CLIMATE VULNERABILITY ASSESSMENT REPORT

Prepared by the Morro Bay National Estuary Program for submittal to the United States Environmental Protection Agency (EPA)

Part of the Climate Ready Estuaries Program

February 2016

(Updated March 2021)

Acknowledgments

The completion of this report could not have been done without the collaborative efforts of the Estuary Program 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.

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

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

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

California Heat Assessment Tool…………………………………………………………………CHAT

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

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

California's Fourth Climate Change Assessment……………………………………………...CCA

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

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

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

Coastal Storm Modeling System………………………………………………………………CoSMoS

Cubic feet per second…………………………………………………………………………………cfs

Dissolved oxygen……………………………………………………………………………………...DO

Environmental Protection Agency……………………………………………………………….EPA

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

Greenhouse Gas Emissions………………………………………………………………………GHGs

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

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

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

Low Impact Development……………………………………………………………………………LID

Morro Bay National Estuary Program's
Comprehensive Conservation and Management Plan…………………………………………..CCMP

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

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

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

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

Our Coast Our Future…………………………………………………………………………..OCOF

Pacific Northwest…………………………………………………………………………………….PNW

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

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

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

Sea level rise…………………………………………………………………………………………...SLR

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

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

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

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

Traditional Ecological Knowledge…………………………………………………………………….TEK

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

University of California Santa Barbara……………………………………………………………UCSB

Wildland Urban Interface………………………………………………………………………………WUI

1. Executive Summary

Under future climate scenarios, the Estuary Program will continue to work toward achieving our watershed goals (as stated in the CCMP) of water quality protection and enhancement, ecosystem restoration and conservation, fostering collaboration and public education, outreach, and stewardship. Although these goals will remain the same, the resulting conditions will be altered by climate change. For example, our work to improve water quality will continue to focus on water quality that supports diverse habitats and wildlife populations. However, the components of such habitats and diversity will be affected by climate change. Different species and habitats will compose the diversity in the watershed. Results include 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 4 and a summary of climate model outputs can be found in section 3.

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 Estuary Program must prepare for both a "warmer wetter" and "warmer drier" climate with more intense droughts. Effects from these possible scenarios include warmer annual temperatures, increased storm intensity, increased drought, sea level rise, ocean warming and acidification, and increased size and intensity of fires. These changes pose significant risks to the Estuary Program's goals and their ability to protect and enhance the local ecosystems.

Experts and Estuary Program staff collaborated to hypothesize possible impacts from climate change on local ecosystems and hydrologic processes. 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 Estuary Program were determined to be those 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 Estuary Program resources. Monitoring and review of this document will occur every five years to ensure that predictions and impacts are up to date with current trends and stressors.

Intermediate Update 2020-February 2021: As climate change is better understood and more models are made with increasingly effective data, the changes to the Morro Bay Estuary are better understood and can be better adapted to. This update focused on the science and knowledge regarding the effects of climate change in Section 3: Climate Change Models and Effects. Updates were made to the rest of the sections in response to these data updates. In an effort to make the document more streamlined, sectioning throughout the document was standardized. This was done both to organize the document and to facilitate the additions to the document as more climate change effects emerge. These are the sections that were organized/standardized in the document to help better understand the effects of climate change and will always be presented in this order throughout:

- Warmer Annual Temperatures
- Increased Storm Intensity
- Increased Drought
- Sea Level Rise
- Ocean Warming and Acidification
- Increased Size and Intensity of Fires

Any of the subheadings following these sections were organized based on the Estuary Program Goals. These subsections also reflect the domino effect of impacts that climate change consequences have on Morro Bay's estuary. These subheadings are only included if related to the above topics. Again, these subheadings are organized and standardized throughout the document for ease of review. These subheadings are:

- Accelerated Sedimentation
- Bacteria/Nutrients/Toxics
- Hydrologic Change
- Environmentally Balanced Uses
- Ecosystem Restoration/Conservation

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 subwatersheds, 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 is primarily 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 (ACOE) 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, including 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 Estuary Program, as well as an adaptation action plan to best prepare for such effects. The assessment is designed to inform how the Estuary Program will address climate-related impacts in the future and reduce the risks these impacts present in order to attain 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.

2.2 Morro Bay National Estuary Program Goals

1. **Water Quality Protection and Enhancement**

    - Priority issues:
        - Accelerated sedimentation
        - Bacterial contamination
        - Elevated nutrient levels
        - Toxic pollutants
        - Scarce freshwater resources
        - Biodiversity
        - Environmentally-balanced use

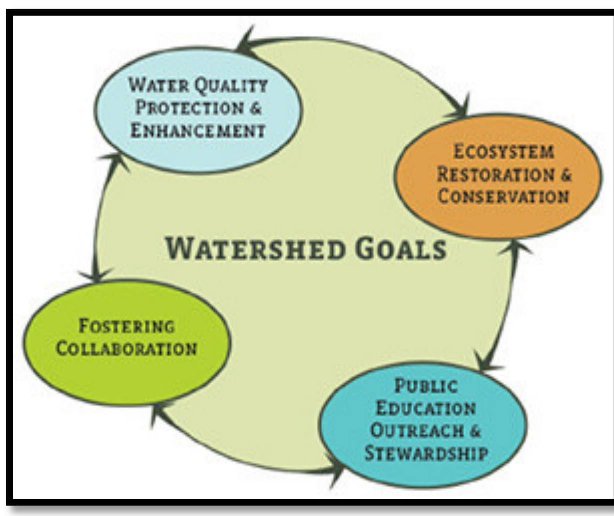

Figure 3: Estuary Program goals.

2. **Ecosystem Restoration and Conservation**

    - Protect and increase ecosystem resilience, connectivity, diversity, function, and economy.
    - Biodiversity effects

3. Public Education, Outreach, and Stewardship

- This goal will not be significantly affected by climate change. Further education on the effects and ways to remediate the effects will benefit the future of the estuary.

4. Foster Collaboration with Other Agencies

- Climate change will require increased coordination of agencies and focusing of resources towards understanding climate change impacts and mitigating their associated effects.

2.3 Current Conditions and Actions Being Taken

Although the Morro Bay estuary and watershed remains one of the least-disturbed wetland systems in California, valuable ecosystem functions and natural resources have become endangered by the changes made to stream and bay functions over time. The current state of these stressors on the Morro Bay National Estuary Program's goals, and the action being taken to achieve those goals, are listed in the sections below. Much of the water quality information for the estuary and watershed has been obtained by the Volunteer Monitoring program run by the Estuary Program. This program has been essential in establishing pollutant information, prioritizing restoration efforts, and improving knowledge of the estuary, the watershed, and their associated functions.

2.3.1 Accelerated Sedimentation

The accumulation of sediment in estuaries naturally occurs over thousands of years and may eventually result in the estuary filling in. Sources of sediment to the Morro Bay estuary include: creeks draining the watershed, stormwater runoff over land, ocean currents carrying sand through the harbor entrance, and prevailing winds and ocean currents altering the morphology of the sandspit. In Morro Bay, these natural processes have been accelerated by activities in the watershed that contribute additional sediment to the flow entering the estuary from creeks and stormwater runoff.

At the time of the 2001 CCMP, local studies and modeling efforts estimated that accelerated sedimentation would cause the estuary to fill in within a few hundred years (TetraTech Inc., 1998). Other observed changes, including rise of the bottom of Chorro Creek at South Bay Boulevard and the increase in salt marsh habitat at the confluence of Chorro Creek and Los Osos Creek, provided additional evidence for accelerated sedimentation. Since the completion of these studies, a more nuanced and complex picture of sedimentation has emerged. It is now understood that the majority of watershed sediment inputs occurs during episodic storm events. The impact of these events varies greatly, depending on the storm intensity and how saturated the ground is prior to any particular storm.

Annual rates of sediment accretion observed in the bay, although difficult to quantify over short time frames, appear to be relatively low. However, catastrophic storm events can contribute vast amounts of sediment to the bay in a very short period of time. This new knowledge is based in part on an ongoing effort by the Estuary Program to track the rate of sediment accretion at various locations in the bay. Rates of accretion and elevation change in the low tidal marsh are similar to recent rates of global sea-level rise (2-3mm/yr.); while the high marsh (1.2-1.3 mm/yr of accretion) are slightly lower than sea level rise and lower than rates from other well-developed salt marsh systems (Callaway, 2015).

Another monitoring effort uses suspended sediment concentrations in creek flow to model sediment loads delivered to the bay. Since this project began in 2008, the results have demonstrated the immense variability in sediment load from year to year (Estuary Program, 2011). In a drought year, sediment monitoring in Chorro Creek indicated less than 200 tons of sediment transport during the winter, whereas in an above average rainfall year, suspended sediment transport was over 900 times that amount. This variability is likely due to fluctuations in the frequency and intensity of storm events.

Sediment deposits in the estuary from creeks and stormwater runoff occur through the natural process of erosion. However, a variety of land uses can exacerbate erosion. Urban development increases the number of impervious surfaces in the watershed, reducing the ability of the ground to absorb rainfall and increasing stormwater volumes and velocities. Certain grazing and cultivation practices can reduce or eliminate ground cover, making hillsides and fields more vulnerable to soil loss. An especially significant issue on the west coast is wildfires, which leave barren hillsides prone to erosion when storm events occur. While this has not been an issue within the watershed, future estimates indicate a potential increase in fires into this area. Alterations in the natural landscape and the spread of nonnative vegetation can increase the intensity of wildfires. In the mid-1990s, the combination of an intense wildfire that scorched a significant portion of the upper watershed and strong El Niño rainstorms the following winter resulted in a tremendous amount of sediment flowing to the bay, with significant impacts on eelgrass beds, oyster farms, and the bay's form and tidal prism (Estuary Program, 2001).

In addition to input from creeks and stormwater runoff, ocean currents also add sediment to the estuary, primarily at the harbor mouth and in the main navigation channel. For this reason, the harbor entrance is maintained with regular dredging to ensure the safety of navigation. Whether sand from the sandspit is contributing to sedimentation is not well understood. Considering that this source is a natural process, the management issue of concern is to minimize erosion on the sandspit from plant removal and human use, while maintaining healthy native habitats on the spit.

Due to the conditions described, Morro Bay, Los Osos, and Chorro Creeks are listed as impaired waters under the federal Clean Water Act Section 303(d) for sediment. The Central Coast Regional Water Quality Control Board (Water Board) has established total maximum daily loads (TMDLs) for sediment. Estimates of the relative contributions of the two major subwatersheds suggest that about 80 percent of the stream-borne sediment comes from the Chorro Valley (Tetra Tech Inc., 1998).

Sedimentation affects the habitat value of the estuary. As the bay fills, rare coastal wetlands are converted to terrestrial habitats. Shallow water results in increased temperatures and reduces circulation, adversely affecting water quality and habitat richness. Sediment can impact eelgrass through depth changes, reduction of light penetration, and direct siltation on top of eelgrass. Sediment also degrades habitat for freshwater species, including the California red-legged frog and southwestern pond turtle.

The potential loss of bay volume affects commercial and recreational boating navigation. The main channels must be dredged regularly due to sediment accumulation. The State Park Marina entrance can become inaccessible for certain vessels during low tides.

Reduced open water area could also affect the recreational values of the bay, limiting such activities as fishing and boating. Reduction in the estuary's recreational potential may adversely affect bay-related tourism. Sediment can also interfere with the commercial cultivation of oysters.

Upstream from the bay, erosion adversely impacts agricultural land by reducing acreage suitable for cultivation and through the loss of topsoil that is essential to intensive farming. In streams, silt reduces the quality of spawning habitat for steelhead and can impede steelhead migration during high-flow events. Biodiversity and general habitat quality can also be reduced by excessive sediment.

Much effort has been directed to addressing the problem of sedimentation. One approach often discussed would be to dredge the bay or to alter the channels to facilitate improved tidal flushing. The Estuary Program and the ACOE conducted a large-scale analysis of these in-bay solutions, including assessing the possibility of opening the south end of the sandspit to the ocean or restoring the bay's natural communication with the sea near Morro Rock (ACOE, 2007). Another specific option was to re-route the mouth of Chorro Creek that had shifted southward in the 1990s from its previous course nearer to the State Park Marina. All of these options were deemed infeasible due their extremely high cost, significant environmental impacts, regulatory impediments, and other concerns.

A variety of best management practices and restoration techniques can be implemented to reduce erosion. The Estuary Program and its partners concluded that the most feasible ways to address sedimentation are by reducing erosion in the watershed and capturing sediment upstream of the bay through various methods, including the restoration of floodplains. These methods have been the focus of the Estuary Program and its partners. The Coastal San Luis Resource Conservation District (CSLRCD) spearheaded "Project Clearwater," funded in part through the Estuary Program, which improved land management practices on private farms and ranches to reduce erosion. The CSLRCD estimated that these efforts prevented thousands of tons of sediment from reaching the bay (CSLRCD, 2009). Examples of other projects that have been undertaken during the last ten years include: riparian corridor restoration along Walters and Chumash Creeks, over 11 miles of riparian fencing, riparian revegetation, remediation of mines that are out of commission, and rural road improvement projects.

Another important project was the Chorro Flats Enhancement Project that opened levees along Chorro Creek, allowing the stream to access its natural floodplain. The CSLRCD estimates that approximately 198,000 cubic yards of sediment had been captured by this project as of January 2001, with the site expected to reach its capacity 35 years from that time (CSLRCD, 2002). Another floodplain restoration project is underway by the CSLRCD on Los Osos Creek. The MBNEP also completed a five-acre floodplain restoration project at the Chorro Creek Ecological Reserve, which regraded two side channels, improved a degraded road crossing, and removed 24,000 cubic yards of sediment.

2.3.2 Bacterial Contamination

Bacteria levels in Morro Bay have significant impacts on recreation, the economy, and the ecosystem. Elevated levels are frequently detected in the bay and watershed, which has led to the Section 303(d) listing for pathogen impairment for the Morro Bay estuary, Chorro Creek, Los Osos Creek, Dairy Creek, and Warden Creek. All of these waterbodies, except for Dairy Creek, have associated TMDLs produced by the Water Board.

Contributors of bacteria to the watershed and estuary include point and nonpoint sources: urban runoff, agricultural runoff, improper boat waste disposal, domestic and wild animal waste, and septic systems (CCRWQCB, 2002). A study of *E. coli* strains in the estuary quantified four main sources of this bacteria type: birds (22%), humans (17%), bovine (14%), and dogs (9%) (Kitts et al., 2002). Bacteria levels originating from urban runoff, agricultural runoff, and animal waste enter the creeks and bays primarily during rainfall events. The amount of bacteria brought into the bay and watershed is dependent upon the intensity and total rainfall during each storm event. Each subwatershed, however, contributes different amounts of bacteria to the bay, with significantly more coming from the Chorro Valley watershed (Tetra Tech Inc., 1999). This may reflect the larger drainage area that contributes to Chorro Creek relative to Los Osos Creek.

Elevated bacteria levels impact much of the local economy and ecosystem in the bay. Oyster farms are reliant on good water quality and are unable to operate when bacteria levels are too high. Regulations do not allow oyster harvesting after any storms large enough to increase the stage height in Chorro Creek to 5.5 feet or above. This regulatory approach was implemented because data showed elevated bacteria levels in the bay at corresponding flow levels. The state has also instituted seasonal closures, where harvesting directly from bay waters is prohibited during certain times of year due to a history of poor water quality. The recreation and tourism industry rely on clean waters to ensure safe swimming, and marine wildlife can also be negatively affected, including iconic Morro Bay species such as sea otters and sea lions (Jessup et al., 2004).

Monitoring data for bay shoreline sites show minimal issues at six of the eight locations that are tested each month. Two sites, Pasadena Point and Baywood Pier, have more frequent exceedances of enterococcus standards protective of safe swimming. Figure 4 shows the percent of samples exceeding safe swimming levels with monthly data from 2006 through 2019.

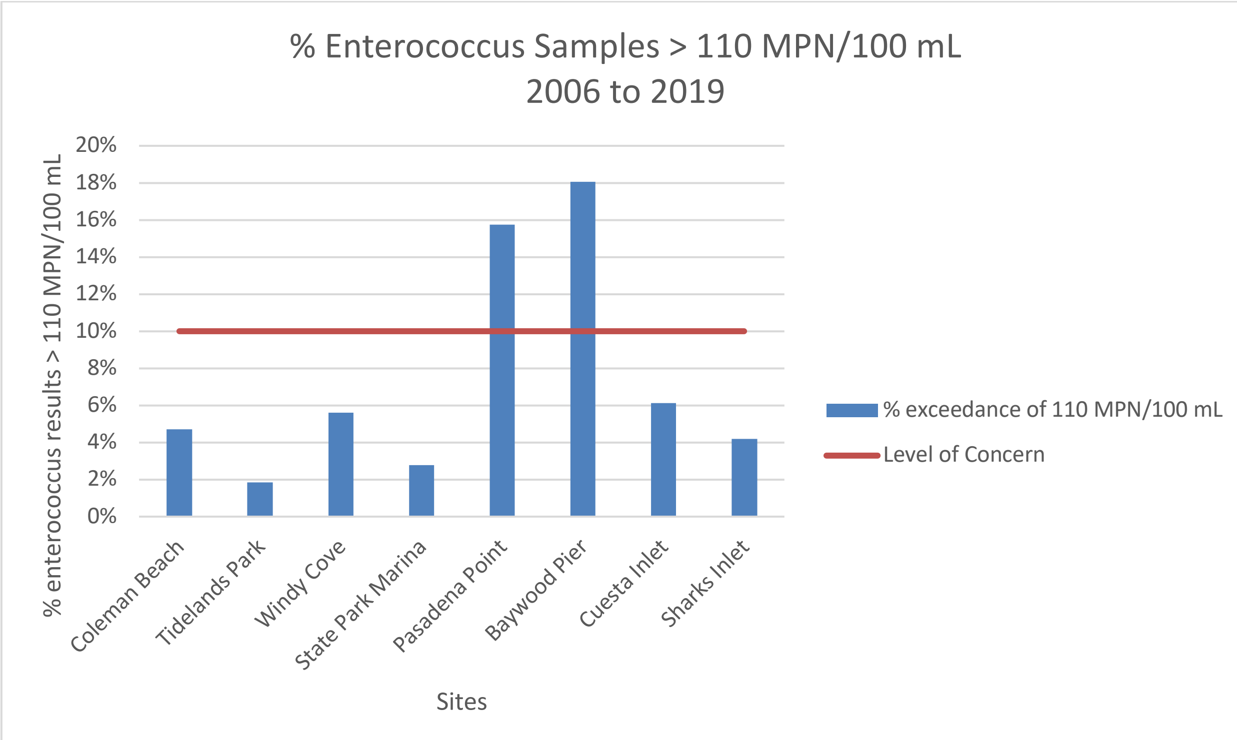

Figure 4: Enterococcus is the preferred indicator in marine waters. Analysis is conducted by Estuary Program staff and volunteers using the IDEXX testing method. Ideally no more than 10% of results exceed the safe swimming criteria.

