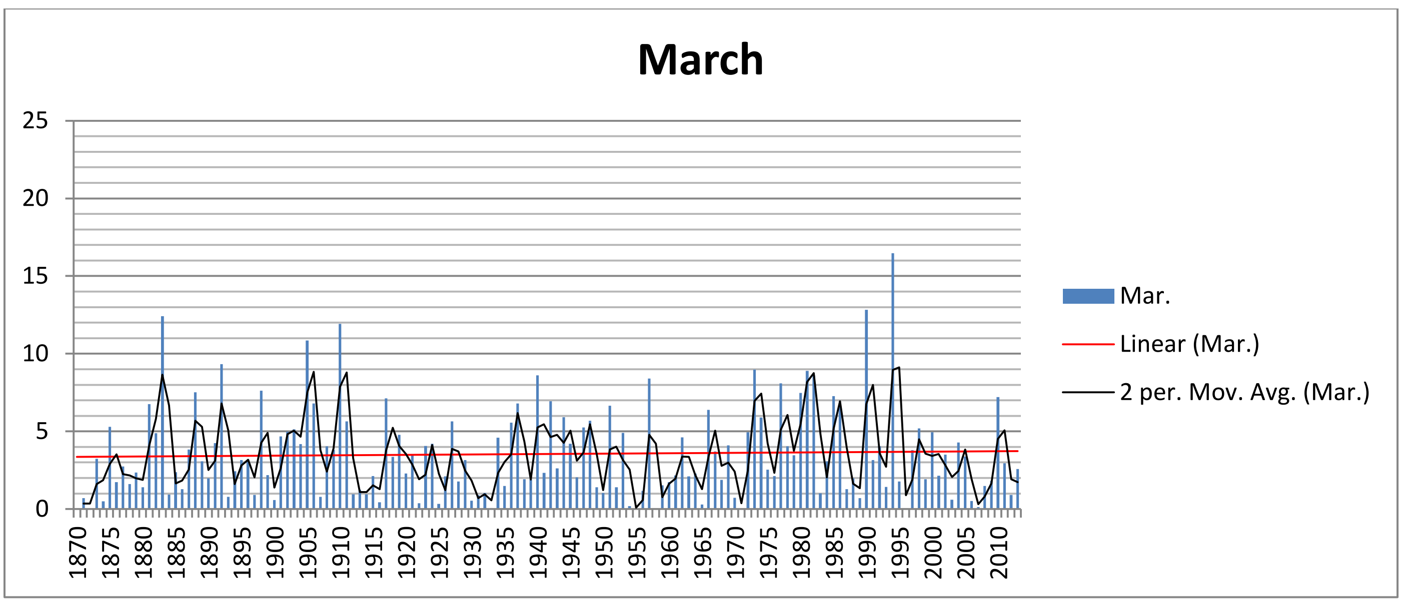

Figure 26: San Luis Obispo monthly precipitation data was downloaded from the Cal Poly Irrigation Training and Research Center (ITRC). Precipitation gauge is located on the Cal Poly campus.