Many actions have been taken to reduce bacterial contamination in the area. The California Men's Colony (CMC) upgraded their wastewater treatment plant in 2007 to tertiary treatment and more recently eliminated chlorine in its discharge by converting to a UV-based treatment system. The CMC treatment plant contributes effluent water to Chorro Creek. Los Osos and Baywood Park decommissioned most of their septic systems, and households connected to a new wastewater treatment plant which came online in 2016. This reduces the possibility of septic failures and any seepage that may be occurring. Monitoring of the bay shoreline freshwater seeps, which are fed by shallow groundwater, has not yet shown a reduction in nitrate or bacteria concentrations. Best management practices are constantly being improved throughout the watershed; they include riparian fencing along rangeland, off-creek water sources for grazing operations, and grazing management.

Many of the tributaries to Chorro Creek frequently have *E. coli* concentrations that are above the level for safe swimming, as shown in Figure 5. Ideally no more than 10% of samples exceed the standard.

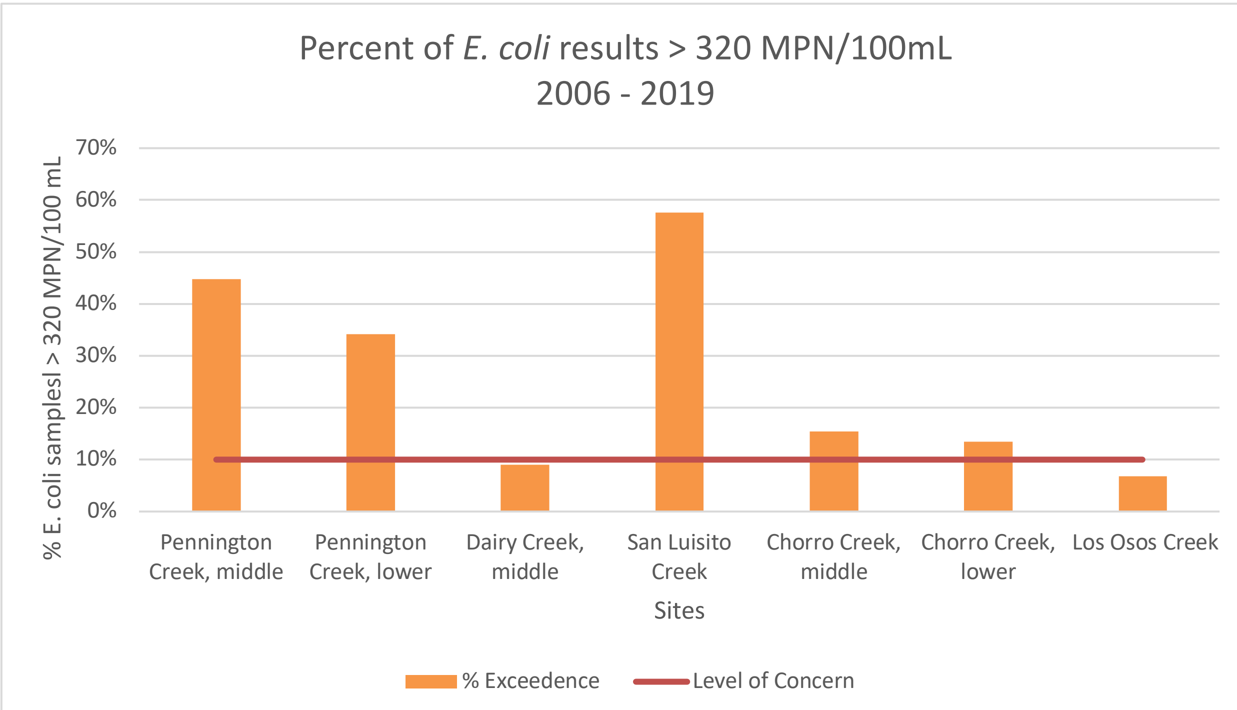

Figure 5. Graph shows percent of *E. coli* results in creeks that exceeded the standard for safe swimming. Ideally no more than 10% of samples exceed these criteria.

Better public education about pet waste and the installation of pet waste bag dispensers eliminates around 350,000 bags worth of waste each year. Another outreach effort includes the Estuary Program staff working in partnership with the California Department of Fish and Wildlife (CDFW), State Parks, and the City of Morro Bay Harbor Department to educate the public about the proper disposal of boating waste.

2.3.3 Elevated Nutrient Levels

Nutrient enrichment in the bay and watershed can have a domino effect on water quality. The primary nutrient of concern for Morro Bay is nitrates, but phosphates can also be of concern. Elevated levels of these nutrients can facilitate algae blooms that consume dissolved oxygen

(DO) and can continue to consume oxygen as they decompose. Thus, high nutrient levels are often linked to the low levels of DO. Appropriate levels of DO are necessary to support aquatic life, such as fish and invertebrates. Objectives for DO concentrations are outlined in the Water Board's Central Coast Basin Plan (Water Board, 2019).

Algal blooms and low DO levels have been regularly observed in Morro Bay, typically in the southern portion of the bay. Elevated nutrients, warmer water temperatures, and poor circulation have all contributed to this recurring problem. Chorro Creek, Los Osos Creek, Warden Creek, and Warden Lake are listed as nutrient impaired waterbodies in Section 303(d) of the Clean Water Act. These waterbodies are also subject to TMDLs adopted by the Water Board. Figure 6 shows Estuary Program monitoring data on DO levels in the bay. The site locations, ordered from the bay mouth to the back bay (north to south), are as follows:

- ATP: Tidelands Park
- SPO: State Park Marina
- LO2: Los Osos Creek where enters the bay
- PSP: Pasadena Point
- CHI: Channel off Cuesta Inlet
- CSI: Cuesta Inlet
- SHI: Sharks Inlet

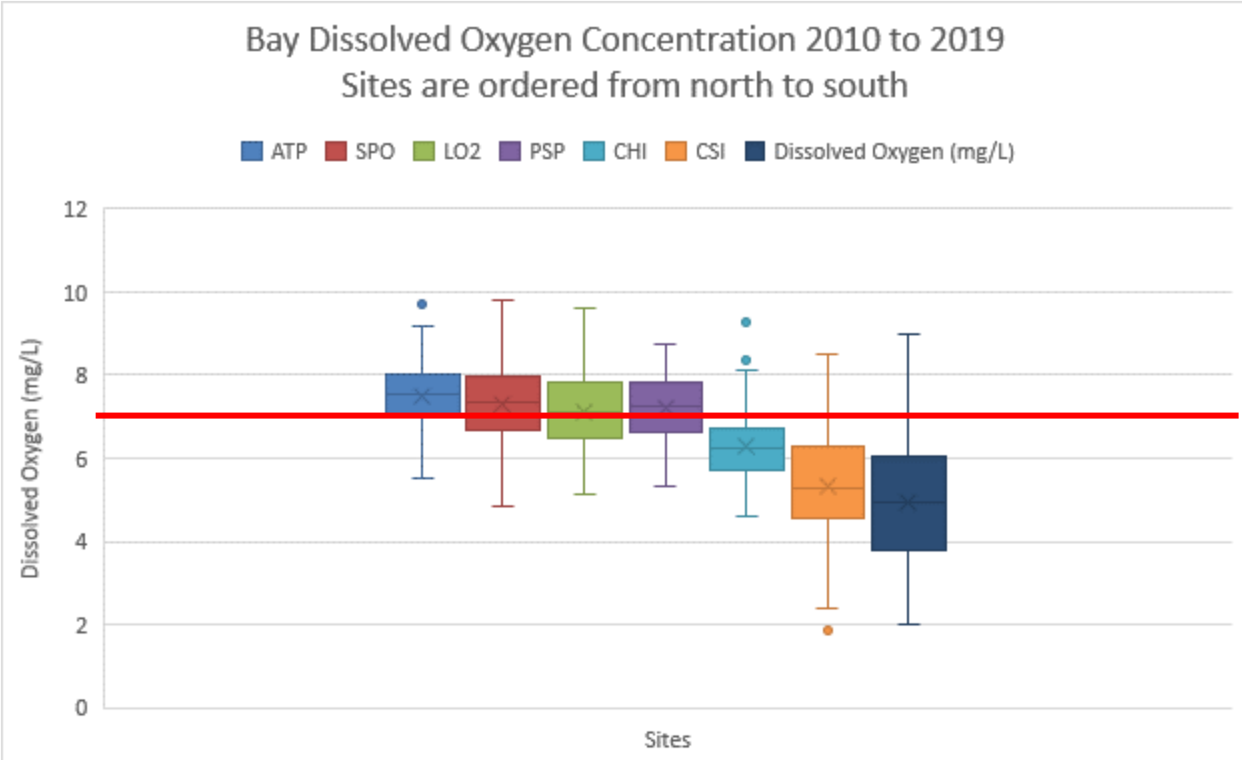

Figure 6: The graph displays DO levels throughout the bay, ordered from north to south. Ideally, DO levels remain above 7 mg/L (represented by the red line on the graph) to be protective of aquatic life.

Sources of nutrients in the Morro Bay watershed include wastewater effluent from CMC, crop and rangeland runoff, and natural background concentrations from biological activity (Water Board, 2005; Water Board, 2007). Nutrient pollution can come from fertilizers and animal waste. Creeks that do not have adequate vegetative shading may have increased surface water temperatures that cause the water column to stratify and reduce circulation. Less circulation can reduce DO levels and may be further impacted if elevated nutrient levels lead to algae blooms.

Figure 7 displays the results of monthly nitrate as nitrogen monitoring from 2016 through 2019 during times of adequate surface flows for sampling. Figure 8 displays results of monthly orthophosphate as phosphorus monitoring for the same timeframe.

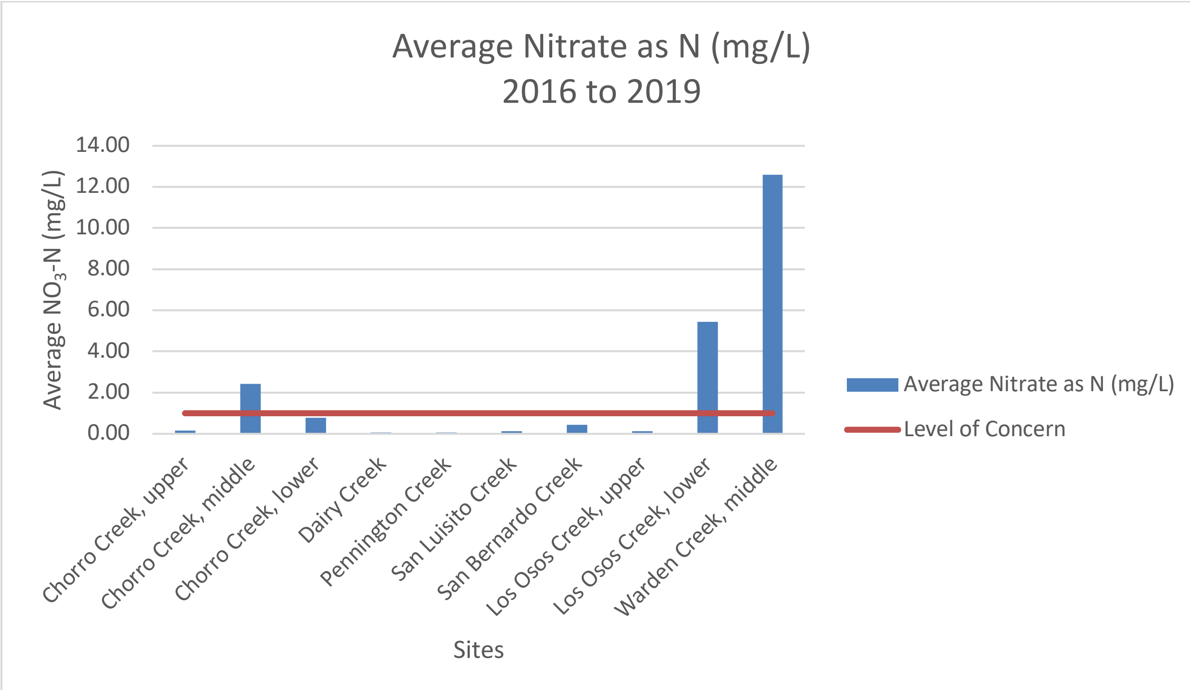

Figure 7: Graph displays nitrate as nitrogen concentrations with data from 2016 through 2019. The red line denotes the level of concern of 1 mg/L nitrate as nitrogen, determined to be protective of aquatic life.

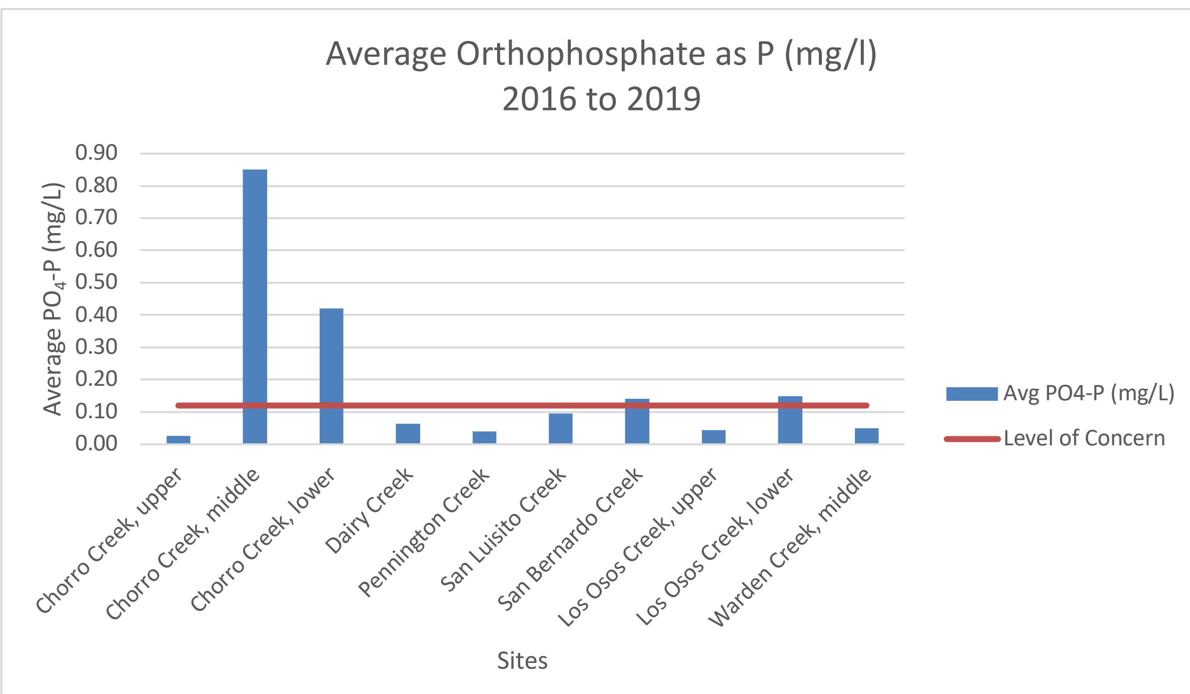

Figure 8: Graph displays orthophosphate as phosphorus concentrations with data from 2016 through 2019. The red line denotes the 0.12 mg/L PO_4-P level of concern protective of aquatic life. This level was based on the value developed for the Pajaro River (Williamson, 1994; Black, 2010).

To combat nutrient pollution in the watershed, the CMC wastewater treatment plant was upgraded in 2007 to include tertiary treatment and reduce nitrates in its effluent. Projects to increase riparian vegetation along Chorro Creek and its tributaries have also been implemented to reduce temperatures and increase dissolved oxygen. Methods for these projects include riparian fencing, revegetation of stream corridors, and restoration of highly degraded stream sections. Other actions include outreach and education by the Estuary Program and its partners about proper fertilizer use on agricultural and urban landscapes and ways to keep pollutants out of stormwater drains.

2.3.4 Toxic Pollutants

Toxic pollutants include pesticides, organic compounds, heavy metals, and a variety of other chemical compounds. The upper Chorro Creek has historically been mined for nickel and chromium, which occur naturally, but can be toxic in high concentrations. When the CCMP was approved for the Morro Bay National Estuary Program in 2001, Chorro Creek was 303(d)-listed by the Water Board for heavy metal impairment. Subsequent analysis, however, observed that the levels for these elements in the watershed did not pose a threat to people or wildlife, and Chorro Creek was delisted.

Other non-natural toxic pollutants continue to impact the water and habitat quality of the bay and watershed. The primary input of these pollutants comes from nonpoint source pollution from stormwater runoff. Sources of toxics include household and agricultural pesticides, detergents and soaps, oils and lubricants from street drainage, and household or commercial cleaning products. Other potential sources are antifouling paints and other chemicals used for boat maintenance, as well as illegal dumping or fuel spills in the harbor. Recent studies have suggested that there are many more toxics that are unregulated, with regards to water quality, and may have unknown environmental impacts. Known as "emerging contaminants," they are proving to be widespread, and their impact on human and aquatic life are often not fully understood.

Toxic pollutants can accumulate in sediments and impact water quality when disturbed. Many species that spend their life cycles in sediment or filter feed like oysters are most impacted by these chemicals as they have the most direct contact with them. However, other species that feed on sediment-dwelling aquatic life may eventually suffer from bioaccumulation. These effects are not well understood at this time.

To date, toxicity analysis has been limited. In reviewing available data from 2004 through 2019, testing indicates sediment toxicity in the following waterbodies: Chorro Creek, Los Osos Creek, Warden Creek, and Morro Bay. The bay data comes from monitoring by EPA's National Coastal Condition Assessment (NCCA), and the creek data is from Central Coast Water Quality Preservation, Inc. and California's Surface Water Ambient Monitoring Program (SWAMP). Results from the bay can be compared to criteria established by EPA for their NCCA effort. Monitoring in the creeks can be compared to the Great Lakes freshwater standards. Results for sediment analysis from this time period show approximately three-quarters of the results were classified as Good while the remaining quarter had Fair and Poor toxicity results in these four water bodies.

The National Oceanic and Atmospheric Administration (NOAA) and the State Mussel Watch Program indicated that metal and toxic concentrations are not present in Morro Bay's shellfish population at levels of concern. However, limited research results have documented the possibility of elevated heavy metal concentrations in bay sediments (Pehaim, 2004). Research is still being conducted, and the understanding of these pollutants will likely change in the future.

State law and county regulations closely control the application of agricultural pesticides. Municipalities and other dischargers of stormwater and wastewater must comply with National Pollutant Discharge Elimination System (NPDES) permits from the Water Board. Construction projects require a Stormwater Pollution Prevention Plan (SWPPP) that details how runoff will be minimized and monitored. The Estuary Program has shared data and technical knowledge to support local partners in meeting NPDES and SWPPP requirements.

Efforts to reduce toxic pollutants from urban runoff and the boating community have centered on education and outreach projects. The Estuary Program has disseminated information about proper use and disposal of toxic materials. The City of Morro Bay, in partnership with the Estuary Program, has implemented programs to collect hazardous waste from boat maintenance, to provide boat maintenance tools that prevent toxics from reaching the bay, and to distribute spill clean-up materials throughout the Embarcadero.

The Estuary Program, City of Morro Bay Harbor Department, State Parks, and CDFW have completed a number of cooperative efforts to remove illegal moorings and abandoned vessels in the bay. These efforts reduced potential pollution sources and also provided aesthetic and safety benefits.

2.3.5 Competition for Scarce Freshwater Resources

Freshwater is critical to the health of the estuary. Estuarine habitats such as saltwater marshes require regular inflows of freshwater to function properly. Creeks must have adequate flows to provide habitat for a variety of water-dependent plants and animals and to accommodate steelhead passage. Freshwater is also critical for the wide variety of land uses in the watershed, including farming, ranching, and urban communities. Competition among domestic, agricultural, and environmental uses for scarce freshwater resources is a priority issue in the Morro Bay watershed. The watershed's Mediterranean climate and variable precipitation patterns—both seasonally and from year to year—limit the amount of freshwater that enters the system. Creek flow naturally diminishes in the summer and autumn due to low rainfall during these times, and shallow wells drawn for agriculture and domestic use can directly affect creek flow. Parts of Chorro Creek are fully appropriated (as regulated by the State Water Resources Control Board), indicating strong competition for scarce freshwater resources in this area.

Groundwater resources are also impacted in the watershed. The Los Osos upper aquifer is impacted by nitrates and the lower aquifer is exhibiting signs of saltwater intrusion. Morro Bay's municipal groundwater wells are also contaminated with nitrates. Additional freshwater is contributed to the system from treated effluent discharged to Chorro Creek from the CMC wastewater treatment plant, although the treated water does increase water temperature in the system. CMC is required, by their NPDES permit, to discharge, at a minimum, continuous flow of 0.75 cfs (cubic feet per second) for the benefit of aquatic resources, such as steelhead.

Reductions to freshwater flows in the watershed have a direct impact on a wide variety of beneficial uses. As noted above, freshwater is a critical element of several rare habitat types. In addition, reduced flows can impede the migration and spawning of steelhead. Low flows that contribute to higher water temperatures can directly affect the viability of steelhead. Freshwater is essential to other special-status species found in the watershed, including the California red-legged frog and southwestern pond turtle. Groundwater provides domestic water to users throughout the watershed, but it is especially essential to Los Osos and Baywood as the sole source of drinking water. The City of Morro Bay also uses wells in the lower Chorro Valley when its primary source, imported state water, is unavailable. In both watersheds, groundwater is used for crop irrigation and to provide water for cattle.

The Water Board regulates surface water rights and issues permits for allowable withdrawals in the watershed. The groundwater basins in the watershed have been extensively studied and the Los Osos groundwater basin is the subject of an Interlocutory Stipulated Judgment (ISJ). The ISJ requires all of the water purveyors in Los Osos to develop a basin management plan to manage withdrawals. In 2015, parties of the ISJ completed the final, approved Los Osos Basin Plan. The plan is now managed by the Los Osos Basin Management Committee. The activities of the Los Osos Basin Management Committee substantially meet the requirements of California's Sustainable Groundwater Management Act (SGMA) for this basin. (More information is available at: [https://www.slocounty.ca.gov/Departments/Public-Works/Forms-Documents/Committees-Programs/Los-Osos-Basin-Management-Committee-(BMC).aspx)](https://www.slocounty.ca.gov/Departments/Public-Works/Forms-Documents/Committees-Programs/Los-Osos-Basin-Management-Committee-(BMC).aspx). In Morro Bay, groundwater is managed by the City of Morro Bay. The city completed an updated water planning effort in 2018, resulting in the One Water Plan for the city that focuses on diversified water sources and infrastructure improvements: https://www.morro-bay.ca.us/313/Water-Division. The County Master Water Plan addresses water resource issues in the county and specifies management approaches. The Estuary Program has focused its efforts on encouraging water conservation practices in the watershed with a wide variety of partners and supporting integrated water management approaches.

2.3.6 Enhancing Biodiversity to Maintain Habitat and Ecosystem Function

The rich biodiversity found in the Morro Bay watershed and estuary is critical to the ecosystem's ability to continue providing important functions, such as habitat for critical species, flood protection, and water filtration. Rich biodiversity strengthens the environment's resilience in the face of future change, including altered precipitation patterns and temperature gradients due to climate change. Community members and scientists alike have expressed concern over species and habitat loss in the watershed over the last twenty years (both recognized as priority issues in the 2001 CCMP), and preserving biodiversity can address both of these concerns. By taking the more holistic approach of emphasizing biodiversity, the Estuary Program anticipates more effective and long-lasting conservation results.

The core conservation issues to be addressed in the Morro Bay watershed to preserve biodiversity include preventing habitat degradation, improving and preserving the ecosystem's ability to be resilient and adapt to changing conditions, protecting and expanding migration corridors, and maintaining ecological connections between habitats to protect important ecosystem functions. Biodiversity comprises many habitats, species, and ecosystem processes in the Morro Bay watershed—wetlands, marshes, mudflats, eelgrass beds, maritime chaparral, riparian canopies, oak woodlands, 15 federally listed species, many endemic species, and the numerous ecosystem processes that support these habitats, species, and important human uses. Habitat loss, degradation, and fragmentation all can negatively impact diversity. Most of these causes occur through land uses that alter the natural landscape, such as urban development and agriculture. Invasive species can also decrease biodiversity by outcompeting native species for habitat and resources. Climate change is likely to impact biodiversity and related ecosystem functions, but the exact consequences are difficult to predict. Poor water quality, pollution, and competition for natural resources also affect biodiversity.

Several habitat types that have survived in and around Morro Bay—brackish wetlands, salt marsh, mudflats, eelgrass beds, coastal dunes complexes, and maritime chaparral—are quite rare in southern and central California. Numerous special status species depend on these habitats. Healthy habitats are also critical to shellfish farming and to recreational and commercial fishing. Morro Bay is renowned for its natural beauty, including its abundance of fish, waterfowl, and marine mammals. These factors form the base of the local recreation and tourist economy and are at risk when biodiversity is threatened.

Land use planning and other policy strategies have provided some buffer to increased development pressure on biodiversity in the watershed. The entire estuary and large portions of the watershed fall under the jurisdiction of the California Coastal Commission, and both the City of Morro Bay and County of San Luis Obispo have Local Coastal Plans and other planning regulations that stipulate protections for native habitats and species. The state of California created two Marine Protected Areas (MPAs) within Morro Bay in 2012 that are managed by California Department of Fish and Wildlife. Much of the undeveloped coastline and marsh habitats are owned by California State Parks or California State Land Commission. Habitat preservation through land acquisition and conservation easements has also helped protect biodiversity. In many cases, acquisitions resulted in the protection of special habitats or species. In other cases, acquisitions helped form greenbelts around the developed communities of Los Osos and Morro Bay to provide clear boundaries between urban growth and open space. Since the adoption of the 2001 CCMP, more than 5,000 acres of land around the bay and in the watershed have been acquired or placed in conservation easements. In addition to preservation, the Estuary Program and its partners have restored many areas of previously degraded habitat. Several miles of riparian corridors and hundreds of acres of land have been enhanced through these efforts. The implementation of best management practices to improve land stewardship has also supported the conservation of biodiversity. Work to improve water quality, such as the goals, ideas, and strategies described in previous sections of this chapter, benefits biodiversity. Finally, many education and outreach efforts in the watershed have increased awareness of important habitats and species and how to reduce impacts to them when people are recreating or engaging in other uses in the watershed.

2.3.7 Environmentally Balanced Uses

Many uses in the watershed and estuary depend on local natural resources—shellfish farming, commercial fishing, farming, ranching, tourism, and water-based recreational activities are just some examples. Although many of these uses were discussed in the 2001 CCMP, the Estuary Program now recognizes the priority issue inherent in the challenge of balancing important economic and social uses with the needs of the ecosystem. Many important human uses necessarily have some impact on natural resources. Agriculture, ranching, and urban development require changes to the natural landscape and produce stormwater runoff. Aquaculture involves infrastructure and growing activities within the estuarine environment. Recreational activities in the bay may disturb wildlife or impact habitats. All of these uses are also integral to the economy and the quality of life people experience in the watershed.

Each of these activities is itself a beneficial use. They can be the cause of impacts to other beneficial uses if they adversely affect important environmental values. Urban development, for example, has occurred on a number of important habitat types, such as coastal dune scrub and marshes. Current development plans and regulations at the state, county, and municipal level now require mitigation of the loss of important habitats. Not only can certain uses result in environmental impacts, but they can also impact each other. For example, stormwater runoff from a variety of land uses can degrade water quality that is essential for shellfish farming operations and recreational activities. Recreational activities, such as kayaking and paddle boarding, can scare away wildlife that bird watchers enjoy. The challenge facing the local community is how to balance these uses with the needs of the ecosystem in a manner that preserves habitats and wildlife as well as important economic and social qualities.

2.4 Project Methods

The Climate Vulnerability Assessment is a document created in order to better understand how the Estuary Program can respond to climate change. This report was also created in response to the EPA's "Workbook for Developing Risk-Based Adaptation Plans". This section has quick summaries for the remainder of chapters in the document.

Chapter 3. Climate Change Models and Effects: This chapter's title is quite expressive of the chapter's contents, including current climate change models that have shown what effects are projected to occur throughout the bay. This takes into account science and modelling from various climate change experts. By learning more about how climate change might modify the watershed, the Estuary Program can develop more effective adaptation plans.

Chapter 4. Climate Change Stressors and Likelihood Analysis: Chapter 4 goes more in-depth into the causal sequence that climate change effects create. These sections are comprised of subtopic ideas that are repeated for each effect including accelerated sedimentation, bacteria/nutrients/toxics, hydrologic change, environmentally balanced uses, and ecosystem restoration/conservation. Each section within this chapter has a summary table to highlight the important takeaways of these ripple effect impacts.

Chapter 5. Significance (Severity) vs. Probability (Likelihood): The summary tables from the previous chapter are then presented in tables that show the likelihood of an impact versus how high a consequence it will have on the watershed. These tables are a direct response to Step 5 of the EPA Workbook in creating these consequence/probability matrices. By creating this table, the Estuary Program is better able to understand which risks are more important to respond to and at what level of response.

Chapter 6. High Significance & Likelihood Effects (Red Boxes): This section simply lists the items that have both a high likelihood and create significant consequences to the watershed.

Chapter 7. Future Mitigation/Adaptation Planning: To be more resilient to the climate change effects described and ranked in the following chapters, Chapter 7 begins to discuss the approaches that need to be taken to help the Estuary Program adapt to climate change. First, each impact receives an approach response, including mitigate, transfer, accept, and avoid. After this, various mitigation and adaptation strategies are explored to better understand what could help reduce the likelihood and impact of a climate change effect. And lastly, some of the adaptation strategies are selected as opportunities for the Estuary Program to make a difference to the watershed.

3. Climate Change Models and Effects

Globally, climate change is occurring at an unprecedented rate. Each year, the total carbon produced globally increases by 2.2% and recently surpassed 49 gigatons of carbon in 2010, almost doubling the 1970 emissions (IPCC, 2014). This increase in carbon gas alters the atmospheric chemistry and creates a cascade effect from the trapping of heat. The IPCC reports that more than half of the global temperature increases over the last 50 years are human-caused, and since 1960 the global atmospheric CO_2 concentration has increased from 290 to 400 ppm (IPCC, 2014). As a result of this, average global temperatures are expected to increase by between 2°F and 11.5°F by 2100 (EPA, 2015). As carbon emissions continue to increase and warm the planet, the global climate will become more variable, especially on a regional scale.

Climate change will create warmer annual temperatures across the globe. This will lead to increasing storm intensity, increasing drought, rising sea levels, acidifying oceans, and increasing size/intensity of fires (EPA, 2014). According to the IPCC, surface temperature is projected to increase under all assessed emission scenarios. Projections also show heat waves and extreme precipitation events becoming more frequent and intense in many regions of the United States (IPCC, 2014).

Climate models also incorporate different emissions scenarios produced by the IPCC in their climate reports. These emissions scenarios include the Special Report Emissions Scenarios (SRES) and the Representative Concentration Pathways (RCP). The IPCC scenarios were created by combining all global climate model information into a single dataset and projecting possible emission rates into the future. The RCP scenarios were produced in 2013, while the SRES scenarios were created in 2009. In Figure 9, below, the difference between outputs is shown. Each scenario is based on a different assumption about the rate at which carbon emissions will increase in the future. The A2 scenario assumes that emissions will continue to increase at the rate they are now, A1B assumes emissions will begin to level off at the end of the century, and B1 assumes emissions will begin to level off now. The RCP scenarios also follow the same assumptions as the A2, A1B, and B1 scenarios, but they were updated in 2013. All of these scenarios are considered equally likely to occur and, therefore, do not have associated probabilities. The scenarios are all displayed in Figure 9 below.

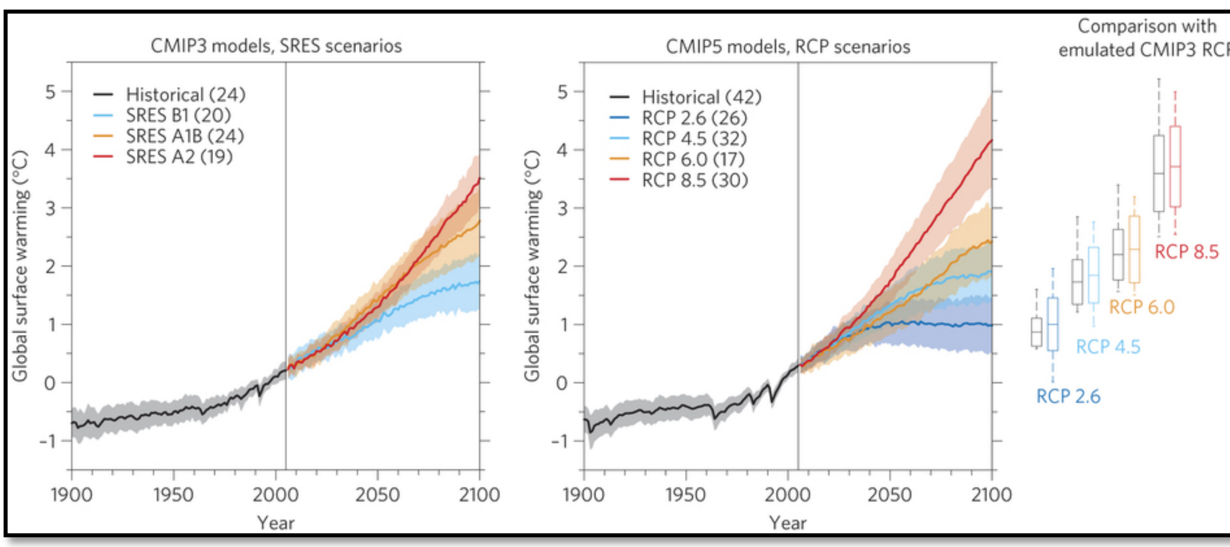

Figure 9: SRES and RCP emissions scenarios (Knutti, 2013).

3.1 Relevant Scenario and Modeling Studies

The State of California has developed their own climate assessment study in order to better understand the effects of climate change. California's Fourth Climate Change Assessment (CCA) incorporates modeling studies regionally throughout California (Bedsworth et al., 2018). In their assessment, the CCA also uses RCPs as well as other modeling studies to assess how Greenhouse Gas Emissions (GHGs) are affecting California's climate. The CCA uses two RCPs, including RCP 8.5 and RCP 4.5. The basis of each of these climate change scenarios are:

- RCP 8.5: a higher carbon emission pathway with carbon usage staying the same (exceeding 900 parts per million (ppm) by 2100). This would triple the current levels.
- RCP 4.5: a moderate scenario with GHGs rising until the mid-21st century. From here, GHGs would decline which would result in carbon concentrations of around 550 ppm by 2100.

The CCA utilized these RCP projections within global climate models (GCMs) to project California's future climate. The CCA's fourth assessment uses ten GCMs and the two RCPs to show future climate outcomes including temperature and precipitation. Because GCMs are used on a more global scale, which can reduce the detail on a regional scale, the CCA used a downscaled technique to gain more detail and variability in different areas. Four GCMs that have been selected by the CCA are:

- HadGEM2-ES: a warmer and drier simulation
- CNRM-CM5: a cooler and wetter simulation
- CanESM2: an average simulation
- MICROC5: a simulation that is the most dissimilar from the other three in order to explore all possible options.

San Luis Obispo County has prepared a climate change analysis using GCMs. The assessment conducted in 2010 by The National Center for Conservation Science and Policy used three different models. Their analysis was focused on county-wide changes and the certainty of climate change effects. They concluded that higher temperatures and shifting distributions of plants and animals were all high-certainty effects of climate change (Koopman et al., 2010). Medium-certainty effects included more frequent storms and changes in precipitation (Koopman et al., 2010). Other low-certainty impacts were changes in vegetation, runoff, and wildfire patterns.

In March 2015, a group of graduate students from the Bren School of Environmental Science and Management at University of California, Santa Barbara (UCSB) completed a report that included climate change modeling for the Morro Bay watershed. Their modeling approach included four climate models within a Basin Characteristic Model (BCM), which reduces the scale of GCMs for smaller scale analysis at the watershed level. They then used their model outputs to project vegetation change using IPCC software. Their analysis focused on vegetation community response to climate change and areas of high conservation priority. The UCSB study provided baseline information for the Climate Vulnerability Assessment of Morro Bay on vegetation changes and watershed processes. Each of these studies provided guidance on different modeling approaches for Morro Bay.