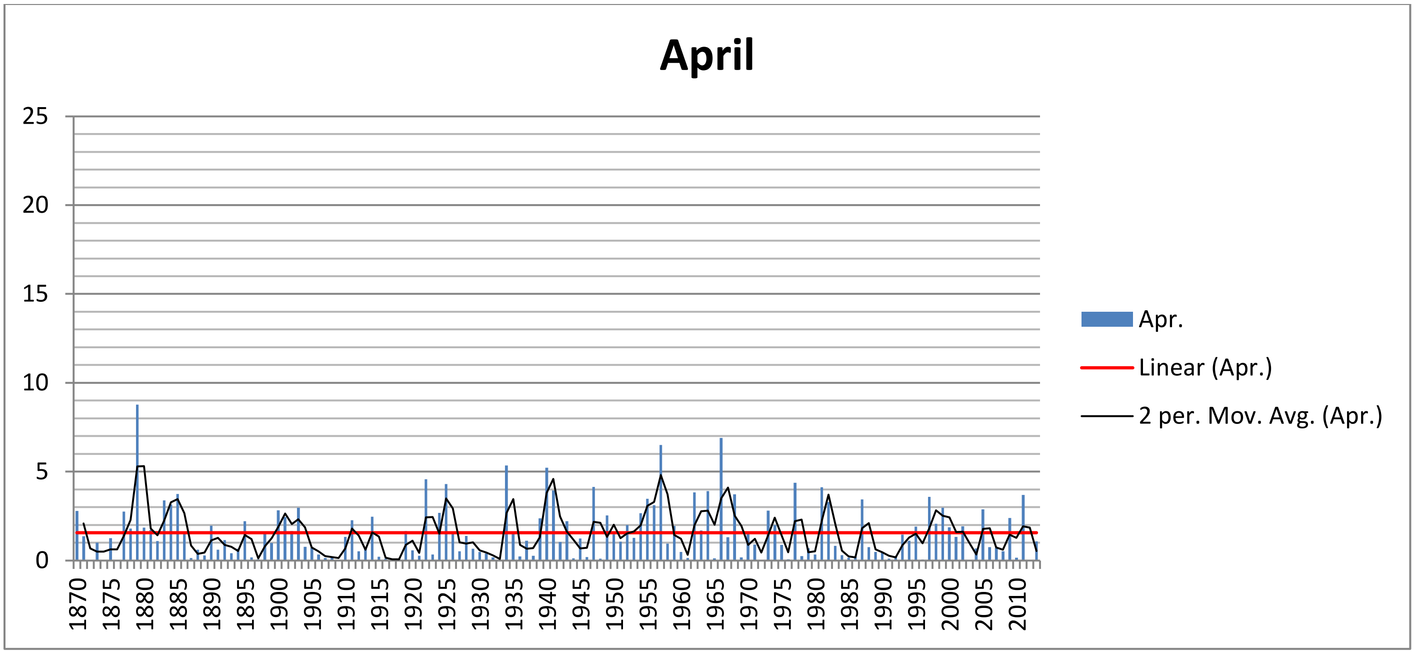

Figure 27: San Luis Obispo monthly precipitation data was downloaded from the Cal Poly Irrigation Training and Research Center (ITRC). Precipitation gauge is located on the Cal Poly campus.