3.2 Climate Change in Morro Bay

As climate change science is better understood, more information is available to apply to different GCMs. California has created various accessible online pieces of software that allow for better exploration into the future of climate change throughout the state. Cal-Adapt, an organization developed by the California Energy Commission and California Strategic Growth Council, is a state portal for the projections completed in the CCA (see: https://cal-adapt.org/tools/annual-averages/). Through this online software, different figures were created to assess Morro Bay's possible change in temperature and rainfall based on the various scenarios and models described above in Section 3.1. Table 1 below utilizes Cal-Adapt data to begin to show the projected climate changes in Morro Bay.

Table 1: Annual Temperature Changes in Morro Bay (Cal-Adapt, 2020).

Projected Annual Temperature in Morro Bay				
	Observed Historical Temperature (1970-2005) (^{0}F)	Modeled Temperature Projections (2006-2050) (^{0}F)	Change in Temperature (^{0}F)	Average Percent Change (%)
RCP 4.5	43.7-67.2	45.8-70.6	2.1-3.4	5.0%
RCP 8.5	43.7-67.2	45.7-72.2	2.0-5.0	6.3%

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 modeled predictions and to capture interannual variations in climate. Historical Morro Bay climate data shows an increase in average annual temperature of about 1^{0}F, with recent records continuing to increase. Average daily minimum temperatures also increased a little over 1^{0}F since 1960. Current projections of temperature change until 2050 suggest about a 2 to 5 ^{0}F change. This temperature increase continues to support climate change theories and is a significant change in temperature that will cause multiple future effects. Figure 10 below shows a graph of this temperature increase in Morro Bay with each of the models used in the CCA.

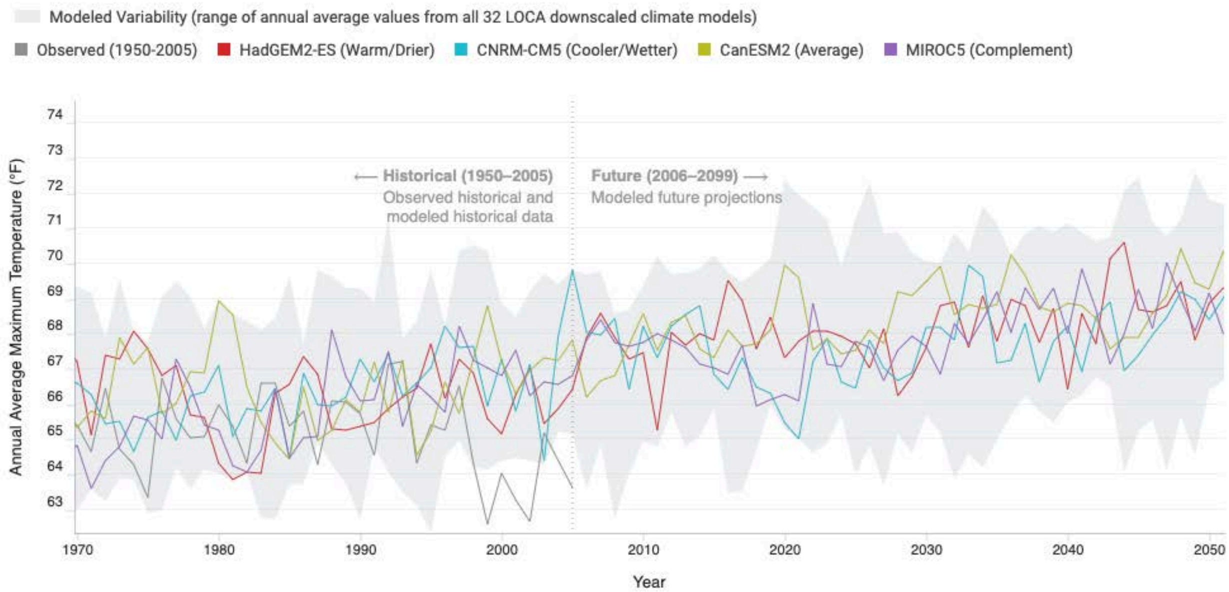

Figure 10: Annual Average Maximum Temperature in Morro Bay for Various Models under the RCP 4.5 Scenario (Cal-Adapt, 2020).

Annual rainfall in Morro Bay historically has been quite consistent seasonally, with rainfall events typically not being too intense. Recently these rainfall events have been occurring later than is seasonally normal and less frequently. When rainfall does occur, the events are more extreme, which results in larger quantities of water for the watershed to manage at once. Table 2 begins to show how the change of rainfall might look over time.

Table 2: Annual Rainfall Changes in Morro Bay (Cal-Adapt, 2020).

Projected Annual Rainfall in Morro Bay				
	Observed Historical Annual Rainfall (1970-2005) (inches)	Modeled Annual Rainfall Projections (2006-2050) (inches)	Change in Annual Rainfall (inches)	Average Percent Change in Annual Rainfall (%)
RCP 4.5	6.2-36.1	5.3-41.9	-0.9-5.8	14.5%
RCP 8.5	6.2-36.1	5.9-36.6	-0.3-0.5	9.1%

The change of annual rainfall column shows how rainfall will occur less frequently extreme event with more extreme events becoming more common. Each of these rainfall changes will cause many effects to the Morro Bay watershed. Figure 11, showing the annual rainfall changes in Morro Bay, displays more extreme peaks and troughs, which are the less frequent and more extreme rainfall events.

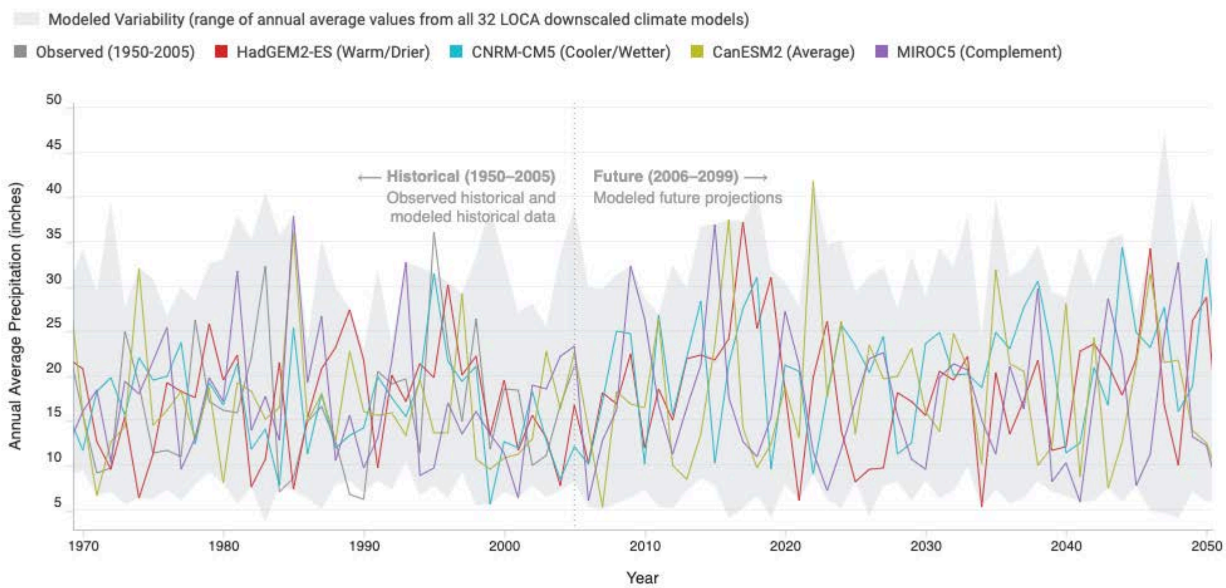

Figure 11: Annual Rainfall Changes in Morro Bay for Various Models under the RCP 4.5 Scenario (Cal-Adapt, 2020).

3.3 Climate Change Effects

While these changes might seem modest to some, with California's Mediterranean climate, these slight changes in the next 30 years could result in substantial impacts to the ecosystems that have adapted to historic temperature and rainfall levels. For instance, a decrease in existing rainfall levels would be significant as existing water resources are almost all being fully utilized. This temperature change could cause extreme effects including warmer annual temperatures, increased storm intensity, increased drought, sea level rise, ocean warming and acidification, and increased size and intensity of fires. These effects are described below in more detail.

3.3.1 Warmer Annual Temperatures

Climate models all agree that surface temperatures throughout the planet will increase between 0.54 ^{0}F and 1.26 ^{0}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).

These temperature increases are projected to be more intense in California overall and increase between 2.5 ^{0}F and 2.7 ^{0}F over the next 20 years and between 4.4 ^{0}F and 5.8 ^{0}F for the next 40 years (Bedsworth et al., 2018). Locally, the Morro Bay watershed is looking at an increase of between 2.0 ^{0}F and 5.0 ^{0}F until 2050 (Cal-Adapt, 2020). This shows that the Morro Bay watershed will have an increase in the number of extreme heat days, resulting in drier conditions and additional effects examined further in Section 4.1.

3.3.2 Increased Storm Intensity

The most recent global climate models suggest a wide range of precipitation outcomes for Morro Bay, including an increase in storm intensity, which is typically measured in an inches per hour (in/hr) rate. 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 Morro Bay suggest that the frequency of very high rain years is increasing. In the recent 15-year period ending in 2020, there was one year with more than 30 inches of rain and four years with more than 20 inches of rain (SLO Public Works, 2020). This suggests that large storm events are becoming more frequent. This alone does not show increasing storm intensity, so a comparison of past storm intensity to recent storm intensity would be necessary. Increased variability of the annual average storm will create a much more dynamic and unpredictable climate in the future, resulting in more pronounced dry and wet years. More intense rainfall events will cause floods and more extreme runoff, as well as other effects described below in Section 4.2.

3.3.3 Increased Drought

Drought is defined as "a long period of time during which there is very little or no rain" (Webster, 2016). For this analysis, rainfall is considered to be abnormally low if it is below the annual average for more than 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 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. The effects of increased drought are discussed below in Section 4.3.

3.3.4 Sea Level Rise

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. Additional factors that contribute to sea level rise include tidal change, storms, climate variability, erosion, and flooding. Throughout California, it is expected that over $150 billion of property and 600,000 people could be affected by sea level rise by 2100 (Barnard et. al., 2019).

Many studies have not included the unstable Antarctic ice sheets; however, recent studies by the Coastal Storm Modeling System (CoSMoS) have included an estimation of melting Antarctic ice sheets as well as the above factors on a study specifically for Coastal California (Barnard et. al., 2020). As the science of sea level rise (SLR) is studied, more factors and estimations are made. It is increasingly important to continuously update the Estuary Program's understanding of SLR and how it will affect the watershed. Data for SLR comes from CoSMoS, and the online accessible map was created by Our Coast Our Future (OCOF), an organization that works collaboratively with various governmental and local associations to create accessible maps and tools related to SLR (see http://data.pointblue.org/apps/ocof /cms/). Sample maps of SLR in Morro Bay are shown below in Figure 12. Since this recent 2019 study has come out with more accurate knowledge of SLR specific to Coastal California, these maps are more accurately depicted than past maps.

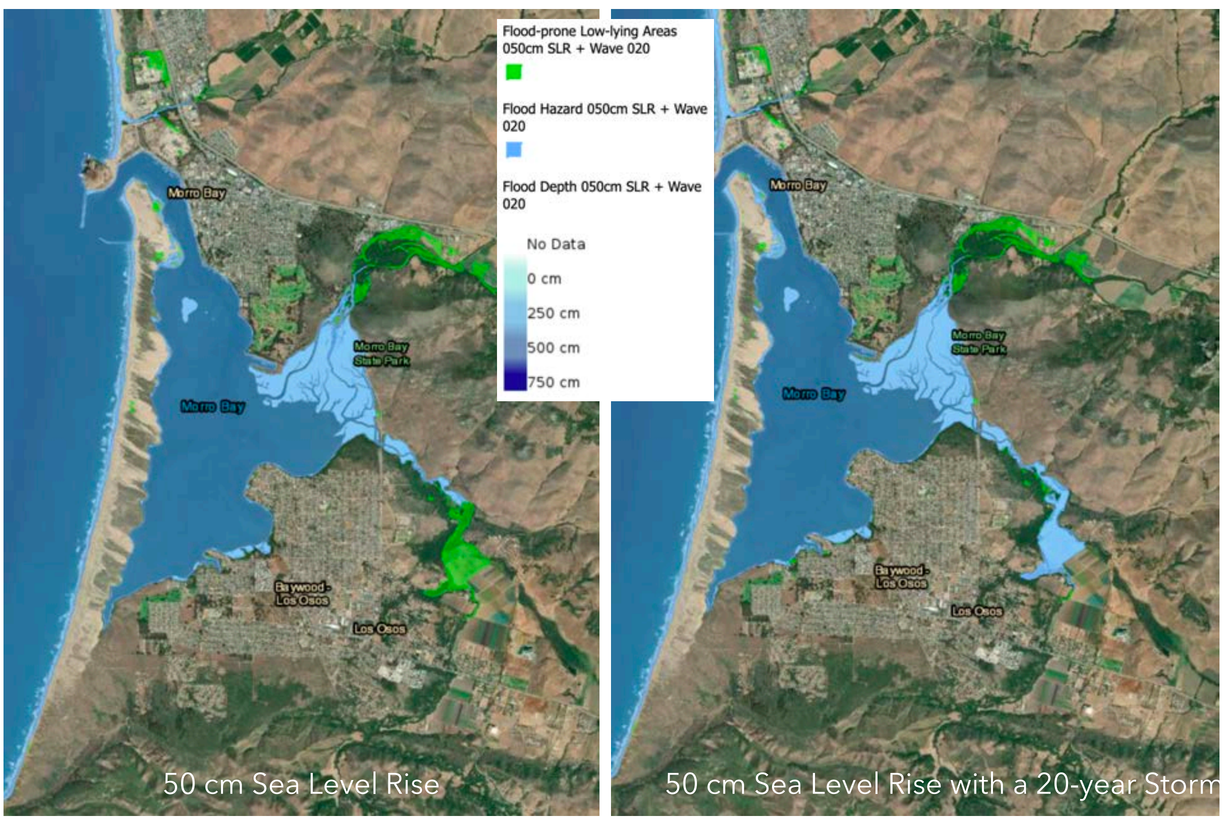

Figure 12: Inundation due to SLR, waves, and storm surge for the year 2050 (Ballard, 2016).

The Figure 12 maps reflect scientific studies that were completed along the coast of California to the year 2050. The estimation is based on various climate change scenarios including, RCP, IPCC, and others. They all estimated SLR along the California Coast to be between 6.2 to 60.8 cm, with the predominate projections between approximately 27 to 50 cm. In Figure 12, a 50 cm SLR examination was used to better understand what areas around the Morro Bay estuary will be most at risk. When SLR projections are included without storm surges, pictured in the map on the left of Figure 12, we begin to see the primary areas likely to be impacted by SLR, including Morro Bay Strand State Beach, Morro Creek inlet, Grassy Island (an island within the bay), Sweet Springs Audubon Preserve, Cuesta Inlet, and the Baywood-Los Osos Coastline. It is important to note that Morro Creek inlet is not part of the estuary's watershed. With a 20-year storm surge, pictured in the map on right of Figure 12, inundation becomes much more extreme in the areas listed above with additional surge along Los Osos Creek within agricultural lands, the edge of the sandspit, and around the northernmost end of the sandspit. Lower Los Osos and Chorro Creeks would both flood as well as the sports fields of Morro Bay High School.

The Federal Emergency Management Agency (FEMA) has also provided flood maps showing areas vulnerable to flooding. This is important to consider when analyzing the effects of SLR during large flood events, like a 100-year storm. Figure 13, below, shows the extent of flooding from the 100- and 500-year storm events. The combination of SLR and flooding events could pose many risks to the Morro Bay estuary in the future and are further explored in Section 4.4.

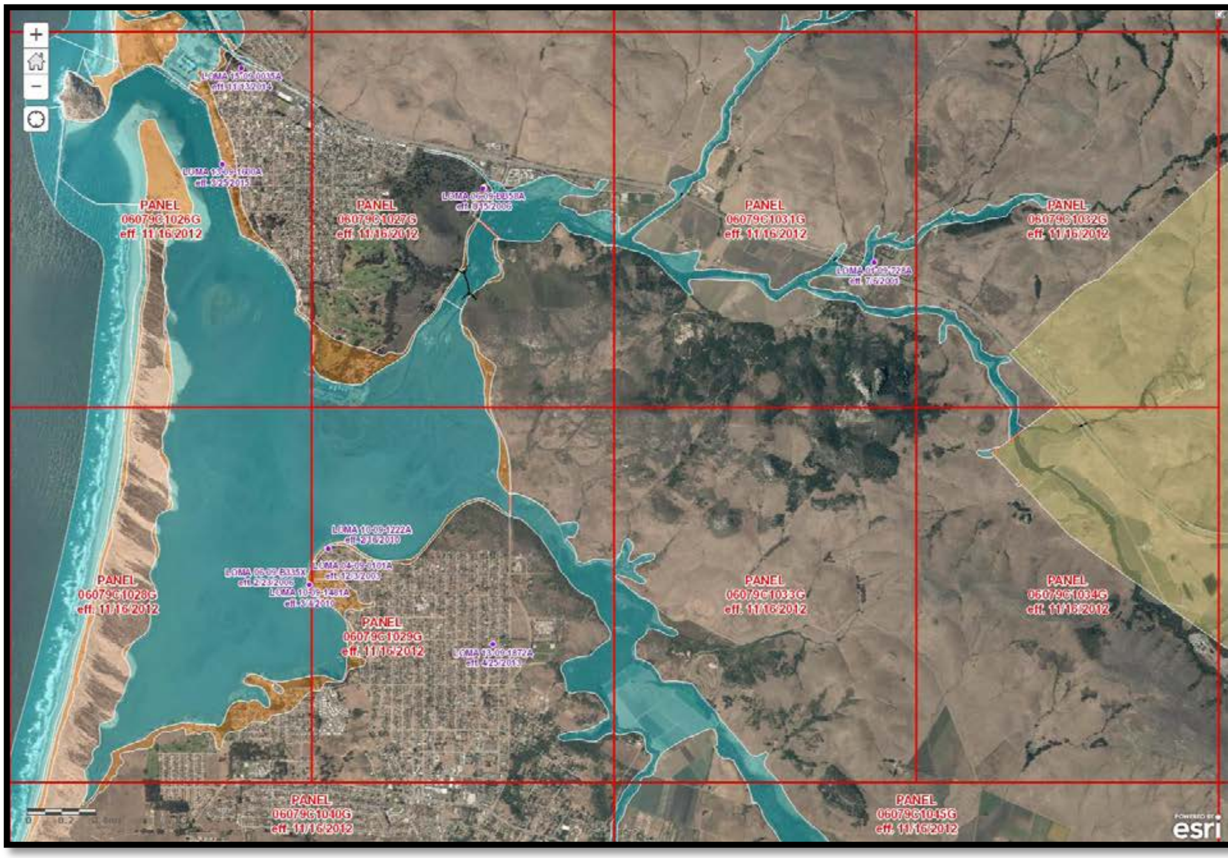

Figure 13: FEMA map showing areas vulnerable to flooding. Blue areas are water levels during the 100-year flood event and orange areas are levels during the 500-year flood event (FEMA, n.d.).

An additional factor of climate change and SLR is wave height. As the sea levels rise, so do the waves and their heights. Figure 14 shows the significant increase in wave height with 50 cm of SLR (left) and 50 cm of SLR combined with a 20-year storm (right). With waves of 5 to 6 meters in combination with SLR, inundation is a greater risk, as discussed further in Section 4.4.

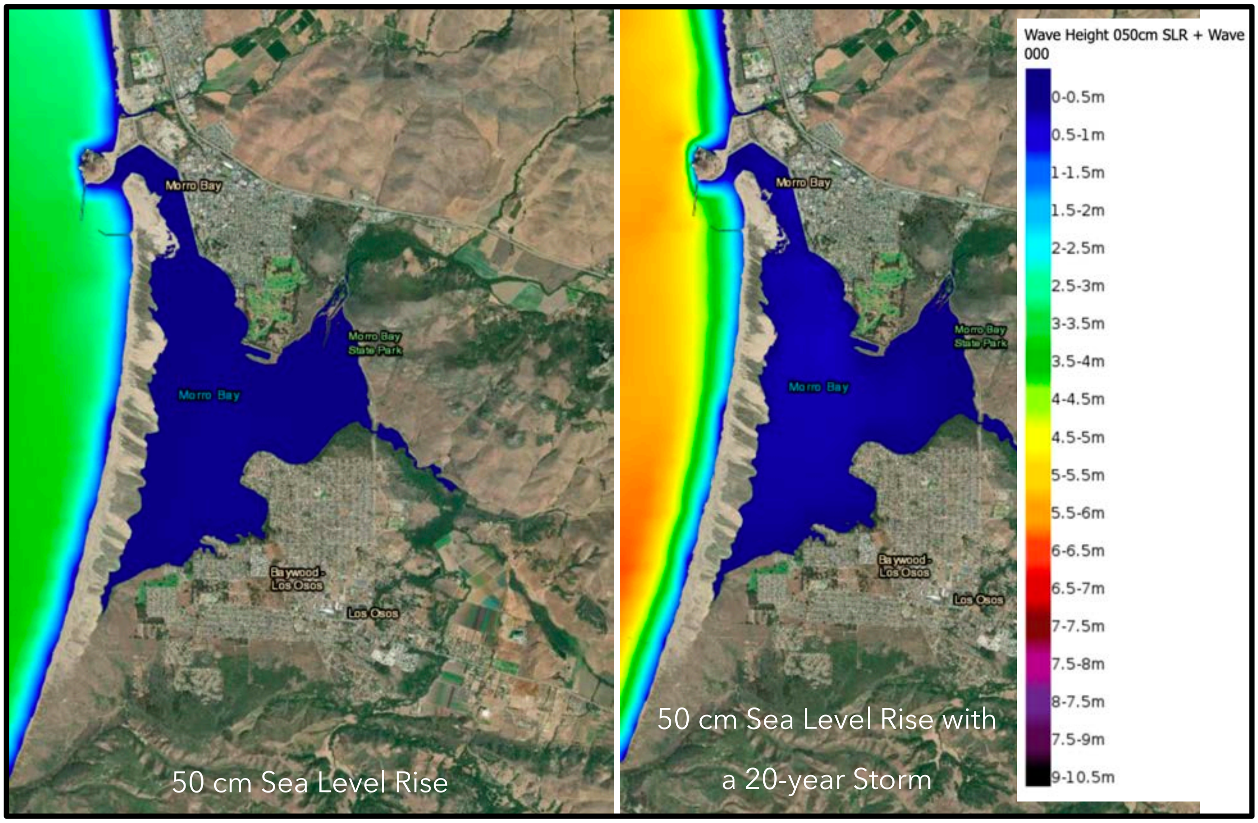

Figure 14: Wave height models for the year 2050 (Ballard, 2016).

3.3.5 Ocean Warming and Acidification

With surface temperature increases comes an increase in the temperatures of oceans. From 1900 to 2016, the California Coast's temperature has increased by 1.26 ^{0}F (Bedsworth et al., 2018). 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 and increase the acidity of the oceans. 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.

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 mean less of it is available for shellfish and 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). Additional consequences of ocean acidification including harmful algal blooms; marine ecosystems being transformed, lost, or degraded; and fishery closures (Bedsworth et al., 2018) are discussed in Section 4.5.

3.3.6 Increased Size and Intensity of Fires

Due to a combination of California's climate and natural systems, the state is predisposed to fires. It is a natural phenomenon for the state and can even be a necessity for many plants to survive (e.g., release of seeds), similar to how plants need water and sunlight (Dicus, 2020). Climate change has increased the vulnerability of California to fires, making them more intense and larger than they have been in California's past. Furthermore, many of California's homes and towns are in areas labeled as the Wildland Urban Interface (WUI). The WUI is the area where urban areas interface with wildlands that are prone to fire. There are multiple factors that determine which areas around California are more prone to fires than others, including its proximity to wildlands, environment such as terrain or aspect, vegetation and existing fuels, climate, and fire history. As a result, California Governor's Office of Emergency Services (CalOES), the state's disaster response agency, has created a map to assist in the development of hazard mitigation plans (see https://myplan.caloes.ca.gov/). A closeup of this map has been provided in Figure 15 below, showing the areas of concern which fall within Morro Bay State Park and Montaña de Oro State Park, as well as various State Park lands, private lands, and multiple residential areas in Baywood-Los Osos and Los Osos.

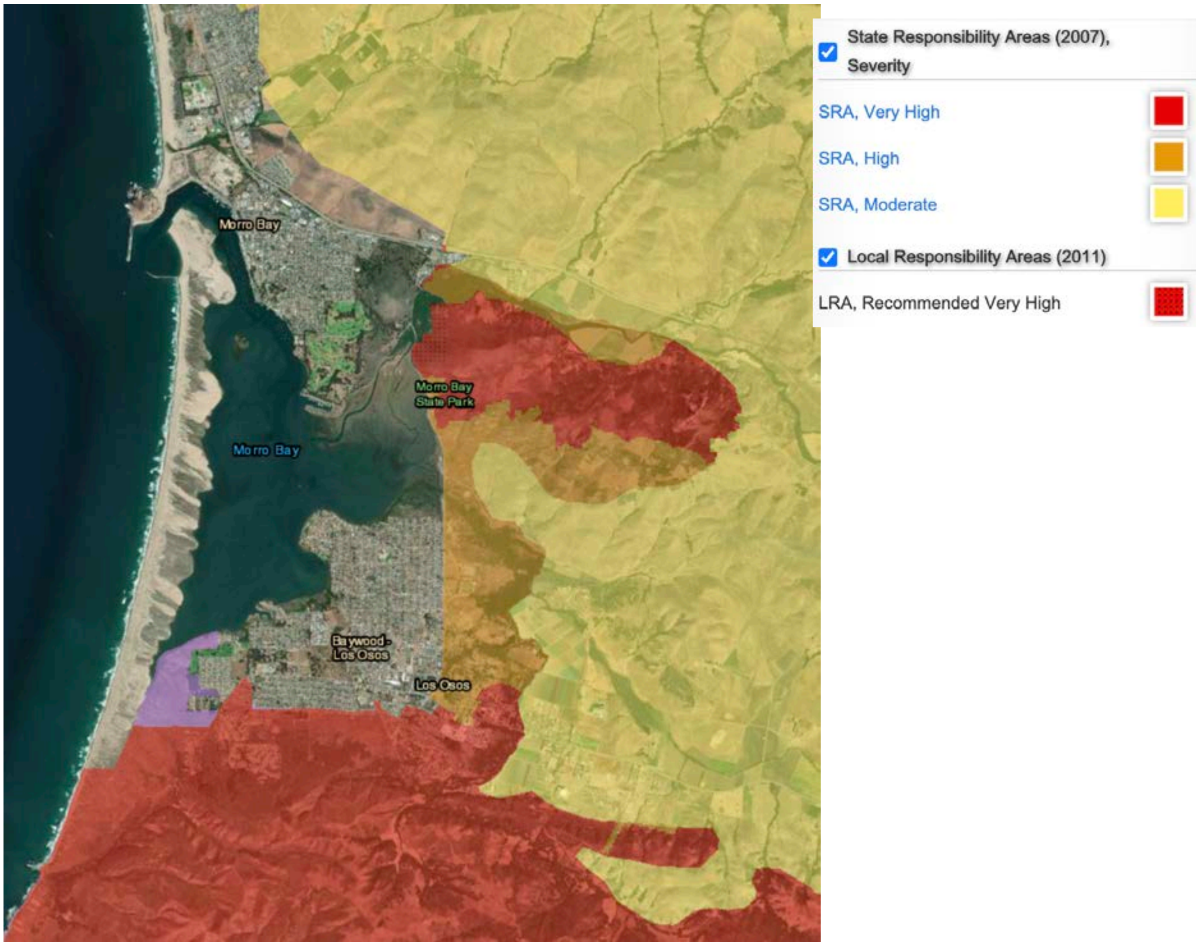

Figure 15: Fire Prone Areas for State Responsibility Areas (CalOES, 2007).

To better understand the increased likelihood of fires and their increased size, Cal-Adapt has analyzed and produced maps and data (see: https://cal-adapt.org/tools/wildfire/). Figure 16 shows the increase in fire potential from 1960 to 2050. While the map does not specifically show the Morro Bay watershed area, Cal-Adapt does utilize various emission scenarios and models to estimate the increase in acreage of fires within the area. Figure 17 shows this increase from a historical average of 54.5 hectares burned until 1990 and then an increase to an average of 78.4 hectares in about 2064. The increase of fires in the area could cause some significant issues which are explored in Section 4.6.

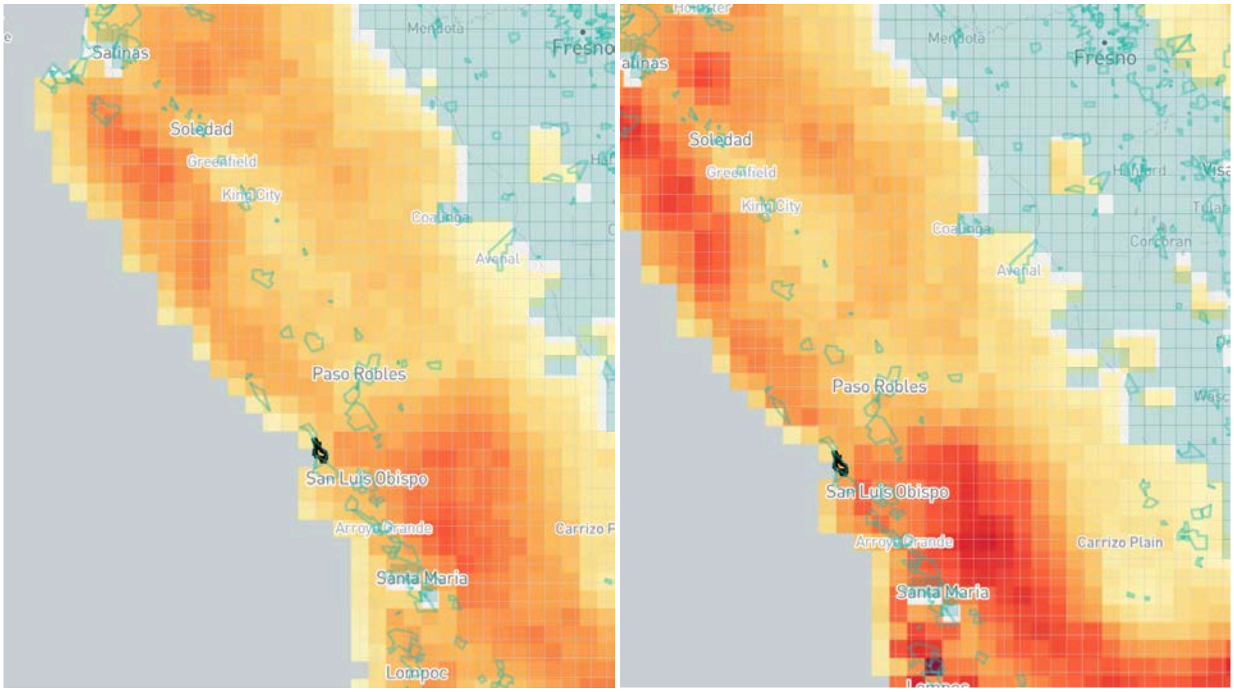

Figure 16: Increase in Fire Severity from Historical Data in 1960 to Projected Models in 2050 (Cal-Adapt, 2020).

Modeled Historical (1961–1990)

Change Year Range

MIN	AVG	MAX
21.0	54.5	101.0

Values in hectares

Mid-Century Projections (2035–2064)

Change Year Range

MIN	AVG	MAX
17.0	78.4	194.0

Values in hectares

Figure 17: Increase in Fire in Hectares, from 1990 to 2064 (Cal-Adapt, 2020).

3.4 Scientific Conclusions about Climate Change

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 drought conditions will also modify the biological and ecological processes that impact the communities that rely on them. 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 4.

3.5 Vulnerable Communities

Vulnerable communities are especially sensitive to the changes in climate throughout the world as they bear a disproportionate burden of the impacts due to the high costs of mitigation and adaptation. This is a significant issue that is discussed in the CCA. It is helpful to identify these vulnerable communities, the potential impacts to them, and ways to lower these impacts.

In addition to identifying these issues, the CCA included a summary on the unique challenges that Tribal and Indigenous Communities face with climate change. Tribes are reliant on multiple resources that are heavily affected by climate change, such as salmon fisheries (Bedsworth et al., 2018). Without the ability to be more nomadic, they are even more vulnerable, and their ways of life, cultural traditions, and livelihoods will continue to be affected. The ancient and traditional practices of tribes are beginning to be seen as a tool to help combat the causes and effects of climate change, including improving physical and mental health. These Traditional Ecological Knowledge (TEK) methods are management techniques such as controlled burns that can be used to help prevent wildfires and ecosystem management.

Climate change effects such as the increase of air pollutants and of air temperatures (Bedsworth et al., 2018) will impact public health. They can affect people in vulnerable communities at a more significant rate, such as people above the age of 65. Due to this issue, the California Heat Assessment Tool (CHAT) prototype was developed to help support those vulnerable communities most affected by the heat related issues of climate change.

Vulnerable communities are especially sensitive to SLR, so it is important to understand where these individuals predominately live. NOAA analyzed the likelihood of SLR on the Central Coast and included a map showing social vulnerability (see: https://coast.noaa.gov/slr/#/

layer/sce/3/13456079.784172922/4211449.529163183/13/satellite/none/0.8/2050/interHigh/midAccretion). Figure 18 shows the level of vulnerability to SLR in the Morro Bay area.

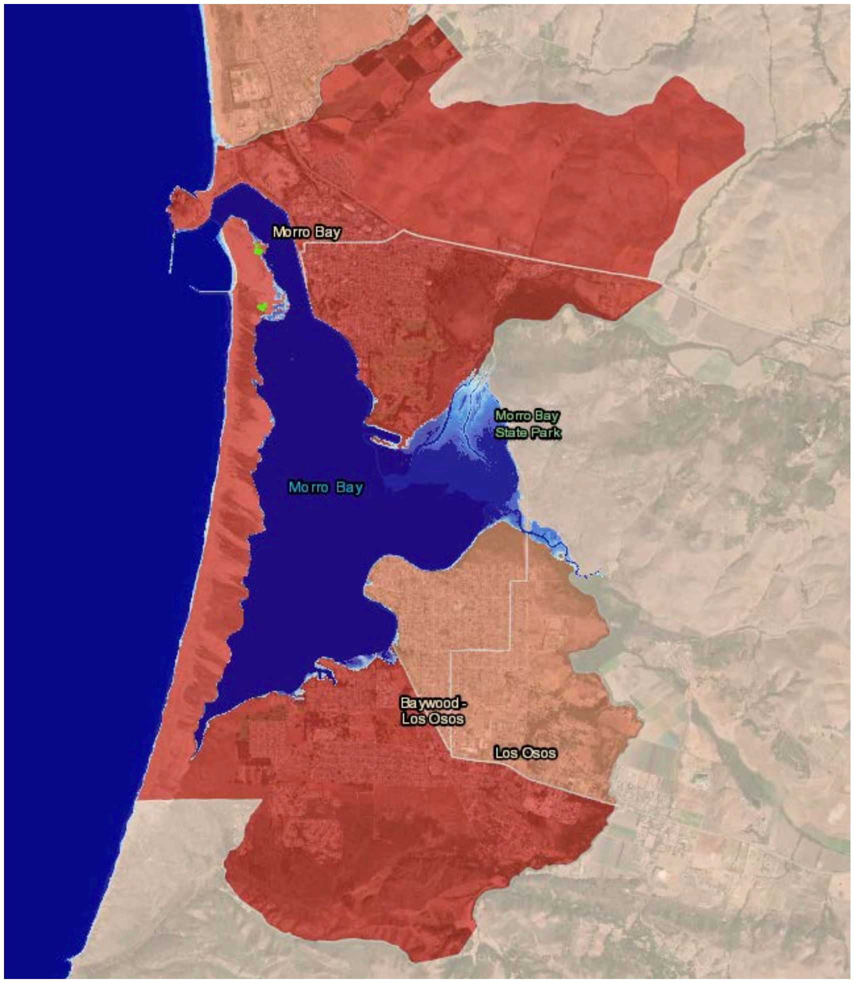

Figure 18: Vulnerable Communities to SLR – Red: Most Vulnerable and Orange: Medium Vulnerability (NOAA, n.d.).