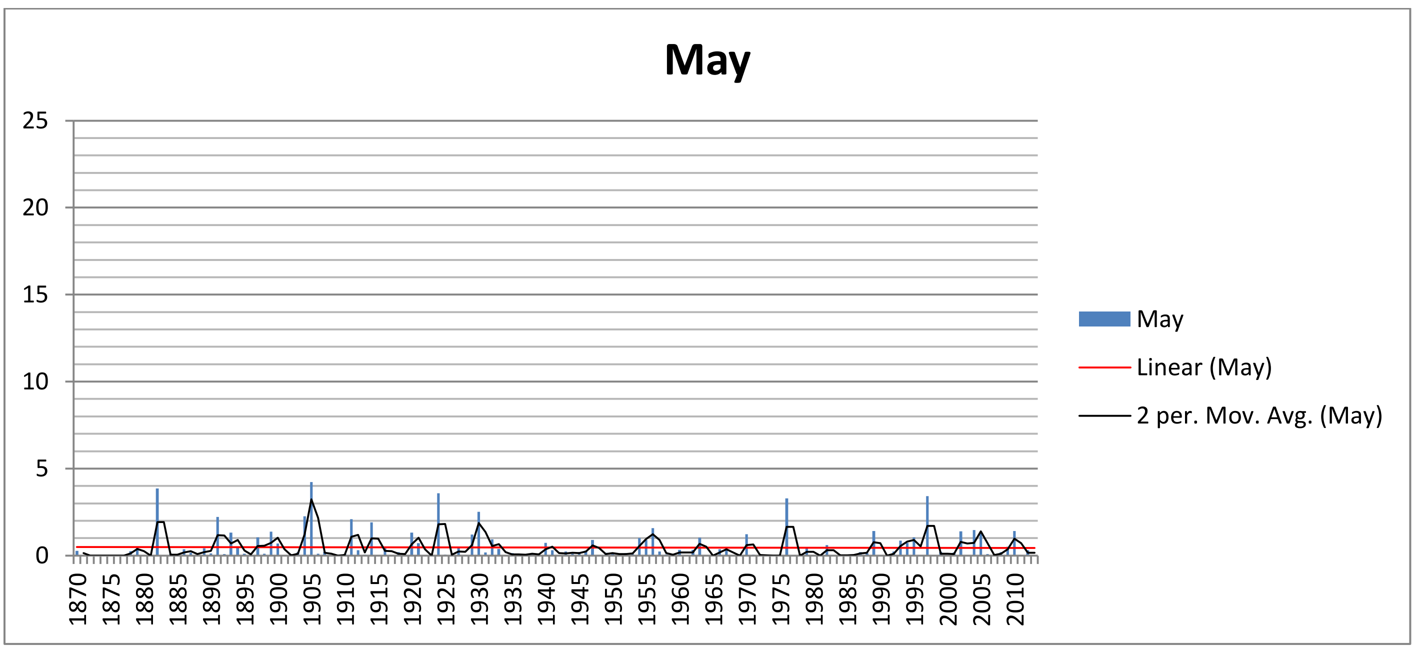

Figure 28: San Luis Obispo monthly precipitation data was downloaded from the Cal Poly Irrigation Training and Research Center (ITRC). Precipitation gauge is located on the Cal Poly campus.

Climate change model output calculations

Estimates for climate change were calculated by taking the minimum and maximum projected temperature, precipitation, and CWD. These values were then averaged to show the average change from the historic values. Once these averages were produced they could be used to calculate percent change. Example equations and tables are shown below.

Equations:

Average temperature/precipitation/CWD L :ÆÜáÔßè>ØÆÔéÔßè;Ø / 6

Projected change in temperature/precipitation/CWD L :2NKFA?PA@=?CEOPKNE?=H;=CA

Percent change in precipitation/CWD L L @ :ÉåâÝØÖ¹çéØ×åÔ;ÚØ / :ÁÜæçâåÜÖÔåÔ;ÚØ FsAÛs r r

Table 21: Table calculations for projected temperature change.

				Change from historic		
Model	**Scenario**	**Min. temp. (C)**	**Max. temp. (C)**	**Average temp. (C)**	**Average temp. in (F)**	**Change in temp. (F)**
	Historic	18	24	21	69.8	N/A
GFDL	B1	20	26	23	73.4	3.6
	A2	22.5	28	25.25	77.45	7.65
PCM	B1	20.5	26	23.25	73.85	4.05
	A2	21.5	27	24.25	75.65	5.85
MIROC 3.2	RCP 4.5	21.5	27	24.25	75.65	5.85
	A2	23.5	28	25.75	78.35	8.55

					Change from historic	
	model	**scenario**	**Min. temp. (C °)**	**Max. temp. (C °)**	**Average temp. (C °)**	**Average temp. in (F °)**
		Historic	18	24	21	69.8
	GFDL	B1	20	26	23	73.4
		A2	22.5	28	25.25	77.45
	PCM	B1	20.5	26	23.25	73.85
		A2	21.5	27	24.25	75.65
	MIROC 3.2	RCP 4.5	21.5	27	24.25	75.65
		A2	23.5	28	25.75	78.35

Table 22: Table calculations for projected precipitation change.

				Change from historic		
Model	**Scenario**	**Min. precip. (mm)**	**Max. precip. (mm)**	**Min. precip. (mm)**	**Max. precip. (mm)**	**Average change (mm)**
	Historic	414	1045	N/A	N/A	N/A
GFDL	B1	344	921	-70	-124	-97
	A2	328	897	-86	-148	-117
PCM	B1	454	1196	40	151	95.5
	A2	453	1172	39	127	83
MIROC 3.2	RCP 4.5	352	879	-62	-166	-114
	A2	257	708	-157	-337	-247

	model	**scenario**	**average rainfall**
	Historic	Historic	729.5
	GFDL B1	B1	632.5
	GFDL A2	A2	612.5
	PCM B1	B1	825
	PCM A2	A2	812.5

	MIROC 3.2 RCP 4.5	RCP 4.5	615.5
	MIROC 3.2 A2	A2	482.5

					Change from historic	
	model	**scenario**	**Min. CWD (mm)**	**Max. CWD (mm)**	**Min. CWD (mm)**	**Max. CWD (mm)**
		Historic	700	1003	na	na
	GFDL	B1	788	1076	88	73
		A2	898	1161	198	158
	PCM	B1	745	1026	45	23
		A2	762	1064	62	61
	MIROC 3.2	RCP 4.5	794	1070	94	67
		A2	904	1164	204	163

Table 23: Table calculations for projected change in CWD.