Further research is needed to better understand how the Estuary Program's work will support the communities discussed in this section to deal with and adapt to the effects of climate change.

4. Climate Change Stressors and Likelihood Analysis

Stressors from climate change are analyzed for their impacts on the Estuary Program'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.

4.1 Warmer Annual Temperatures

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. These issues are summarized in Table 3 below.

4.1.1 Accelerated Sedimentation

- Surrounding soils and vegetation will dry out faster and earlier in the season in the projected future, which increases the sedimentation loads during weather events.

4.1.2 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.

4.1.3 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.

4.1.4 Environmentally Balanced Uses

- Water supplies will be increasingly stressed by plants, agriculture, and urban demand due to increased heat stress (National Climate Assessment, 2014).
- While initially the rise in temperature will allow agriculture to produce more food year-round, the continued increase in temperature and scarcity of water supplies will ultimately diminish food supplies.

4.1.5 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 boat traffic.
- 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.
- 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 mistime the food supply along their migration corridor. Migratory bird species that mistime 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 species may be unable to adapt at the rate of climate change (Both et al., 2006). 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). 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 interannual 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.

Table 3: Impacts from Warmer Temperatures and their Likelihood.

Warmer temperatures	Climate Change Impact Likelihood			
	Likely	**Possible**	**Not likely**	**Comments**
	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/ moisture stress on plants			Warmer/drier climate conditions
	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
	Increased sedimentation potential			As soils and vegetation dry up, there is less moisture and fewer roots to hold the soil in place

Table 3 continued...

Warmer temperatures	Climate Change Impact Likelihood			
	Likely	**Possible**	**Not likely**	**Comments**
	Food supply reduced			The warm temperatures will initially increase food supplies but over time the warm temperatures and reduced water will make food production unstable
	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 enhance bacteria growth
	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 3 continued…

Warmer temperatures	Climate Change Impact Likelihood			
	Likely	**Possible**	**Not likely**	**Comments**
		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 outfall, may require them to release cooler water
			Semi-permanent thermocline	More intense winds may mitigate thermoclines by mixing bay water

4.2 Increased Storm Intensity

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, which can be seen in Figure 12 and 13 above. These areas will be more frequently inundated during intense rainfall events. High precipitation rates and intense storms also carry more pollutants and sediment 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 have 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 claypans have low permeability and high water-holding capacity. All climate projections show drought stress, Climate Water Deficit (CWD), on soils increasing between 4% to 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. The impacts of increased storm intensity are summarized below in Table 4.

4.2.1 Accelerated Sedimentation

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

- 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 et al., 2008). Sedimentation can degrade 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.

4.2.2 Bacteria/Nutrient/Toxics

- More frequent high-precipitation events may lead to more pollutants during wet years. The increase in stormwater runoff could result in higher loads of nonpoint source pollution, including cattle and pet waste, excess fertilizer, pesticides, and many others. Oyster farms have automatic closures when water levels in Chorro Creek increase to 5.5 feet or above. This regulatory approach was implemented because data showed elevated bacteria levels in the bay at elevated flow levels. The state has also instituted seasonal closures, where harvesting directly from bay waters is prohibited during certain times of year due to a history of poor water quality (Christen, 2020). As a result of increasing storminess, these closures may increase in frequency as more storms exceed 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).

- Currently, a new wastewater treatment plant is being constructed and a relatively new plant is now in use within the Morro Bay watershed. The City of Morro Bay is constructing a treatment plant located upslope and inland at the Rancho Colina site, and it is projected to be finished by 2023. 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 and flooding at the plant from large storms. The Los Osos Water Reclamation Facility began operations in 2016 and is outfitted with updated technology with no discharge into surface waters. Instead, the plant injects treated effluent into aquifers to combat saltwater intrusion or uses the recycled water for irrigation.
- 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 to back up and spill. These pump stations are well-engineered for this risk, but more pressure from storms may occur in the future.

4.2.3 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 so 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.

4.2.4 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, less recharge may occur during intense rainfall events than during a storm with the same amount of rainfall over a longer time period.
- Frequencies for such large flood events, such as the 100- and 500-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 in danger of flooding.
- Landslide risk may increase as larger storms may oversaturate soils.

4.2.5 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 are 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. Streams will breach their banks more frequently 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 4: Impacts from Increased Storm Intensity and their Likelihood.

Increased Storm Intensity	Climate Change Impact Likelihood			
	Likely	**Possible**	**Not likely**	**Comments**
	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 significant pollution flushes			Pollution peaks from rainfall events will become more significant due to increases in intense storms, which carry more pollutants from agriculture and urban areas through the stream system
	More frequent oyster farm closures from bacteria pollution			The Chorro Creek stage height threshold will be exceeded more frequently with more intense storms
	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
	Increased stormwater runoff			More rain means more runoff from compacted areas
		Increased groundwater recharge		High precipitation years will be more frequent
		More sediment to tidal marsh to keep pace with SLR		As sediments flows down into the bay's tidal marsh it will help build up these marshes

Table 4 continued…

Increased Storm Intensity	Climate Change Impact Likelihood			
	Likely	**Possible**	**Not likely**	**Comments**
		Septic tank failure		There is still a possibility for failure during large storm events due to the fact that some areas of Los Osos were allowed to remain on a septic system.
		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

4.3 Increased Drought

Increasing drought and extreme high temperatures have already been experienced throughout the Central Coast. Warmer temperatures and more drought will affect the ecosystem and exacerbate the issues of climate change including drying soils at a faster rate, which could potentially increase of air pollution and reduce groundwater recharge. Table 5 below summarizes the effects of increased drought.

4.3.1 Bacteria/Nutrients/Toxics

- More intense droughts will increase water temperatures in creeks, which favor bacterial growth, algal blooms, decomposition, and lower DO levels in the estuary and watershed (EPA, 2012).
- Loss of ground cover due to drought and increased temperatures can leave soils vulnerable to erosion. These conditions also allow for an increase in air pollution

due to dried out soil particles that are unable to adhere and thus more likely to be transported as wind-borne dust.

4.3.2 Hydrologic Change

- Groundwater levels may decline, and more saltwater intrusion may occur. This has become a problem for Los Osos during the current drought. The groundwater has become increasingly salty from the decreasing aquifer levels (Wilson, 2015). This may also become a threat to Morro Bay's water supply as state water becomes less available.
- Lower water tables will result in lower base flows year-round and less water available for wetland and off-channel habitats.

4.3.3 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 per the CWD 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.

4.3.4 Ecosystem Restoration/Conservation

- Invasive plant species may 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.

Increased Drought	Climate Change Impact Likelihood			
	Likely	**Possible**	**Not likely**	**Comments**
	Decreased creek and estuary DO levels			Warmer water holds less DO and facilitates algal blooms and decomposition
	Loss or early dry-out of wetland habitats			Drier conditions, lower water tables, and increased evapotranspiration will impact water supplies.
	Increased moisture/temperature stress on plants			Drier conditions overall
	Stressed water budget			Drier conditions leading to increased water use
	Saltwater intrusion			Lower groundwater levels could increase saltwater intrusion
	Increase of creek temperature			Lower flows and warmer air temperatures will increase water temperatures

Table 5 continued…

Increased Drought	Climate Change Impact Likelihood			
	Likely	**Possible**	**Not likely**	**Comments**
	Favors invasive plant species			More intense droughts may favor invasive plant species that are more drought tolerant
	Loss of specialized wetland species			Early dry out and loss of wetland habitats may cause a loss in specialized species
	Increased air pollution			Soil that dries out and becomes sediment is likely to contribute to dust issues
	Decline in eelgrass			Warmer waters linked to decline in Chesapeake Bay
		Impacted steelhead trout migration		Drought leading to lower flow levels throughout the year

4.4 Sea Level Rise

As the temperatures throughout the world increase, ice will melt, and water will expand resulting in the sea levels rising. Recently, researchers have been able to more accurately predict where SLR will happen along California's coast (see Figure 12). More precise information increases understanding of the potential effects on Morro Bay. These issues are summarized in Table 6 below.

4.4.1 Accelerated Sedimentation

- SLR will inundate the estuary, which has been aggrading over time. This may mitigate some of the negative effects of sedimentation in the estuary by raising the water levels to compensate, but the current sediment inputs are not expected to be enough for estuary habitats to keep pace without adaptation efforts (e.g., sediment augmentation).

This is likely to lead to conversion of habitat types. Modeling completed by the U.S. Geological Survey (USGS) (Thorne, 2012) found that under a mid SLR scenario (63 cm), there is loss of mid and high marsh beginning in 2030 and significant expansion of mudflat between 2070 and 2110. Under a high SLR scenario (166 cm), habitat changes occur more rapidly with an almost complete dominance of mudflat across the existing tidal marsh by 2080 (Thorne, 2012). Tidal marsh habitat may migrate inland to higher elevations but there is limited space given the topography of Morro Bay.

- Increased water levels in the estuary may cause a shift in suitable habitat for eelgrass as some of its current habitat extent becomes deeper.
- SLR may reduce the retention time of sediments and water in the back bay. In recent history, portions of the mid and back bay have been eroding due to eelgrass decline, possibly due to loss of eelgrass in those areas (Walter et al., 2018). Walter et al. 2018 has also shown that the bay can experience high residence times in the back bay, especially when there is low freshwater input from the watershed. Higher water levels and a larger tidal prism may help mitigate aggradation and flush out water and sediments more frequently.
- Increases in coastal erosion may occur in some areas. The sandspit may help mitigate storm surges and reduce wave impacts on coastal communities but may also lose some of its buffering capacity. The net effect is uncertain, as the sandspit may also build up due to littoral sand transport. The sandspit is also likely to shift to the east from higher sea levels, which would decrease the overall size of the estuary. The extent of migration has not yet been modeled.
- 4.4.3 Saltwater intrusion into the groundwater table can alter the salinity gradient and threaten drinking water supplies (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.

4.4.4 Environmentally Balanced Uses

- Morro Bay Strand State Beach, Morro Creek inlet (not part of the Morro Bay watershed), Grassy Island (an island within the bay), Sweet Springs Audubon Preserve, Cuesta Inlet, and the Baywood-Los Osos coastline are all areas that are vulnerable to SLR. With the addition of a 20-year storm surge, SLR becomes much more extreme in the areas listed above, potentially resulting in additional surge along Los Osos Creek within agricultural lands, the edge of the sandspit, and around the northernmost end of the sandspit. Lower Los Osos and Chorro Creeks would both flood as well as the sports fields of Morro Bay High School. Nearby areas 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 SLR, it is possible that the combination could endanger infrastructure near the confluence of Los Osos and Chorro Creeks with the estuary. Los Osos is currently vulnerable to flooding in some areas, regardless of climate change.

4.4.5 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. Those that cannot adapt 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 saltwater intrusion			Saltwater influence on surface and groundwater could 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 in bay			The back bay will have deeper water, which may improve circulation and increase flushing of sediment
	Increased infrastructure risk			Many low-lying areas near the bay will be more vulnerable to king tides, storm surges, and daily tides
	Conversion of habitats with deeper water in the bay (e.g., tidal marshes to mudflats)			Higher water will likely inundate current wetlands and where there is space, may migrate them inland; although, much of the marshes could be lost without management
		Where feasible, tidal marshes may migrate inland		The tidal marshes will most likely convert to mudflats with SLR

Table 6 continued…

Sea Level Rise	Climate Change Impact Likelihood			
	Likely	**Possible**	**Not likely**	**Comments**
			Sewer overflows	Larger storm surges could overwhelm sewage collection systems
		Loss of specialized wetland species intolerant of salinity change		Species unable to migrate to new habitats and intolerant of salinity change may be lost
		Sandspit may move inland		This is due to the higher sea levels and added sediment impacts
		Sandspit buffer high wave impacts		With SLR there is also an increase in wave height and speed; the sandspit may mitigate this
			Sandspit buildup	The sandspit may increase in size from littoral sand transport

4.5 Ocean Warming and Acidification

As the surface temperatures rise, so do ocean levels. The warming is caused excess carbon dioxide in the atmosphere, which is causing the oceans to become more acidic. Ocean acidification has been affecting oyster farms in the Pacific Northwest for the past decade. Oysters rely on aragonite to form their initial shells. In acidic waters, aragonite 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. While problems with acquiring seed have caused trouble for oyster farms in the bay, there is no concrete evidence of adverse growth affects from low pH levels on their product. The effects of ocean warming and acidification are summarized below in Table 7.

4.5.1 Bacteria/Nutrients/Toxics

- 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.
- Lower pH may result in increased toxicity of pollutants and more free metals. However, pH change will likely 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).
- 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 *Labyrinthula macrocystis,* to have greater abundance, survival, and transmission. *Labyrinthula* 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. When Oregon and northern California experienced record high stream temperatures from lack of snowpack, warmer annual temperatures, and warmer El Niño conditions, there was 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 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 water depth available to buffer temperature changes. This may affect the salt marshes, mudflat habitats, and much of the back bay. Streams within the watershed will also be very vulnerable. Chorro Creek, 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. 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.

4.5.2 Hydrologic Change

- Warmer waters can hold less DO (IPCC, 2014). Steelhead trout can begin to exhibit symptoms of oxygen distress at DO levels of 6.5 mg/L and below (Carter, 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.

4.5.3 Environmentally Balanced Uses

- Oyster hatcheries in the Pacific Northwest (PNW) 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, or farmers would need to seek another source of seed. Other areas such as Hawaii, also with oyster hatcheries, may not have similar impacts.
- More acidic waters may corrode infrastructure in the bay more rapidly. Corrosion rates of pipes, boats, pilings and many other metal fixtures that are inundated by sea water may increase. Thus far, this effect has been found to be insignificant since the decrease in pH is not enough to increase corrosion rates significantly (Raven et al., 2005).
- Warm waters can cause oysters to naturally spawn in Morro Bay, which can lead to poor meat quality (Trevelyan, 2015).
- Temperature criteria for California Men's Colony wastewater treatment plant outflow may need to be reconsidered due to warmer receiving waters. In order to minimize effects downstream, it may be necessary to reduce the temperature of discharged effluent.

4.5.4 Ecosystem Restoration/Conservation

- 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).

- More acidic ocean water may increase the number 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).
- 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.
- 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 outside this range in Morro Bay. The worst-case scenario for ocean pH is projected to be 7.8.
- 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 ^{0}F, or an average temperature above 70.7 ^{0}F (Moyle et al., 2008). Their optimal mean stream temperature range is 42.8 ^{0}F to 50 ^{0}F. Mean temperatures exceeding 55.4 ^{0}F indicate poor habitat (NMFS, 2007). Climate change may cause more sections of the Morro Bay watershed to become unsuitable or degraded habitat for steelhead. Climate change conditions may also favor invasive species, 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 sources. 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 7: Impacts from Ocean Warming and Acidification and their Likelihood.

Ocean Warming and Acidification	**Climate Change Impact Likelihood**			
	Likely	**Possible**	**Not likely**	**Comments**
	Loss of fitness of species sensitive to pH and warm water			Flora and fauna may be reduced or lost
	More toxic pollutants			The warmer temperatures can result in pollutants that are more bioavailable, etc.
	Increase in invasive species			Warmer waters may favor invasive over native species
	Eelgrass decline			Elevated temperatures could result in eelgrass could die off
		Decrease in available substrates for $CaCO_3$ users		Oysters and other shellfish could be impacted
		Seed shortage or loss of PNW hatcheries		Potential seed shortage and production problems

Table 7 continued…

Ocean Warming and Acidification	Climate Change Impact Likelihood			
	Likely	**Possible**	**Not likely**	**Comments**
		Reduced juvenile rearing habitat		Warmer water during summer and fall may negatively impact sensitive species like steelhead
		Steelhead trout impairment		Warmer water temperatures and reduced DO can negative impact steelhead
		Poor oyster quality		Warm waters can cause natural spawning, resulting in poor oyster quality
		Facilitate new pathogens and diseases in the estuary		Bacteria grow faster with warmer water temperatures
		Facilitate algae growth		More algae shades out native plants and is toxic to many animals. Can also cause low DO.
		Jellyfish invasion		Not expected to present a danger to the ecosystem
		Complete shift in biodiversity		A loss of eelgrass would impact water quality and result in habitat loss
			Corrosion of infrastructure	Not expected to have significant impacts
			Increased pollutant toxicity	Shift in pH is expected to be small enough that this will not be a significant issue

Table 7 continued…

Ocean Warming and Acidification	Climate Change Impact Likelihood			
	Likely	**Possible**	**Not likely**	**Comments**
			Stratified water	Could be offset by more intense winds mixing DO and other nutrients
			More bacteria	Warmer waters may create favorable conditions for bacteria.

4.6 Increased Size and Intensity of Fires

As temperatures and drought increase, the likelihood increases for larger and hotter fires in California. The state has already seen an increase in these types of fires, which have affected the ecosystems and economy. While fires are a natural phenomenon throughout the area, the increased size, intensity, and frequency of them would have substantial impacts. The effects of fires increasing in size and intensity are summarized below in Table 8.

4.6.1 Accelerated Sedimentation

- 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 increase the frequency of fires in the watershed. Wildfires remove ground cover and can lead to increased soil erosion.
- A study of 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).

- In 1994, fires along Highway 41 in the Morro Bay watershed followed by heavy rains led to significant increases in sediment to the estuary.

4.6.2 Bacteria/Nutrients/Toxics

- More frequent fires increase the amount of carbon dioxide and other chemicals and pollutants in the air and atmosphere. These pollutants can be toxic and be extremely harmful to animals and people.
- Excess carbon dioxide pollution in the air will also increase with more frequent and intense fires.

4.6.3 Ecosystem Restoration/Conservation

- 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 is anywhere from 40 to 70 years for maritime chaparral 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 the 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 fires will also be important because spring burns favor native grasses, while fall burns favor nonnative species (NPS, 2007).
- Fuels management has been present throughout the watershed through grazing and agricultural practices, which is reflected by the infrequency of fires in the area.

Table 8: Impacts from Increased Size and Intensity of Fires and their Likelihood.

Increased Size and Intensity of Fires	Climate Change Impact Likelihood			
	Likely	**Possible**	**Not likely**	**Comments**
	Increased fire season length and frequency			Longer and more intense droughts may increase fire risk
	Increased soil erosion and landslides (impacts to eelgrass and steelhead spawning habitat)			Fires will make lands bare and more prone to erosion
	Increase in carbon dioxide and other pollutants			Fire increases air pollutants
		Shift to more grasslands		More frequent fires will not give scrub and chaparral communities time to rebound from a fire
			Invasive species altering fire regime	Invasive species have already compromised many communities

4.7 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.
- While plant species within the flood prone and SLR areas of the watershed will be more susceptible to inundation, this may cause a shift to wetland and hydrophytic

communities. The shift increases viable habitats for species that need these conditions such as the California red-legged frog *(Rana draytonii)* and allow for water to pool and increase groundwater recharge.