				Change from historic		
Model	**Scenario**	**Min. CWD (mm)**	**Max. CWD (mm)**	**Min. CWD (mm)**	**Max. CWD (mm)**	**Average change (mm)**
	Historic	700	1003	na	na	na
GFDL	B1	788	1076	88	73	80.5
	A2	898	1161	198	158	178
PCM	B1	745	1026	45	23	34
	A2	762	1064	62	61	61.5
MIROC 3.2	RCP 4.5	794	1070	94	67	80.5
	A2	904	1164	204	163	183.5

	model	scenario	average CWD
		Historic	851.5
	GFDL	B1	932
		A2	1029.5
	PCM	B1	885.5
		A2	913
	MIROC 3.2	RCP 4.5	932
		A2	1034

8. Works Cited

Morro Bay National Estuary Program. (2012). *Comprehensive Conservation and Management Plan for the Morro Bay Estuary: 2012 Update*. Morro Bay, CA.

Morro Bay National Estuary Program. “Morro Bay Sediment Loading Update.” Morro Bay, CA, 2011.

Kitajima, A. “Morro Bay National Estuary Program’s Data Summary Report 2014.” Morro Bay National Estuary Program. October 2014.

Garfin, G., A. Jardine, R. Merideth, M. Black, and S. LeRoy, eds. 2013. *Assessment of Climate Change in the Southwest United States: A Report Prepared for the National Climate Assessment*. A report by the Southwest Climate Alliance. Washington, DC: Island Press.

Flint et al.: *Fine-scale hydrologic modeling for regional landscape applications: the California Basin Characterization Model development and performance*. Ecological Processes, 2013, 2:25.

Micheli et al.: *Adapting to Climate Change: State of the Science for North Bay Watersheds.* North Bay Watershed Association. December 2010.

Cayan, D. Tyree, M. Iacobellis, S. *Climate Change Scenarios for the San Francisco Region*. Scripps Institution of Oceanography, University of California San Diego. July 2012.

Carter, Katherine. *Effects of Temperature, Dissolved Oxygen/Total Dissolved Gas, Ammonia, and pH on Salmonids: Implications for California's North Coast TMDLs.* North Coast Regional Water Quality Control Board. July 2008.

The Royal Society. *Ocean Acidification Due to Increasing Atmospheric Carbon Dioxide.* The Royal Society. June 2005.

Green, Richard. *Infiltration of Water into Soils as Influenced by Antecedent Moisture*. Iowa State University. 1962.

Olsen, Hillary. *Analysis of San Luis Obispo Historic Precipitation Data and Calibration of the Cal Poly Weather Station.* Cal Poly, San Luis Obispo. 2014.

National Audubon Society. 2014. *Audubon's Birds and Climate Change Report: A Primer for Practitioners*. National Audubon Society, New York. Contributors: Gary Langham, Justin Schuetz, Candan Soykan, Chad Wilsey, Tom Auer, Geoff LeBaron, Connie Sanchez, Trish Distler. Version 1.2.

Garfin, G., G. Franco, H. Blanco, A. Comrie, P. Gonzalez, T. Piechota, R. Smyth, and R. Waskom, 2014: Ch. 20: Southwest. *Climate Change Impacts in the United States: The Third National Climate Assessment*, J. M. Melillo, Terese (T.C.) Richmond, and G. W. Yohe, Eds., US Global Change Research Program, 462-486. doi:10.7930/J08G8HMN.

Moser, S. C., M. A. Davidson, P. Kirshen, P. Mulvaney, J. F. Murley, J. E. Neumann, L. Petes, and D. Reed, 2014: Ch. 25: *Coastal Zone Development and Ecosystems. Climate Change Impacts in the United States: The Third National Climate Assessment*, J. M. Melillo, Terese (T.C.) Richmond, and G. W. Yohe, Eds., US Global Change Research Program, , 579-618. doi:10.7930/J0MS3QNW.

US EPA (2009). *Synthesis of Adaptation Options for Coastal Areas*. Washington, DC, US Environmental Protection Agency, Climate Ready Estuaries Program. EPA 430-F-08-024, January 2009.

US EPA (2012). *The Causal Analysis/Diagnosis Decision Information System (CADDIS) Volume 2: Sources, Stressors & Responses: pH*. Environmental Protection Agency. July, 2012.

US EPA (2012) *Vulnerability Assessments in Support of the Climate Ready Estuaries Program: A Novel Approach Using Expert Judgment, Volume I: Results for the San Francisco Estuary Partnership*. National Center for Environmental Assessment, Washington, DC; EPA/600/R-11/058Fa. Available online at http://www.epa.gov/ncea.

US EPA. (2014) *Being Prepared for Climate Change: A workbook for Developing Risk-Based Adaptation Plans*. EPA office of water, Climate Ready Estuaries.

US EPA (2015).*Climate Change and Harmful Algal Blooms*. Environmental Protection Agency. February, 2015.

Snover et al. *Choosing and Using Climate-Change Scenarios for Ecological-Impact Assessments and Conservation Decisions*. Conservation Biology. Volume 27, No. 6, 2013.

Peter B. Moyle, Joshua A. Israel, Sabra E. Purdy. *Salmon, Steelhead, and Trout in California: Status of an Emblematic Fauna*. Center for Watershed Sciences, University of California, Davis. 2008.

BA Stein et al. *Preparing for and Managing Change: Climate Adaptation for Biodiversity and Ecosystems*. Frontier Ecol Environ 2013; 11(9): 502–510, doi:10.1890/120277

Nicole E. Heller, Erika S. Zavaleta. *Biodiversity Management in the Face of Climate Change: A Review of 22 Years of Recommendations*. Environmental Studies Department, University of California, Santa Cruz. 2008.

Doerr, Veronia A. J., Tom Barrett, and Erik D. Doerr. *Connectivity, Dispersal Behaviour and Conservation under Climate Change: A Response to Hodgson Et Al*. Journal of Applied Ecology 48 (2011): 143-47. British Ecological Society.

Burgiel, S.W. and A.A. Muir. 2010. *Invasive Species, Climate Change and Ecosystem-Based Adaptation: Addressing Multiple Drivers of Global Change*. Global Invasive Species Programme (GISP), Washington, DC, US, and Nairobi, Kenya.

Björk M., Short F., Mcleod, E. and Beer, S. (2008). *Managing Seagrasses for Resilience to Climate Change*. IUCN, Gland, Switzerland. 56pp.

Doney, S., A. A. Rosenberg, M. Alexander, F. Chavez, C. D. Harvell, G. Hofmann, M. Orbach, and M. Ruckelshaus, 2014: *Ch. 24: Oceans and Marine Resources*. Climate Change Impacts in the United States: The Third National Climate Assessment, J. M. Melillo, Terese (T.C.) Richmond, and G. W. Yohe, Eds., US Global Change Research Program, 557-578. doi:10.7930/J0RF5RZW.

Furniss, Michael J.; Roby, Ken B.; Cenderelli, Dan; Chatel, John; Clifton, Caty F.; Clingenpeel, Alan; Hays, Polly E.; Higgins, Dale; Hodges, Ken; Howe, Carol; Jungst, Laura; Louie, Joan; Mai, Christine; Martinez, Ralph; Overton, Kerry; Staab, Brian P.; Steinke, Rory; Weinhold, Mark. 2013. *Assessing the vulnerability of watersheds to climate change: results of national forest watershed vulnerability pilot assessments*. Gen. Tech. Rep. PNW-GTR-884. Portland, OR: US Department of Agriculture, Forest Service, Pacific Northwest Research Station. 32 p. plus appendix.

IPCC, 2014: Summary for Policymakers. In: *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1-32.

NRCS, 2009. *Streambank Erosion Factors, Mechanisms, and Causes*. Companion Document 580-4. EFH Notice 210-WI-119. February, 2009.

McKeon, John, and Brian Cluer. *Building Hydrologic Resilience to Climate Change Is Analogous to and Synonymous with Salmonid Ecosystem Restoration*. 33rd Annual Salmonid Restoration Conference. Santa Rosa, CA. 11 Mar. 2015. Web.

Michael J. Furniss, MJ Furniss & Associates. *A Brief Introduction to Vulnerability Assessments: Conceptual Model, Terminology, and Early Lessons*. 33rd Annual Salmonid Restoration Conference. Santa Rosa, CA. 13 Mar. 2015. Web.