- SLR may improve habitat in the back bay by providing more water and allowing for more tidal influence to help with flushing of sediments and increasing DO. Currently, aggradation of the estuary has caused waters and sediments to stagnate in the back bay as water becomes shallower. SLR may counteract these impacts by deepening water, which can decrease temperatures, increase mixing, and inundate areas that are aggrading. This may mitigate some of the negative effects of sedimentation.
- Large sediment inputs in a short time period could cover estuary habitat such as eelgrass in the short-term but watershed sediment inputs will be essential for habitats keeping pace with SLR (see Section 3.3.4).
- The sandspit may mitigate storm surge SLR issues, but rising seas and storm surge could impact areas such as tidal marshes.
- 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.
- Warmer temperatures in the ocean 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 by more intense winds that can cause turbulent mixing.

4.8 Compounding Impacts

- Sediment acceleration is compounded by an increase in temperatures, storm intensity, drought, and size and intensity of fires. As temperatures rise and droughts become more frequent, soils dry out faster and can be moved more easily by wind and water, especially during more intense storms. More and larger fires can also increase the square footage of areas prone to erosion. Accelerated sedimentation may also worsen with SLR from storm surges and tidal influence.

- Water quality issues are compounded by an increase in storm intensity, drought, SLR, ocean warming and acidification, and size and intensity of fires. Similar to accelerated sedimentation , man-made pollutants are spread due to the effects described above.
- Bacteria/nutrients/toxics may be increased by an increase in annual temperatures, storm intensity, drought, ocean acidification, and size and intensity of fires through the same processes described in sediment acceleration.
- Groundwater recharge issues are made worse by increases in annual temperatures, storm intensity, and drought. Both warmer temperatures and drought reduce opportunities for water infiltration. These drought conditions also dry the soil to where water will run off rather than infiltrate during storm events.
- Water supplies, including the groundwater table, are stressed by an increase in annual temperatures, drought, SLR, and ocean warming and acidification. This includes the groundwater recharge issues described above. Water supply issues are also affected by saltwater intrusion due to SLR and drought.
- Wetlands and seasonal creeks will dry out faster due to the warmer temperatures and increased drought, which will affect many plant and animal communities.
- Invasive plants and animals could benefit from warmer annual temperatures, increased drought, SLR, ocean warming and acidification, and increased size and intensity of fires.
- The lifespans of steelhead trout and other migratory animals are affected by the compounding effects of an increase in annual temperatures, storm intensity, drought, and size and intensity of fires. With warmer annual temperatures and increased drought, waterbodies will evaporate more than is typical, making migration at certain times of the year more difficult. These effects have already stranded multiple steelhead trout in pools of seasonal streams that have had lower than average flow rates . With an increase in sedimentation (described above), many of the habitats crucial for these species are being degraded.

- Eelgrass and other marine vegetation survival is impacted by an increase in annual temperatures, storm intensity, drought, SLR, ocean warming and acidification, and size and intensity of fires. Warmer annual temperatures and drought will warm the oceans and impact plant survival. An increase in sedimentation may also bring additional harmful pollutants to the estuary.
- As the SLRs, it may begin to reduce the land area of the sandspit and impact its buffering capacity against storms and storm surges. These changes 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. The sandspit is also projected to migrate inland (to the east) with rising seas.
- 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 Morro Bay Strand State Beach, Morro Creek inlet, Grassy Island (an island within the bay), Sweet Springs Audubon Preserve, the Cuesta Inlet, and the Baywood-Los Osos shoreline. These areas are most susceptible to SLR, which may be compounded by storm surges. Large peak flows may exacerbate these effects in the estuary, increasing susceptibility to flooding. With a 20-year storm surge, flooding becomes much more extreme in the areas listed above and along Los Osos Creek within agricultural lands, along the edge of the sandspit, and around the northernmost end of the sandspit. Lower Los Osos and Chorro Creek would both flood as well as the sports fields of Morro Bay High School. Warmer annual temperatures, increased storm intensity, and SLR will degrade existing and future infrastructure like roads, railroads, port facilities, energy infrastructure, and water infrastructure.

5. 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 are discussed in section 4. Organizing each impact by both likelihood and priority in the following tables allows the Estuary Program to prioritize them 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.

5.1 Warmer Annual Temperatures

Table 9: Likelihood versus Consequence for Warmer Annual Temperature Effects.

Likelihood (Probability) of Occurrence	Consequence of Impact: Low	Consequence of Impact: Medium	Consequence of Impact: High
Low		• Semi-permanent thermocline (+) • CMC lower discharge requirements (+)	• Toxicity of pollutants may increase • Decreased coastal fog
Medium		• Increased use of herbicides/pesticides • Aquatic habitats may dry out earlier • Favors invasive species • Invasive insects	• Food supply reduced • Eelgrass declines • Favorable conditions for bacteria • Introduction of new pathogens/ diseases • Warmer streams during summer and fall • Oyster infections
High		• Increased temperature stress on plants • Bird migration shifts and population declines • Less suitable habitats for steelhead • Increased sedimentation potential • Increased algal blooms and decomposition rate	• Increased urban and agricultural water use • Increased water budget stress

5.2 Increased Storm Intensity

Table 10: Likelihood versus Consequence for Increased Storm Intensity Effects.

Likelihood (Probability) of Occurrence	Consequence of Impact: Low	Consequence of Impact: Medium	Consequence of Impact: High
Low		• Increased groundwater recharge (+)	
Medium	• Septic tank failure	• More frequent landslides • High stream velocities disrupt steelhead • More sediment to tidal marsh to keep pace with SLR (+)	• More frequent oyster farm closures from bacteria pollution • Altered flood-prone area habitat
High		• Sedimentation increase • Increased stormwater runoff	• More frequent floods • Aggradation of estuary • More significant pollution flushes • Landscape runoff (overland flow) increase

5.3 Increasing Drought

Table 11: Likelihood versus Consequence for Increasing Drought Effects.

Likelihood (Probability) of Occurrence	Consequence of Impact: Low	Consequence of Impact: Medium	Consequence of Impact: High
Low			• Decline in eelgrass
Medium		• Impacted steelhead trout migration	• Favors invasive plant species • Loss of specialized wetland species
High		• Increased moisture/temperature stress on plants • Increased temperatures in creeks	• Decreased creek and estuary DO levels • Loss or early dry-out of wetland habitats • Stressed water budget • Saltwater intrusion • Increased air pollution

5.4 Sea Level Rise

Table 12: Likelihood versus Consequence for SLR Effects.

Likelihood (Probability) of Occurrence	Consequence of Impact: Low	Consequence of Impact: Medium	Consequence of Impact: High
Low	• Sandspit buildup (+)	• Sewer overflows	
Medium	• Sandspit buffer high wave impacts (+)	• Sandspit may move inland	• Conversion of habitats with deeper water in the bay (e.g., tidal marsh to mudflats) • Where feasible, tidal marsh may migrate inland • Loss of specialized wetland species intolerant of salinity change
High	• Shift/increase in suitable eelgrass habitat (-/+) • Reduced water/sediment retention times in bay (+)	• Change in wetland inundation frequency and salinity	• Increased saltwater intrusion • Increased infrastructure risk

5.5 Ocean Warming and Acidification

Table 13: Likelihood versus Consequence for Ocean Warming and Acidification Effects.

Likelihood (Probability) of Occurrence	Consequence of Impact: Low	Consequence of Impact: Medium	Consequence of Impact: High
Low		• Corrosion of infrastructure • Increased pollutant toxicity • Stratified water • More bacteria	
Medium	• Jellyfish invasion	• Decrease in available substrates for $CaCO_3$ users • Poor oyster quality • Complete shift in biodiversity	• Seed shortage or loss of PNW hatcheries • Reduced juvenile rearing habitat • Steelhead trout impairment • Facilitate new pathogens and diseases in the estuary • Facilitate algae growth
High			• Loss of fitness of species sensitive to pH and warm water • More toxic pollutants • Increase in invasive species • Eelgrass decline

5.6 Increased Size and Intensity of Fires

Table 14: Likelihood versus Consequence for Increased Size and Intensity of Fires Effects.

Likelihood (Probability) of Occurrence		Consequence of Impact: Low	Consequence of Impact: Medium	Consequence of Impact: High
	Low			• Invasive species altering fire regime
	Medium		• Shift to more grasslands	
	High		• Increased soil erosion and landslides (impacts to eelgrass and steelhead spawning habitat)	• Increased fire season length and frequency • Increase in carbon dioxide and other pollutants

5.7 Discussion

By sorting impacts into categories via the probability vs. significance tables, climate change effects were prioritized by level of concern. Out of 79 impacts, 48 were listed as high priority (red), 20 were listed as medium priority (yellow), and 11 were listed as low priority (green).

6. High Significance & Likelihood Effects (Red Boxes)

Discussion on the impacts and likelihood of each stressor can be found in Sections 4 and 5 above. The following lists contain the items in Section 5 that were of high likelihood of occurrence and consequence of impact – those that were in red boxes. These items are not ranked in order of importance.

Warmer Annual Temperatures

- Increased urban and agricultural water use
- Increased water budget stress
- Increased temperature stress on plants
- Bird migration shifts and population declines
- Less suitable habitats for steelhead
- Increased sedimentation potential
- Increased algal blooms and decomposition rate
- Food supply reduced
- Eelgrass declines
- Favorable conditions for bacteria
- Introduction of new pathogens/ diseases
- Warmer streams during summer and fall
- Oyster infections

Increased Storm Intensity

- More frequent floods
- Aggradation of estuary
- More significant pollution flushes
- Landscape runoff (overland flow) increase
- Sedimentation increase
- Increased stormwater runoff
- More frequent oyster farm closures from bacteria pollution
- Altered flood-prone area habitat

Increased Drought

- Decreased creek and estuary DO levels
- Loss or early dry-out of wetland habitats
- Stressed water budget
- Saltwater intrusion
- Increased air pollution
- Increased moisture/temperature stress on plants
- Increased temperatures in creeks
- Favors invasive plant species
- Loss of specialized wetland species

Sea Level Rise

- Increased saltwater intrusion
- Increased infrastructure risk
- Change in wetland inundation frequency and salinity
- Conversion of habitats with deeper water in the bay (e.g., tidal marsh to mudflats)
- Where feasible, tidal marsh may migrate inland
- Loss of specialized wetland species intolerant of salinity change

Ocean Warming and Acidification

- Loss of fitness of species sensitive to pH and warm water
- More toxic pollutants
- Increase in invasive species
- Eelgrass decline
- Seed shortage or loss of PNW hatcheries
- Reduced juvenile rearing
- Steelhead trout impairment
- Facilitate new pathogens and diseases in the estuary
- Facilitate algae growth

Increased Size and Intensity of Fires

- Increased fire season length and frequency
- Increase in carbon dioxide and other pollutants
- Increased soil erosion and landslides (impacts to eelgrass and steelhead spawning habitat)

6.1 Climate Change Conclusions for the Morro Bay National Estuary Program

Many of the Estuary Program's goals focus primarily on two things: habitat conservation and clean waters. As the local climate undergoes changes, these goals will be placed under much greater stress. More intense rainfall events will be able to carry higher levels of pollutants and sediment into the Morro Bay watershed and estuary. Drier conditions will further stress native plants and water supplies in the area. Warmer temperatures will increase the temperatures of the bay and stream waters that lead to poor habitat conditions. As sea levels rise, unique habitats may be in danger of inundation and more saltwater intrusion will occur. However, through the collaboration of local agencies and the Estuary Program, many of these impacts may be mitigated to lower risk levels.

7. Future Mitigation/Adaptation Planning

Risks are broken down by their priority zone (high/medium/low) and the approach to be taken. Discussion and information on each of the climate change stressors can be found in section 4. Identification of priority issues can be found in section 5. This section begins the discussion of hazard mitigation by looking at mitigation before the disaster happens. This allows the Morro Bay watershed to be more resilient to climate change effects, by making the changes needed to help the watershed adapt.

Approach Definitions (US EPA, 2014)

Mitigate: Risks that have *a potential action* that can lower the risk level and likelihood of the threat. Mitigation includes actions such as prevention, property protection, public education and awareness, natural resource protection, emergency services, and structural projects.

Transfer: *Utilizing another organization* that may be already or willing to take over the reduction of a risk. In these cases, 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*.

7.1 Possible Transfer Organizations

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

Table 15: List of Partners and Organizations.

Partners/Organizations	Common Goal/Objective/Work Area
Black Brant Group	Brant populations, eelgrass restoration
Cal Poly	Education, eelgrass, water quality, range management
Cal Trans	Highways, development/protection of infrastructure
California Conservation Corps	Restoration projects
California Department of Fish and Wildlife (CDFW)	Steelhead, other sensitive species, CCER, eelgrass
California Men's Colony	Wastewater treatment plant impacts to Chorro Creek
California Native Plant Society	Native plant protection, conservation, and education
California State Parks	Mudflats and watershed health, habitat protection, monitoring of sensitive species, identification and removal of invasive species.
Camp San Luis Obispo National Guard Base	Stormwater management
Central Coast Regional Water Quality Control Board	Water quality, stormwater management, project funding
Creek Lands Conservation	Habitat acquisition and management, education
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
Coastal San Luis Resource Conservation District	Provide programs to assist farmers, ranchers, landowners and other watershed users in improving and protecting soil and water resources
Cuesta College	Education and outreach, research
ECOSLO	Volunteers for ecosystem health and trail repair, beach cleanups
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, conservation management

Table 15 continued…

Partners/Organizations	Common Goal/Objective/Work Area
Morro Bay Natural History Museum	Education and outreach
Morro Coast Audubon Society	Bird populations, habitat protection, education and outreach
National Oceanic and Atmospheric Administration	Coastal grants, eelgrass, bay circulation and hydrodynamics
Natural Resource Conservation Service	Conservation of ecosystems, development of implementation projects
San Luis Obispo Botanical Garden	Education and outreach
San Luis Obispo County	Planning for the area, stormwater management, water management, wastewater management, flood control
San Luis Obispo County Office of Education	Education and outreach
SLO County Weed Management Area	Invasive plant management
Small Wilderness Area Preservation	Elfin Forest management, public education
State Coastal Conservancy	Conservation of coastal habitats, restoration, funding
State Water Resources Control Board	Funding, technical assistance
Trout Unlimited	Restoration efforts
U.S. Environmental Protection Agency	Funding, policy guidance, regulatory guidance
United States Forest Service	Manage upper-watershed land
Watershed Stewards Partnership	Restoration, monitoring, education and outreach

7.2 Warmer Annual Temperatures

Table 16: List of Approaches to Warmer Temperature Impacts.

Risk	Severity level: High (Red)/ Medium (Orange)/ Low (Green)	Approach: (Mitigate/Transfer/Accept/Avoid)
Increased urban and agricultural water use	High	Transfer/Mitigate
Increased water budget stress	High	Transfer/Mitigate
Increased temperature stress on plants	High	Accept
Bird migration shifts and population declines	High	Accept
Less suitable habitats for steelhead	High	Mitigate/Transfer
Increased sedimentation potential	High	Mitigate/Transfer
Increased algal blooms and decomposition rate	High	Mitigate/Transfer
Food supply reduced	High	Avoid
Eelgrass declines	High	Mitigate
Favorable conditions for bacteria	High	Transfer
Introduction of new pathogens/diseases	High	Transfer
Warmer streams during summer and fall	High	Transfer/Mitigate
Oyster infections	High	Transfer
Increased use of herbicides/pesticides	Medium	Transfer/Mitigate
Aquatic habitats may dry out earlier	Medium	Mitigate/Transfer
Favors invasive species	Medium	Transfer/Mitigate
Invasive insects	Medium	Transfer/Mitigate
Toxicity of pollutants may increase	Medium	Transfer
Decreased coastal fog	Medium	Avoid
Semi-permanent thermocline	Low	Avoid
CMC lower discharge requirements	Low	Accept/Transfer

7.3 Increased Storm Intensity

Table 17: List of Approaches to Increased Storm Intensity Impacts.

Risk	Severity level: High (Red)/ Medium (Orange)/ Low (Green)	Approach: (Mitigate/Transfer/Accept/Avoid)
More frequent floods	High	Transfer/Mitigate
Aggradation of estuary	High	Mitigate/Transfer
More significant pollution flushes	High	Mitigate/Transfer
Landscape runoff (overland flow) increase	High	Mitigate/Transfer
Sedimentation increase	High	Mitigate/Transfer
Increased stormwater runoff	High	Transfer/Mitigate
More frequent oyster farm closures from bacteria pollution	High	Transfer/Mitigate
Altered flood-prone area habitat	High	Accept/Transfer
More frequent landslides	Medium	Avoid
High stream velocities disrupt steelhead	Medium	Mitigate/Transfer
More sediment to tidal marsh to keep pace with SLR	Medium	Avoid
Septic tank failure	Low	Transfer
Increased groundwater recharge	Low	Avoid

7.4 Increased Droughts

Table 18: List of Approaches to Increased Drought Impacts.

Risk	Severity level: High (Red)/ Medium (Orange)/ Low (Green)	Approach: (Mitigate/Transfer/Accept/Avoid)
Decreased creek and estuary DO levels	High	Mitigate/Transfer
Loss or early dry-out of wetland habitats	High	Transfer
Stressed water budget	High	Transfer/Mitigate
Saltwater intrusion	High	Transfer
Increased air pollution	High	Transfer
Increased moisture/temperature stress on plants	High	Accept
Increased temperatures in creeks	High	Mitigate/Transfer
Favors invasive plant species	High	Transfer/Mitigate
Loss of specialized wetland species	High	Transfer/Mitigate
Impacted steelhead trout migration	Medium	Transfer/Mitigate
Decline in eelgrass	Medium	Mitigate

7.5 Sea Level Rise

Table 19: List of Approaches to SLR Impacts.