Digital Coast Sea Level Rise and Coastal Flooding Impacts Viewer. Computer software. NOAA Coastal Services Center. NOAA, n.d. Web. <http://coast.noaa.gov/slr/>.

NPS. *Point Reyes National Seashore Wildland Fire Resource Advisor Guide July 2007*. National Park Service, US Department of the Interior. Point Reyes National Seashore, Point Reyes Station. 2007.

Matthew L. Brooks, Carla M. D'Antonio, David M. Richardson, James B. Grace, Jon E. Keeley, Joseph M. Ditomaso, Richard J. Hobbs, Mike Pellant, And David Pyke. *Effects of Invasive Alien Plants on Fire Regimes*. BioScience 54.7 (2004): 677-88. Web.

Cal Poly, San Luis Obispo. *Irrigation Training & Research Center*. Historic Climate Data online. California Polytechnic State University, ITRC. <http://www.itrc.org/databases/precip/>

Morro Bay Fire Department. *Climate Summary Data*. Historic Climate Data online. Morro Bay Fire Dept., CA. < http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?camorr+sca>

Heather Dennis, Stephanie Falzone, Hilary Walecka, Kari Zajac, Ashley Zavagno.; *Informing Biodiversity Conservation and Water Quality Management in the Morro Bay Watershed*. UCSB school of BREN. March 2015.

Both, C., Bouwhuis, S., Lessells, C. M., & Visser, M. E. (2006). *Climate change and population declines in a long-distance migratory bird.* Nature, 441(7089), 81-83.

Richard A. Lovett. *A warming Earth could mean stronger toxins.* Nature. doi:10.1038/news.2010.593. November 2010.

Sims, A.E. 2010. *Atlas of Sensitive Species of the Morro Bay Area*. Morro Bay National Estuary Program, Morro Bay, CA, and CA Dept. of Parks and Recreation, San Luis Obispo Coast District, San Simeon.

Marni E. Koopman, Richard S. Nauman, Jessica L. Leonard.; *Projected Future Climatic and Ecological Conditions for San Luis Obispo County*. National Center for Conservation Science and Policy. April, 2010.

"Warm Water Killing Fish in Columbia, Willamette, the West." KGW Portland. N.p., 09 July 2015. Web. <http://www.kgw.com/story/news/2015/07/09/salmon-warm-water-drought-fish-death/29908103/>.

Wilson, Nick. "Seawater Seeping into Los Osos Water Basin Poses Threat." SanLuisObispo.com. The Tribune, 13 July 2015. Web. <http://www.sanluisobispo.com/2015/07/13/3720506_seawater-seeping-into-los-osos.html?rh=1>.

Torregrosa, A., T. O'Brien, and I. Faloon (2014), *Coastal fog, climate change, and the environment*, Eos Trans. AGU, 95(50), 473–474, doi:10.1002/2014EO500001.

Carey C. *The impacts of climate change on the annual cycles of birds*. Phil. Trans. R. Soc. 2009;364:3321–3330.

Condon, R.H., C.M. Duarte, K.A. Pitt., K.L. Robinson, C.H. Lucas, K.R. Sutherland, H.W. Mianzan, M. Bogeberg, J.E. Purcell, M.B. Decker, S. Uye, L.P. Madin, R.D. Brodeur, S.H.D. Haddock, A. Malej, G.D. Parry, E. Eriksen, J. Quinones, M. Acha, M. Harvey, J.M. Arthur, W.M. Graham (2012). *Recurrent jellyfish blooms are a consequence of global oscillations*. Proceedings of the National Academy of Sciences 110 (3):1000-1005.

FEMA Flood Map Service Center. Computer software. FEMA Flood Map Service Center. Federal Emergency Management Agency, Oct. 2015. Web. <https://msc.fema.gov/portal/search?AddressQuery=morro bay>.

Alfano, Andrea. *Changing Ranges: Why Bigger Isn't Always Better*. *The Audubon Birds & Climate Change Report*. National Audubon Society, 27 Oct. 2014. Web.

9. Maps

The following maps show the historic temperature, climate water deficit, and precipitation for Morro Bay and the projected changes by 2099 using the 3 models and 6 emissions scenarios chosen.

Other maps not included in this section were model projections for precipitation change over December, January, and February, and CWD change over the month of July. These maps were less certain and were only used for brainstorming in the initial phases of the report. They are available upon request.