Risk	Severity level: High (Red)/ Medium (Orange)/ Low (Green)	Approach: (Mitigate/Transfer/Accept/Avoid)
Increased saltwater intrusion	High	Transfer
Increased infrastructure risk	High	Accept
Change in wetland inundation frequency and salinity	High	Transfer/Mitigate
Conversion of habitats with deeper water in the bay (e.g., tidal marsh to mudflats)	High	Avoid
Where feasible, tidal marsh may migrate inland	High	Avoid
Loss of specialized wetland species intolerant of salinity change	High	Transfer/Mitigate
Shift/increase in suitable eelgrass habitat	Medium	Mitigate/Transfer
Reduced water/sediment retention times in bay	Medium	Accept
Sewer overflows	Low	Transfer/Accept
Sandspit may move inland	Low	Avoid
Sandspit buffer high wave impacts	Low	Avoid
Sandspit buildup	Low	Avoid

7.6 Ocean Warming and Acidification

Table 20: List of Approaches to Ocean Warming and Acidification Impacts.

Risk	Severity level: High (Red)/ Medium (Orange)/ Low (Green)	Approach: (Mitigate/Transfer/Accept/Avoid)
Loss of fitness of species sensitive to pH and warm water	High	Transfer/Accept
More toxic pollutants	High	Transfer
Increase in invasive species	High	Transfer/Mitigate
Eelgrass decline	High	Mitigate/Transfer
Seed shortage or loss of PNW hatcheries due to poor oyster survival	High	Avoid
Reduced juvenile rearing habitat	High	Avoid
Steelhead trout impairment	High	Transfer/Mitigate
Facilitate new pathogens and diseases in the estuary	High	Mitigate/Transfer
Facilitate algae growth	High	Mitigate/Transfer
Decrease in available substrates for $CaCO_3$ users	Medium	Avoid
Poor oyster quality	Medium	Accept
Complete shift in biodiversity	Medium	Mitigate/Transfer
Jellyfish invasion	Low	Accept
Corrosion of infrastructure	Low	Avoid
Increased pollutant toxicity	Low	Mitigate
Stratified water	Low	Avoid
More bacteria	Low	Mitigate

7.7 Increased Size and Intensity of Fires

Table 21: List of Approaches to Increased Size and Intensity of Fires Impacts.

Risk	Severity level: High (Red)/ Medium (Orange)/ Low (Green)	Approach: (Mitigate/Transfer/Accept/Avoid)
Increased fire season length and frequency	High	Transfer/Avoid
Increase in carbon dioxide and other pollutants	High	Mitigate/Transfer
Increased soil erosion and landslides (impacts to eelgrass and steelhead spawning habitat)	High	Transfer/Avoid
Shift to more grasslands	Medium	Accept
Invasive species altering fire regime	Medium	Transfer/Mitigate

7.7 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 22: 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)?
Increase of sedimentation/ Aggradation of estuary	Levee removal projects	Yes	Yes
	Floodplain restoration	Yes	Yes
	Transfer some mitigations to CDFW/State Parks	Yes	Yes
	Road erosion repairs	Yes	Yes
	Planting native vegetation	Yes	Yes
	Erosion control measures/Low Impact Development (LID)	Yes	Yes
More frequent floods/Increased landscape runoff (overland flow)/ Increased stormwater runoff/High stream velocities disrupt steelhead	Widen stream buffers	No	Yes
	Floodplain restoration	Yes	Yes
	LID (rainwater capture)	Yes	Yes
	Planting native vegetation	Yes	Yes
	Percolation projects	Yes	Yes
Warmer water temperatures	Plant evergreen, resilient shade trees in upland tributaries	Yes	Yes
	Lower CMC discharge temperatures	Yes	Yes
	Maintaining flows	Yes	Yes

Table 22 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)?
Drier habitats/Less suitable habitats for steelhead/Aquatic habitats may dry out earlier/Impacted steelhead trout migration/Change in wetland inundation frequency and salinity	Plant species that maintain soil moisture	Yes	Yes
	Maintaining riparian corridors	Yes	Yes
Algal blooms/Decreased creek and estuary DO levels/Steelhead trout impairment	Riparian fencing and off-creek water	Yes	Yes
	Stream shading (to decrease temperatures)	Yes	Yes
	Stormwater management	Yes	Yes
	On-farm BMPs	Yes	Yes
Increased water budget/Drought stress/Increased urban and agricultural water use	Plant drought-tolerant plants	No	Yes
	Rainwater harvesting	Yes	Yes
	Water conservation	Yes	Yes
	Create bioswales	No	Yes
	Other LID methods	No	Yes
Eelgrass declines/ Shift in suitable eelgrass habitat	Eelgrass planting	Yes	Yes
	Help maintain physical conditions that support eelgrass habitat	Yes	Yes
Increased use of herbicides/pesticides	Education of alternatives	No	Yes
Invasive insects	Controlled burns	No	Yes
More significant pollution flushes	LID	Yes	Yes
More frequent oyster farm closures from bacteria/ Facilitate new pathogens and diseases in the estuary/ Increased pollutant toxicity	LID	Yes	Yes

Table 22 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)?
Saltwater intrusion	Los Osos recycled water	Yes	Yes
	Rainwater harvesting	Yes	Yes
	Water conservation	Yes	Yes
Fires/Increase in carbon dioxide and other pollutants	Reduce fuel loads and increase fire management with Cal Fire	Yes	Yes
	Reduce invasive plant species	No	Yes
	Planting fire tolerant natives	Yes	Yes
	Plant evergreen resilient shade trees	Yes	Yes
	Controlled burns	Yes	Yes
Invasive species	Removal projects	Yes	Yes
	Plant more natives	Yes	Yes
	Prescribed grazing/fires	Yes	Yes
Sea Level Rise	Support local planning efforts that protect migration areas from development and encourage climate-smart growth	No	Yes
	Facilitate plant migration	No	Yes
	Sediment augmentation to tidal marsh for SLR	No	Yes
Loss of specialized wetland species/Loss of wetland species intolerant of salinity/Complete shift in biodiversity	Planting projects	Yes	Yes
	Sediment augmentation	Yes	Yes
	Grading of upland areas	Yes	Yes
	Dune stabilization	Yes	Yes

7.8 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, similar to municipal public works, very expensive, or not possible? 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 or maladaptive.

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, or no, the action disproportionately affects others.

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 this action? Is it a no-regrets action?

Table 23: 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?
Levee removal projects	Yes	High	Very Expensive	Beneficial	Yes	Robust and adaptive	Yes, with CCER
LWD installation	Yes	High	Very Expensive	Beneficial	Yes	Robust but maladaptive	Yes
Transfer some mitigations to CDFW/State Parks	Yes	Moderate	Cost Minor	Maladaptive	Yes	Unknown	Yes
Road erosion repairs	Yes	Moderate	Similar to Municipal Public Works	Beneficial	Yes	Robust and adaptive	Yes
Erosion control measures/LID	Yes	High	Similar to Municipal Public Works	Beneficial	Yes	Robust and adaptive	Yes, with CCC and Los Osos landowners
Create bioswales	Yes	High	Similar to Municipal Public Works	Beneficial	Yes	Robust and adaptive	Yes, with CCC
Widen stream buffers	Yes	High	Cost Minor	Beneficial	Yes	Robust and adaptive	Yes, with CCC
Floodplain restoration	Yes	High	Very Expensive	Beneficial	Yes	Robust and adaptive	Yes, planned at RCD
Percolation projects	Yes	Moderate	Very Expensive	Beneficial	Yes	Robust and adaptive	Yes, planned at RCD

Table 23 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?
Plant evergreen, resilient, shade trees in upland tributaries	Yes	High	Similar to Municipal Public Works	Beneficial	Yes	Robust and adaptive	Yes
Lower CMC discharge temperatures	Yes	Low	Very Expensive	Beneficial	Yes	Robust, but maladaptive	No
Maintaining flows	Yes	High	Very Expensive	Beneficial	Yes	Robust and adaptive	No
Plant species that maintain soil moisture	Yes	High	Similar to Municipal Public Works	Beneficial	Yes	Robust and adaptive	Yes
Maintaining riparian corridors	Yes	High	Very Expensive	Beneficial	Yes	Robust and adaptive	Yes
Riparian fencing and off- creek water	Yes	High	Similar to Municipal Public Works	Beneficial	Yes	Robust and adaptive	Yes
Stream shading	Yes	High	Similar to Municipal Public Works	Beneficial	Yes	Robust and adaptive	Yes

Table 23 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?
Stormwater management	Yes	High	Similar to Municipal Public Works	Beneficial	Yes	Robust and adaptive	Yes
On-farm BMPs	Yes	High	Cost Minor	Beneficial	Yes	Robust, but maladaptive	Yes
Plant drought tolerant and native plants	Yes	High	Similar to Municipal Public Works	Beneficial	Yes	Robust and adaptive	Yes
Water conservation	Yes	High	Cost Minor	Beneficial	Yes	Robust and adaptive	Yes
Eelgrass planting	Yes	High	Similar to Municipal Public Works	Maladaptive	Yes	Robust and adaptive	Yes
Help maintain physical conditions that support eelgrass habitat	Yes	High	Very Expensive	Beneficial	Yes	Robust and adaptive	Yes
Education of herbicide and pesticide alternatives	Yes	Moderate	Cost Minor	Maladaptive	Yes	Robust, but maladaptive	Yes, with RCD

Table 23 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?
Reduce fuel loads/work with Cal Fire	Yes	Moderate	Cost Minor	Beneficial	Yes	Robust and adaptive	Yes
Invasive species/ removal projects	Yes	Moderate	Similar to Municipal Public Works	Beneficial	Yes	Robust and adaptive	Yes
Plant fire tolerant natives	Yes	Moderate	Similar to Municipal Public Works	Beneficial	Yes	Robust and adaptive	Yes
Prescribed grazing/fires	Yes	Moderate	Cost Minor	Beneficial	Yes	Robust and adaptive	Yes
Support local planning efforts that protect migration areas from development and encourage climate-smart growth	Yes	High	Similar to Municipal Public Works	Beneficial	Yes	Robust and adaptive	Yes
Facilitate plant migration	Yes	Moderate	Similar to Municipal Public Works	Beneficial	Yes	Robust, but maladaptive	Yes

Table 23 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?
Sediment augmentation to tidal marsh for SLR	Yes	High	Similar to Municipal Public Works	Beneficial	Yes	Robust and adaptive	Yes
Rainwater harvesting	Yes	Moderate	Similar to Municipal Public Works	Beneficial	Yes	Robust and adaptive	Yes
Grading of upland areas	Yes	Moderate	Very Expensive	Beneficial	Yes	Robust and adaptive	Yes
Dune stabilization	Yes	Moderate	Similar to Public Works	Beneficial	Yes	Robust and adaptive	Yes

7.9 Summary of Adaptation Actions and Program Goals

Out of the 33 potential adaptation actions formulated by the Estuary Program, 31 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 that they provide regardless of climate change.

7.9.1 Proposed Adaptation Actions

Below are the adaptation actions that have been selected as possible to proceed with in alphabetical order. These actions could be taken on by the Estuary Program, in collaboration with partners or other organizations.

Create bioswales: Swales allow for increased groundwater recharge and filtration of pollutants. They can provide important habitat for many plant and animal species. These areas may also reduce the risk of flooding and provide refuge during intense droughts.

Dune stabilization: There are multiple methods to dune stabilization, such as planting, which combats the effects that humans have had on dunes. Dune stabilization can help reduce air pollution and provide more habitat for native wetland species.

Eelgrass planting: In order to combat the decline of eelgrass in our Bay, the Estuary Program and partners have worked on planting eelgrass in different areas throughout the Bay.

Education of herbicide and pesticide alternatives: To combat different diseases and pests, there are many natural/organic options available that the Estuary Program can educate the community about. Many herbicides and pesticides that are available are very damaging to the environment and can hurt the ecosystems that exist in the Bay.

Erosion control measures/LID: Erosion control measures and LID strategies help reduce the sediment loads during rain events.

Facilitate plant migration: Some ecosystems and plants in the bay may need to migrate in order to survive the effects of climate change. The Estuary Program can help these ecosystems by facilitating the migration of these plants to ensure their survival.

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. The Estuary Program has been involved in many past floodplain restoration projects and plans to continue to be involved in these projects in the future.

Grading of upland areas: Grading upland areas of streams can help reduce the loss of wetlands species.

Help maintain physical conditions that support eelgrass habitat: In addition to planting eelgrass, research to better understand water quality and sedimentation in the bay could lead to management actions to support eelgrass.

Invasive plant species removal projects: The Estuary Program 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, which involves many partners, 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 a changing climate favors these plants.

Levee removal projects: The removal of levees will allow for more natural stream flows. An alternative to having a levee includes widening stream buffers in order to lessen the potential for flooding.

LWD Installation: The installation of LWD provides more complex channels that enhance habitat and support fish populations.

Maintaining riparian corridors: In addition to restoration of riparian corridors, they must be maintained due to human impacts, sediments, and invasives that could degrade them.

On-farm BMPs: BMPs are a list of management strategies that can help lessen the effects of sediment and other human impacts to natural environments.

Percolation projects: Percolation projects provide opportunities for runoff to sink into the ground, which can help improve groundwater supplies and maintain surface flows in streams.

Plant drought tolerant and native plants: Drought tolerant plants and drought tolerant native plants help reduce the need for irrigation, thus reducing pressure on water resources, such as groundwater aquifers.

Plant evergreen, resilient shade trees in upland tributaries: 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 would mostly focus on upland tributaries that have little shade.

Plant fire tolerant natives: Native and drought tolerant species are less prone to burning fires can help reduce fire potential.

Plant species that maintain soil moisture and are drought tolerant: Species chosen for planting should help maintain 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.

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.

Rainwater harvesting: The collection of rainwater can help to reduce use of groundwater and surface waters. By reducing use from rangeland and agriculture, streams may have higher and longer lasting flows while enhancing groundwater recharge. Providing off-creek water will also keep livestock away from sensitive riparian corridors and reduce their impacts on nearby streams, thus protecting water quality and habitat quality.

Reduce fuel loads/work w/ Cal Fire: Projects that remove excess dry/dead brush, trees, and grasses can reduce fuel loads that are likely to cause damaging fires. Cal Fire can help educate the community and contribute to the management of fuel load .

Riparian fencing: The Estuary Program has been, and continues to be, involved in riparian fencing installation. These projects protect sensitive riparian habitat and water quality.

Road erosion repairs: Repairing roads more frequently and with the correct erosion control methods may reduce sediment loading during rain events.

Sediment augmentation to tidal marsh for SLR: The Estuary Program is hoping to study the likelihood that sedimentation helps mitigate tidal marsh loss due to the effects of climate change and human impacts on the environment. The results may support future sediment augmentation efforts on tidal marshes.

Stormwater management: More frequent and intense storms will increase inputs of stormwater and pollution into the estuary and watershed. A San Luis Obispo County Stormwater Resource Plan was completed in 2020, which includes stormwater projects throughout the County and a number of locations in the Morro Bay watershed. For example, a range of projects such as bioswales, permeable pavement, and stormwater capture and re-use are suggested for being implemented at Camp SLO. In the future, the Estuary Program 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.

Stream shading: Improving stream shading through planting efforts will buffer streams from increasing surface temperatures.

Support local planning efforts that protect migration areas from development and encourage climate-smart growth: Development must be completed in an ecologically friendly and climate conscious way in order to lessen human impact on local ecosystems and the environment. The Estuary Program can participate in local planning efforts to encourage a development approach that protects migration areas.

Transfer some mitigations to CDFW/State Parks: Part of our work should be in partnership or transferred to CDFW/State Parks and other partners/organizations to help increase the area in which mitigation methods are occurring.

Water Conservation: While the Morro Bay climate naturally experiences periodic droughts, the future is projected to become drier and warmer across all scenarios. Depletion of groundwater will also contribute to more saltwater intrusion that may be compounded by SLR. Current projects have been undertaken by the Estuary Program and surrounding communities to increase water conservation.

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.

7.9.2 Other Agencies Adaptation Actions

- Cal Poly completed a rainwater capture project in partnership with the Estuary Program.
- Camp SLO and Cal Poly completed a roads improvement project to reduce erosion from ranch roads.
- CCC has completed stormwater/swale projects at their sites.
- Land Conservancy does invasive species management.

- The County of San Luis Obispo encouraged Los Osos residents to reuse and repurpose their septic systems after decommissioning them (Beneficial Reuse, 2015). The document they created gave guidance to homeowners on converting septic system into stormwater and grey water reuse. These conversions would help provide groundwater recharge to the area, while also reducing stormwater runoff.
- The Coastal San Luis RCD has completed Climate Ready Rangeland projects in the Morro Bay watershed to prepare for climate change. These projects implemented multiple water conservation and soil building methods and improved grassland ecosystem health. Implementation demonstrated climate-ready management of rangelands for the many other cattle ranchers in the area. The project is considered an example of carbon farming, a method of building resiliency and capturing carbon through on-farm BMPs (Carbon Farm Plan, 2020).
- The Coastal San Luis RCD also completes projects like floodplain restoration, widening stream buffers, percolation projects, and education on herbicide and pesticide alternatives.
- The Coastal San Luis RCD continues to be involved in facilitating best management agricultural practices throughout the Morro Bay watershed. Their efforts in soil conservation, biodiversity, and water stewardship continue to prepare agriculture in the area for climate change. The Estuary Program will continue to collaborate with the RCD on soil building and carbon farming projects in the future.
- The Estuary Program will continue to work with CDFW and State Parks in the management of natural resources within the watershed. Many species habitat enhancement and invasive species management projects are led by these agencies and will be important to the resilience of the watershed in the future.
- The Morro Coast Audubon Society, manager of the Sweet Springs Nature Preserve, has worked collaboratively with California Native Plants Society on assisted migration

efforts for salt marsh plant species. Their past projects have proven to be successful, and more are likely needed to address future SLR. The Estuary Program will plan to consult with CNPS on future assisted migrations within the estuary in areas that will be most affected by SLR in order to reduce the risk of losing specialized species.

- The City of Morro Bay re-sited the location of their wastewater treatment plan to address concerns about future flooding due to climate change-related events, SLR, and tsunami flood risk. The former site was outside the Morro Bay watershed boundary, but the new site is within the watershed, in the Chorro Creek sub-watershed. More information about the project is available at https://morrobaywrf.com/.

7.9.3 Monitoring and Review

The Climate Vulnerability Assessment will be monitored and reviewed every five years. This matches the update frequency of the Estuary Program's 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.

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This project has been funded wholly or in part by the United States Environmental Protection Agency under assistance agreement CE-99T43601 to the Bay Foundation of Morro Bay. The contents of this document do not necessarily reflect the views and policies of the Environmental Protection Agency, nor does the EPA endorse trade names or recommend the use of commercial products mentioned in this document.